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Performance Analysis of Single Cylinder Diesel Engine with 2EHN Cetane Number Enhancer on Biodiesel

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Abstract: Diesel engines remain a critical technology across multiple sectors, including transportation, industry, marine, and agriculture, due to their well-known benefits such as high fuel efficiency, robust durability, and superior torque output. Even as electric vehicle technology rapidly advances, diesel engines continue to be utilized in demanding applications that require reliable, high-power performance under harsh conditions. This enduring relevance stems from their higher thermal efficiency and remarkable ability to function in extreme environments. However, diesel fuel differs from petrol in its combustion characteristics, notably having a lower combustion rate. This rate is measured by the cetane number, with higher cetane values indicating better combustion quality. To optimize engine performance, especially when using lower-cetane diesel fuel, additives are often used to increase the cetane number. This study explores the effects of combining 2-ethylhexyl nitrate, a cetane number enhancer, with Pertamina's biodiesel product, bio solar. Using a single-cylinder diesel engine and a prony brake for testing, the study found that a 1:100 ratio of cetane number enhancer to fuel delivered the best results among all mixtures. This blend achieved the highest thermal efficiency at 30.23% and recorded the lowest brake specific fuel consumption at 7.78265E-05 kg/kWh.

Keywords: diesel; engine; biodiesel; fuel; cetane

7 AFFORDABLE AND CLEAN ENERGY

SDGs Problem Solving

This research supports SDGs Chapter #7 by applying experimental findings to improve biodiesel, resulting in cleaner combustion and better engine efficiency. Cetane enhancement upgrades fuel quality and enables wider use of renewable energy sources, making it easier to implement affordable, reliable, and sustainable energy systems on a larger scale for communities.

1. INTRODUCTION

Diesel fuel is essential in contemporary industrial operations, especially in transportation, power generation, and heavy machinery functions. As a non-renewable natural resource, its availability is progressively constrained by ongoing extraction and escalating worldwide demand. The disparity between supply and consumption has elicited apprehensions about long-term energy security, economic stability, and environmental sustainability. As a result, much research has focused on discovering alternative fuels that can partially or completely replace traditional diesel without undermining engine performance or dependability.

Biodiesel has emerged as one of the most promising alternatives. Biodiesel is a sustainable fuel obtained from organic materials, including vegetable oils, animal fats, and used cooking oils. Biodiesel, in contrast to traditional diesel derived from fossil fuels, is synthesized using chemical processes primarily transesterification employing catalysts to transform raw biological components into fuel compatible with diesel engines (Ferguson and Kirkpatrick, 2016). Its chemical makeup enables its utilization as either a pure fuel or in conjunction with petroleum diesel in varying ratios.

Biodiesel not only diminishes reliance on fossil fuels but also provides environmental benefits, such as reduced emissions of particulate matter, carbon monoxide, and uncombusted hydrocarbons. Moreover, its biodegradable and non-toxic characteristics augment its viability as a sustainable and eco-friendly substitute for traditional diesel fuel (Mahmudul *et al.*, 2017).

Biodiesel has garnered significant interest as a renewable substitute for traditional diesel fuel, as it can be synthesized from biological resources independent of fossil fuels. Biodiesel, despite its distinct origin, demonstrates physicochemical features that closely resemble those of petroleum-based diesel, enabling its utilization in current diesel engines with few or no modifications (Verma and Sharma, 2016). This compatibility has prompted substantial study aimed at assessing biodiesel's performance, combustion characteristics, and overall efficiency in diesel engines, as noted by Suhara et al. (Suhara *et al.*, 2024). The cetane number is a crucial indication of diesel fuel quality, reflecting the fuel's igniting properties during combustion. A higher cetane number often indicates a shorter ignition delay, enhanced combustion stability, and less engine noise, whereas lower values may lead to incomplete combustion and increased emissions. The cetane number of diesel fuels generally varies from 40 to 55, contingent upon fuel composition and refining methods (ASTM, 2010, 2023). Biodiesel frequently exhibits cetane levels within or beyond this range owing to its oxygenated molecular composition, which can improve ignition quality (Nasikin, Arbianti and Azis, 2002). Consequently, examining the cetane number is crucial when considering biodiesel as an alternative to conventional diesel, since it directly affects engine performance, fuel efficiency, and emission properties (Lin and Wu, 2022).

In accordance with the ASTM D613 standard, this value is determined by first obtaining the cetane number value through the combustion of diesel fuel in an engine developed by the Cooperative Fuel Research. Subsequently, the cetane number value is computed by determining the outcomes of the mixtures of cetane and isocetane during the same period of combustion time (Brahma *et al.*, 2022). According to Dave et al. (Dave, Sharma and Chandrakant, 2024), the addition of chemical additive compounds to diesel fuel, namely Cetane Number Enhancer (CNE), has the potential to alter the value of the cetane number in diesel fuel's composition.

According to Ahmed et al. (Ahmed *et al.*, 2025), the performance of the diesel engine may be altered by the addition of CNE to the fuel. This variation is dependent on the type of CNE that is added as well as the quantity of CNE that is supplied. In this investigation, an experiment was carried out using the cetane number enhancer additive 2EHN on biodiesels. The experiment was based on the fuel volume ratio, and the purpose of the experiment was to find the ideal ratio of fuel to additive in order to improve the performance of biodiesel fuel in diesel engines.

2. METHODOLOGY

This analysis employs an experimental method using a specific arrangement of equipments in a schematic can be seen in Figure 1.

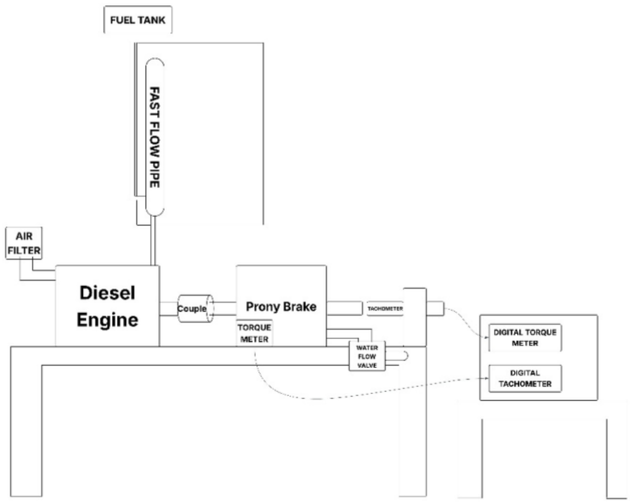


Figure 1. Schematic diagram

The diesel engine that is used is a JianDong 170F with the specification listed in Table 1. The measuring equipment that was used is a TecQuipment TD114, which consists of a Prony brake, a test bench, a measuring glass, a fuel tank, an impeller, a t-pipe, a torquemeter, a tachometer, and indicators to show the data that are being taken during the experiment.

Table 1. Spesification diesel engine

Spesification Jiangdong 170 F	
Model	JD170F
Type	Single Cylinder
Bore x Stroke (mm)	70 x 60
Injection Pressure (MPa)	14
Dimension (mm)	395 x 305 x 361

A tachometer is then placed and fastened to the end of the test bench to measure the number of rotations being made from the machine (see Figure 1). Once the engine is connected successfully to the test bench and the hydro brake, make sure the engine is connected to the fuel tank and measuring glass is filled to brim. The engine is then started and once the engine starts, the hydro brake is then filled with water from the t-pipe which is connected to the water valve in the lab, which then will flow through the hydro brake and back to the drain. Once the hydro brake is filled completely with water, adjust the speed of engine according to the variables that has been stated for the experiment. The data that are being measured will be shown on the indicator on the test bench. This study is conducted experimentally on a single cylinder diesel engine with a varying ratio of cetane number enhancer to total fuel used in the experiment. The variable of the fuel mixtures is chosen based on the cetane number enhancer recommended ratio written on the packaging, which is 1:300 volume based on diesel fuels with lower cetane number such as biodiesel. The variable for the speed of the engine was based on the range of the maximum and minimum speed on the engine, which were 3000 and 1800 RPM. For this experiment, the fuel to CNE ratios that were used are 0.5%, 1%, 2%, and 3% by the volume of the fuel used (Şimşek and Uslu, 2021), while the speed that were used are 1800, 2000, 2200, 2400, and 2600 RPM to prevent the engine from overheating.

Once the variables of the experiment have been tested on, change the fuel inside the fuel tank with the fuel variables in the experiment, and then repeat the experiment until all the fuel variables have been tested. With the data obtained, calculations are carried out on the data to obtain certain data to determine the specific performance of the machine according to the experiments carried out. The formula used in this experiment is based on the experimental study done by Das et al. (Das *et al.*, 2024).

$$T = F \times r \tag{1}$$

where T is Torque (Nm); F is Force (N); and r is Distance from the axis of the impeller to the point of force.

$$BHP = \frac{2\pi n T}{60 \times 1000} \tag{2}$$

where BHP is Brake Horsepower (kW) and n is Rotation Speed (RPM).

$$mf = \frac{\rho \times V}{t} \tag{3}$$

where mf is Fuel Usage (kg/s); ρ is Density (kg/m^3); V is Volume (m^3); and t is Time (s).

$$\eta_{ther} = \frac{BHP}{LHV \times mf} \times 100\% \tag{4}$$

where η_{ther} is Thermal Efficiency (%) and LHV is Lower Heat Value (kJ/kg).

$$BSFC = \frac{mf}{BHP} \tag{5}$$

where $BSFC$ is Brake Specific Fuel Consumption (g/kWh).

$$IHV = \frac{mf \times LHV}{BHP} \tag{6}$$

where IHV = Indicated Heat Value (kJ/kWs).

3. RESULTS AND DISCUSSION

The experimental study that is conducted firstly is the calorie experiment, where the value of the lower heat value is obtained for each fuel mixtures. The lower heat value data is shown on Figure 2. In the calorie experiment conducted on biodiesel fuel samples, the calorific value per weight of the fuel test sample used was obtained. The results obtained showed that the highest calorific value per weight was achieved at 1% CNE, with stagnant calorific values in other fuel mixtures, where the lowest calorific value was obtained by a mixture of 3% CNE, followed by 2% CNE, which was reflected by the efficiency and specific fuel usage which was lower compared to other fuel mixtures. This is due to the optimal CN value, which is 55 (Sudarmanta, Darsopuspito and Sungkono, 2014), where when compared to the CN value of the fuel used, which is 48, the addition of 1% CNE results in an increase in CN of 7 (Vera-Rozo *et al.*, 2022), resulting in a CN value of 55. And if more CNE is added to the fuel, no better results are obtained, but rather a decrease in performance to the original according to the previous fuel mixture variable. In addition, it is concluded as well that the lower heat value is affected by the value of cetane number in the fuel. With the data obtained, the data will then be converted to kJ/kg, and the LHV data is obtained for each fuel mixtures (see Table 2).

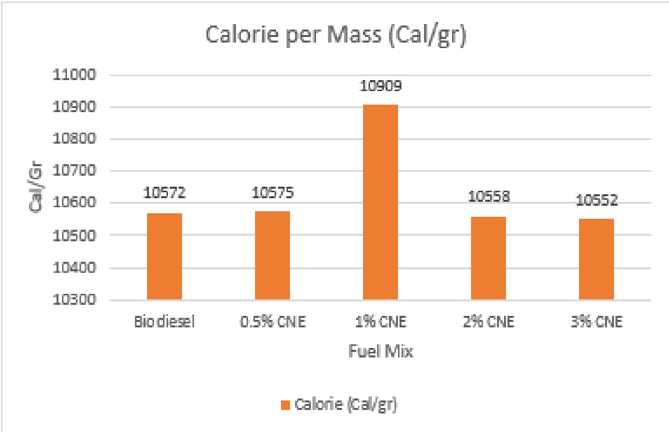


Figure 2. Lower heat value graph

Table 2 shows the Lower Heating Value (LHV) of bio solar fuel and bio solar combined with CNE additives at several percentages (0.5%, 1%, 2%, and 3%). The findings indicate that pure bio solar possesses a lower heating value (LHV) of 44,263 kJ/kg. The incorporation of CNE at 0.5% marginally elevates the LHV to 44,275 kJ/kg, but the peak LHV occurs at a CNE concentration of 1%, attaining 45,674 kJ/kg. Nonetheless, additional increments in CNE concentration to 2% and 3% lead to a reduction in LHV to 44,202 kJ/kg and 44,179 kJ/kg, respectively.

Table 2. LHV results

Fuel	LHV (kJ/kg)
Bio solar	44,263
CNE 0.5%	44,275
CNE 1%	45,674
CNE 2%	44,202
CNE 3%	44,179

The data demonstrate that a 1% CNE addition yields the most substantial enhancement in energy content, whereas greater concentrations do not confer further advantages. With LHV of each fuel mixtures obtained, the experiment for each fuel performance can be studied. The raw data for each fuel is shown on Table 3. The information in Table 4 will then be processed based on the variables that have been set. Data processing includes computing the calculated torque, fuel mass per second, produced power, thermal efficiency, and specific fuel consumption using the established equations (1) - (6).

Table 3. Experiment results

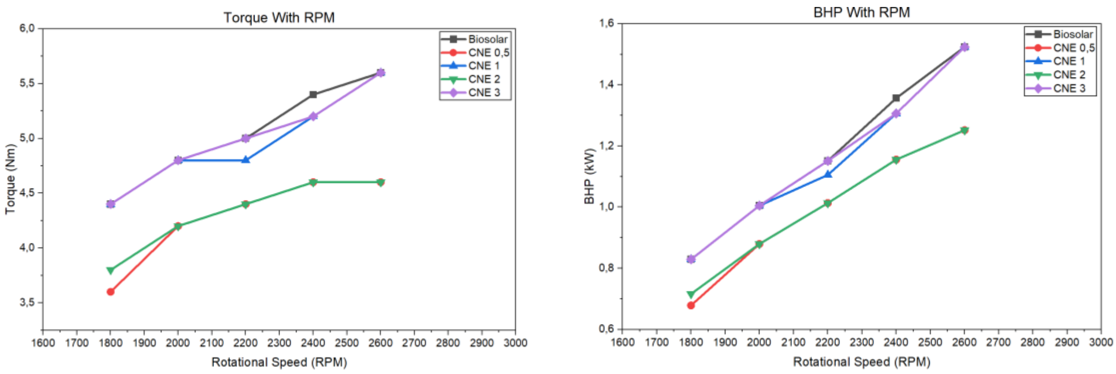
Fuel	Rotation Speed (RPM)	Vol (L)	Time (s)	Indicator Torque (Nm)
Biodiesel	1800	8	76	22
	2000	8	69	24
	2200	8	64	25
	2400	8	59	27
	2600	8	53	28
CNE 0.5%	1800	8	83	18
	2000	8	76	21
	2200	8	70	22
	2400	8	62	23
	2600	8	58	23
CNE 1%	1800	8	83	22
	2000	8	78	24
	2200	8	79	24
	2400	8	62	26
	2600	8	59	28
CNE 2%	1800	8	85	19
	2000	8	78	21
	2200	8	70	22
	2400	8	64	23
	2600	8	60	23
CNE 3%	1800	8	78	22
	2000	8	69	24
	2200	8	63	25
	2400	8	57	26
	2600	8	51	28

Table 4 shows a comparison of engine performance with different fuel blends at speeds between 1800 and 2600 RPM. The metrics listed are brake horsepower (BHP), torque, fuel mass flow rate, indicated heat value (IHV), thermal efficiency, and brake specific fuel consumption (BSFC). As the engine speed goes up, biodiesel's torque and BHP go up as well, and its thermal efficiency goes up and its BSFC goes down. This means that the fuel is being used better at higher RPM. The biodiesel is mixed with 0.5% CNE, the torque and power production go down, especially at lower speeds, compared to pure biodiesel. But thermal efficiency is still competitive, which means that adding tiny amounts of CNE doesn't seem to hurt combustion quality by much. When the CNE percentage is raised to 1%, the thermal efficiency goes up noticeably, hitting a peak of over 30% at 2600 RPM. At the same time, the BSFC goes down even more, showing that energy conversion is becoming more efficient. The blend ratios are greater (CNE 2% and 3%), the engine works better. At some speeds, torque and BHP are a little lower than pure biodiesel, but thermal efficiency usually gets better with RPM, and BSFC stays low. The results reveal that a reasonable amount of CNE blending can improve combustion efficiency and lower fuel consumption. The 1% CNE blend is the best balance between power output and efficiency.

Table 4. Engine performance based on varying fuel mixtures

Fuel	RPM	Vol (l)	Time (s)	Indicated Torque	Actual Torque	m_f (kg/s)	LHV (kJ/kg)	BHP (kW)	IHV (kJ/kW.s)	Thermal Efficiency	BSFC (g/kWh)
Biodiesel	1800	8	76	22	4.4	9.20737E-05	44262.85	0.82896	4.720531	21.18%	0.000111
	2000	8	69	24	4.8	0.000101414	44262.85	1.0048	4.289526	23.31%	0.000101
	2200	8	64	25	5	0.000109338	44262.85	1.151333	4.036054	24.78%	0.00009497
	2400	8	59	27	5.4	0.000118603	44262.85	1.35648	3.715974	26.91%	0.00008743
	2600	8	53	28	5.6	0.00013203	44262.85	1.523947	3.682073	27.16%	0.00008664
CNE 0.5%	1800	8	83	18	3.6	8.43084E-05	44275.41	0.67824	5.282951	18.93%	0.000124305
	2000	8	76	21	4.2	9.20737E-05	44275.41	0.8792	4.450787	22.47%	0.000104724
	2200	8	70	22	4.4	9.99657E-05	44275.41	1.013173	4.193303	23.85%	0.000098666
	2400	8	62	23	4.6	0.000112865	44275.41	1.15552	4.151154	24.09%	0.000097674
	2600	8	58	23	4.6	0.000120648	44275.41	1.251813	4.096099	24.41%	0.000096379
CNE 1%	1800	8	83	22	4.4	8.43084E-05	45673.8	0.82896	4.322414	23.14%	0.000101704
	2000	8	78	24	4.8	8.97128E-05	45673.8	1.0048	3.794581	26.35%	0.00008928
	2200	8	79	24	4.8	8.85772E-05	45673.8	1.10528	3.405953	29.36%	0.00008014
	2400	8	62	26	5.2	0.000112865	45673.8	1.30624	3.672175	27.23%	0.00008640
	2600	8	59	28	5.6	0.000118603	45673.8	1.523947	3.307625	30.23%	0.00007783
CNE 2%	1800	8	85	19	3.8	8.23247E-05	44204.23	0.71592	4.887138	20.46%	0.000114991
	2000	8	78	21	4.2	8.97128E-05	44204.23	0.8792	4.336664	23.06%	0.000102039
	2200	8	70	22	4.4	9.99657E-05	44204.23	1.013173	4.193303	23.85%	0.00009867
	2400	8	64	23	4.6	0.000109338	44204.23	1.15552	4.021431	24.87%	0.00009462
	2600	8	60	23	4.6	0.000116627	44204.23	1.251813	3.959563	25.26%	0.00009317
CNE 3%	1800	8	78	22	4.4	8.97128E-05	44179.11	0.82896	4.599492	21.74%	0.000108223
	2000	8	69	24	4.8	0.000101414	44179.11	1.0048	4.289526	23.31%	0.000100930
	2200	8	63	25	5	0.000111073	44179.11	1.151333	4.100119	24.39%	0.00009647
	2400	8	57	26	5.2	0.000122765	44179.11	1.30624	3.994296	25.04%	0.00009398
	2600	8	51	28	5.6	0.000137208	44179.11	1.523947	3.826468	26.13%	0.00009003

With the data processed, trends can be seen on Figure 3. The torque obtained from the experiment is the original torque based on data obtained from the torque indicator (see Figure 3a). In the analysis of the calculated torque on the variation of fuel used according to the data torque displayed by the indicator. The largest calculated torque results were obtained using biodiesel fuel, CNE 1% and CNE 3% of 5.6 Nm. However, for a mixture of CNE 0.5% and CNE 2%, a much lower value was obtained, with the lowest torque value of 3.8 Nm (Lin and Wu, 2022). The graph depicts the correlation between engine torque and rotational speed (RPM) for four distinct fuels: Bio solar, CNE 1, CNE 2, and CNE 3.



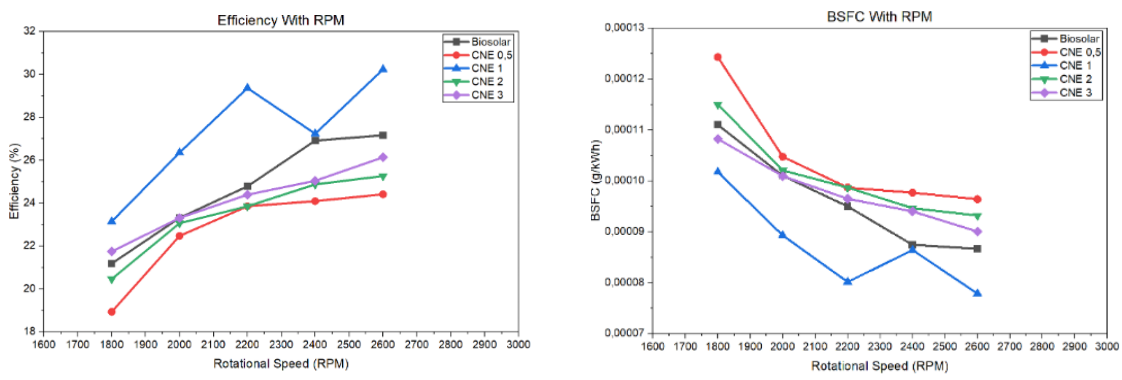
(a). Torque vs RPM (b). BHP vs RPM

Figure 3. Tren rotational speed vs torque and BHP

Torque universally escalates with increasing engine speed across all fuel types, signifying enhanced engine performance as RPM rises within the examined range. Bio solar has a consistent rise in torque from low to high RPM, attaining the peak torque value at maximum rotational speed. This indicates that Bio solar has robust combustion properties and consistent power output, particularly at elevated engine speeds. CNE 3 has a performance trajectory comparable to Bio solar, with torque values continually rising and nearing those of Bio solar at elevated RPMs. This suggests that CNE 3 possesses significant promise as an alternate fuel with similar performance capabilities. CNE 1 and CNE 2 have reduced torque values in comparison to Bio solar and CNE 3. CNE 1 has the lowest torque at lower RPM, progressively enhancing as RPM escalates, whereas CNE 2 demonstrates a modest and more consistent rise throughout the speed spectrum. The disparities in torque output across the fuels can be ascribed to variances in fuel qualities, including calorific value, combustion efficiency, and ignition characteristics.

BHP is the power generated from the resistance generated in opposition to the engine, where the resistance is generated from the water in the hydro brake and is directly proportional to the engine speed and torque generated, where the faster the engine speed and torque, the greater the BHP generated (see Figure 3b). The graph depicts the correlation between BHP and engine speed under various fuel situations, BHP consistently rises with elevated RPM across all fuel types, signifying that higher engine speeds yield enhanced power production due to augmented combustion frequency and optimized air-fuel mixing. Diesel fuel often generates more brake horsepower at lower RPM than some CNG mixes, indicative of its superior energy density and well-established combustion properties in compression ignition engines. Among the CNG examples, CNG 3 has the maximum brake horsepower at elevated RPMs, ultimately nearing or exceeding diesel performance. This indicates that increased CNG ratios can improve power production at higher engine speeds, perhaps due to more thorough combustion and better ignition conditions. CNG 0.5 consistently demonstrates the lowest BHP over the RPM spectrum, suggesting that a diminished concentration of CNG may be inadequate for energy output compared to alternative fuels.

Concurrently, CNG 1 and CNG 2 exhibit intermediate characteristics, with brake horsepower values increasing more swiftly as revolutions per minute increase. In the BHP analysis of the fuel used, results were obtained with a trend like the calculated torque, where biodiesel fuel and a mixture of 1% CNE and 3% CNE produced a power of 1.523946667 kW. However, the same trend can also be seen in the mixture of 0.5% and 2%, where much lower power was generated compared to other mixtures, with the largest BHP value of 1.251813333 kW.



(a). Efficiency vs RPM (b). BBSFC vs RPM

Figure 4. Tren rotational speed vs efficiency and BSFC

In the fuel efficiency analysis provided on Figure 4a, the correlation between RPM and efficiency (%) for five distinct fuel types: bio solar, CNE 0.5, CNE 1, CNE 2, and CNE 3. As the RPM escalates from 1700 to 2700, all fuel types typically exhibit a rise in efficiency, but the degree of enhancement differs among them. CNE 1 continuously exhibits the best efficiency, reaching almost 30% at 2200 RPM before seeing a minor decline, however it remains better to the others at most RPM values. Bio solar and CNE 2 exhibit analogous tendencies, with their efficiency values tightly correlated and progressively rising with RPM. CNE 0.5 exhibits the lowest efficiency initially but demonstrates significant enhancement as RPM escalates, ultimately exceeding CNE 3 at elevated speeds. CNE 3 has intermediate efficiency, positioned between CNE 0.5 and the more efficient fuels. The research indicates that increased RPMs often enhance efficiency across all fuels, with CNE 1 demonstrating notable effectiveness. The comparison of the power produced compared to the best fuel mass per second was obtained in a 1% CNE mixture with the highest efficiency value of 28.13%. Although the 1% CNE mixture has the highest efficiency value, the longest fuel usage time is obtained by a 2% CNE fuel mixture, but this fuel has a lower efficiency value because the power produced is smaller than the 1% CNE fuel mixture, where 2% CNE produces 0.71592 kW at the longest time of 85s, 1% CNE produces power of 0.82896 kW at the longest time of 83 s. Although there is a deviation in the fuel mixture of CNE 1% between the experiment rotation speed of 2200 and 2600RPM, the data surrounding the fuel mixtures aligns with the trend, where the efficiency through the rotation speed is still significantly better than the other fuel mixtures (Paneerselvam *et al.*, 2021). Especially with the calorie experiment data that indicates CNE 1% puts out the highest calorie per mass output between the other fuel mixtures.

BSFC analysis has an inverse trend with fuel efficiency, where the faster the engine rotates, the lower the amount of fuel used (see Figure 4b). The graph illustrates the correlation between BSFC and RPM for five distinct fuel blends: bio solar, CNE 0.5, CNE 1, CNE 2, and CNE 3. Brake Specific Fuel Consumption serves as a crucial metric for engine efficiency; reduced BSFC values indicate enhanced fuel economy. The graph clearly indicates that all fuel types exhibit a reduction in BSFC as RPM rises from 1800 to around 2300 RPM, after which the numbers either stable or see a tiny increase. CNE 1 regularly exhibits the lowest brake specific fuel consumption across the RPM spectrum, signifying superior economy. Conversely, CNE 0.5 has the greatest BSFC, indicating diminished efficiency relative to the other mixes. bio solar, CNE 2, and CNE 3 exhibit intermediate performance, with bio solar surpassing CNE 0.5 and CNE 2 at elevated RPMs.

This pattern suggests that raising engine speed to a specific threshold enhances fuel efficiency across all mixes. Nevertheless, when attaining an ideal RPM (about 2300–2400 RPM), additional increments in speed may not markedly decrease BSFC and may even result in a minor gain. The statistics indicate that CNE 1 is the most efficient formulation for this engine configuration, particularly at elevated RPMs. Following this trend, the lowest BSFC was obtained using a 1% CNE mixture, where the fuel usage was obtained at 0.00007783 g/kWh. Although at lower engine speeds longer fuel times were obtained, the BSFC obtained was greater than at higher engine speeds, because BSFC comes from the comparison of fuel mass per second divided by BHP, where the BHP produced is directly proportional to the torque value produced by the engine. Therefore, the greater the torque produced, the smaller the mass of fuel required to produce power (Sudarmanta, Darsopuspito and Sungkono, 2014).

4. CONCLUSION

The use of CNE in biodiesels enhances the lower heating value of the fuels, yielding a greater caloric content per unit mass. As the caloric density per unit mass increases, the engine performance examined in this study adjusts correspondingly. Fuel mixes with a greater caloric value per mass exhibit superior performance compared to those with a lesser caloric value per mass. The fuel combination with the highest caloric density per mass is CNE 1%. The other mixes exhibit negligible differences without the use of CNE or even possess a lower caloric value per mass. While CNE 1% may not excel in generating torque or braking horsepower, it demonstrates superior economy, particularly in thermal efficiency and brake-specific fuel consumption. The reduced caloric density of higher CNE fuel mixes is attributable to alterations in combustion timing, resulting in suboptimal ignition relative to the CNE 1% combination. Particularly seen in the graphs of thermal efficiency and brake-specific fuel consumption.

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