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Experimental and numerical study of the adaptability of the palmitic acid methyl ester extracted from palms oil as a clean low-cost fuel alternative to diesel for combustion engines

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ABSTRACT

Biofuel as a sustainable source of energy was investigated in several earlier studies to look for environmentally friendly alternatives to fossil-based fuels. This study aims to investigate a new type of low-cost biofuel based on the palm oil extracted from the palms. The experimental investigation was carried out on an agricultural tractor powered by a four-cylinder, direct-injection diesel engine. Biofuel is produced using a chemical transesterification reaction of the palm oil, in its pure form free of any blend. A 1-D gas dynamics engine model was built to numerically investigate the engine performance and emissions as it is fed with such biofuel. The 1-D engine model was validated against test data for both PAME biofuel and traditional diesel. Based on the findings, the emissions in terms of CO, and CO_2 were figured out under six different engine speeds ranging from 800 to 2800 rpm. Also, torque and power as well as the brake-specific fuel consumption (BSFC) were predicted and compared to test data. The use of PAME biodiesel led to up to a 50% reduction in CO emissions, especially at low engine speeds, and up to 20% decrease in CO_2 emissions. The findings suggest that the produced PAME biodiesel can be an efficient and cost-effective alternative to traditional diesel.

Keywords: palm oil, palmitic acid methyl ester, diesel, 1-D engine model, emissions, torque, power.

INTRODUCTION

These days, the population's sharp increase resulted in extensive growth in the required energy (Bakri et al., 2019). During the past few years, energy consumption heightened by 1.8% which was reported by the Energy Policy and Planning Office of Thailand (Al-Aseebee et al., 2025). Consequently, searching for unconventional fuel sources has become initially significant within the field of energy production. Vegetable renewable oils are potentially infinite sources of energy such as biomass, biodiesel, alcohol, and other biofuels (Al-Aseebee et al., 2024). Pollutant mission levels appearing from the rising usage of fossil fuels are having adverse impacts on the environment. The United Nations Annual Climate Summit (UNACS) focused on decreasing greenhouse gas emissions using ecofriendly clean or low-carbon energy alternatives. In the same way, the Kyoto Protocol has requested the usage of biodiesel around the world as a partial solution that can contribute to the reduction in the global warming effect. Many countries around the globe have passed legislation that diesel should include a minimal proportion of biofuels (Lomeu et al., 2023). Biodiesel resulted from nontraditional sources such as vegetable oils, fat, palm oil, soybeans, coconut, and others offer a practical substitute fuel for diesel engines. Furthermore, these substitute fuels for biodiesel are readily accessible and can be got regionally in large quantities. The combination of pure diesel and even low percentages of biodiesel will take part to the regional economy of the nation and cut down poverty levels. Biodiesel is a biodegradable fuel that includes fatty acid methyl or ethyl esters. It may result from many various raw materials such as vegetable crops, animal fats, algae, or waste cooking oil. In Thailand, palm oil is the easiest oil to get for producing biodiesel. It has been announced that the average rate of annual palm oil production enhanced in roughly 13.18% per year for palm oil production during 2017–2020 (Yaseen et al., 2023). Natural fats like palm oil mainly include triglycerides, mono, and triglycerides. Unbound fatty acids, moisture, dirt, and minor parts of non-oil fatty matter are recommended to collectively as unsupportable matter. Palm oil is made of fatty acids, esterified with glycerol just like any typical fat. It is highly in fats that are saturated. Palm oil provides its name to the 16-carbon saturated fatty acid palmitic acid. Monounsaturated oleic acid is also a participant of palm oil (Al-Aseebee et al., 2024). This way cuts down on the viscosity and enhances the fuel characteristics of raw properties to enable their usage in diesel engines. The use of alcohols in transesterification reactions are those of short-chain carbon such as methanol (CH_3OH) and ethanol (C_2H_6O). The major alcohol that can be used in biodiesel production is methanol mainly due to it is less costly than ethanol. The main elements affecting the transesterification reaction and the production rate are raw materials, molar ratio of alcohol to raw materials, reaction time, kinds of catalysts, catalyst concentration, mass-transfer rate, reaction temperature, and kinds of reactor (Osorio-González et al., 2020). The process of biodiesel production confronts different concerns which are related to the reaction reversibility and immiscibility of raw materials and alcohol, which results in low quantity and quality of the produced biodiesel. Nowadays, this trouble can be solved by using ultrasonic, microwave which helps to enhance the transesterification rate and expanding biodiesel yield (Bhanu Teja et al., 2023). Consequently, the palm oil biodiesel can be used without any modifications directly in a diesel engine due to its physicochemical characteristics comparable to pure diesel (Ojapah & Diemuodeke, 2023). Torres et al. (2024) run the palm oil diesel on a 5 kW Cussons air-cooled single-cylinder indirect-injection diesel engine with a Ricardo comet-type-swirl combustion chamber. Their outcome showed about 10% higher brake-specific fuel consumption with the palm oil biodiesel in contrast with the pure diesel fuel, and brake thermal efficiency diminished to about 5% lower due to the heating value of the biodiesel while CO and HC emissions diminished on average by 51% and 55% correspondingly. The NO_x was increased by 33% on average in contrast to pure diesel fuel.

The objective of this work is to evaluate the feasibility of utilizing the palm oil biodiesel as a sustainable alternative fuel through an integrated approach combining experimental testing and numerical simulation. Experimental measurements were carried out on a diesel engine mounted on an agricultural tractor. Complementary numerical simulations were performed using a one-dimensional (1-D) engine model, which employs the finite volume method for the intake and exhaust manifolds and incorporates analytical sub-models to represent engine operation and boundary conditions. The 1-D model was applied to a direct-injection diesel engine operating at six distinct speeds ranging from 800 to 2800 rpm, and its predictions were compared with experimental data. Model accuracy was checked by evaluating the performance of the produced palmitic acid methyl ester (PAME) biodiesel relative to conventional diesel fuel, using cycle-averaged brake torque and brake power as validation parameters. Once validated, the 1-D engine model was further used to predict instantaneous in-cylinder parameters such as pressure, net heat release rate, and temperature. In addition, the brake-specific fuel consumption (BSFC) and exhaust emissions of the engine such as CO, CO_2, and NO_x were assessed for both the PAME biodiesel and standard diesel fuel.

EXPERIMENTAL STUDY

Biofuel production

The study involved the manufacture of biodiesel from the palm oil extracted from palms, using the transesterification reaction to create the PAME as depicted in Figure 1a. The process of transesterification involves converting an organic ester group into an organic alcohol group, often catalyzed by the addition of an acid or base catalyst. Following the reaction, glycerol and methyl esters can be separated using a centrifuge or a settling tank.

In Figure 1b, the state of the mixture after the separation step between the glycerol and the ester is shown, highlighting the ease and speed of separation due to the low solubility of the ester. The unreacted residual methanol acts as a solvent. Figure 1c illustrates the final state of the PAME biodiesel product after washing with distilled water and separation through heating. Table 1 shows the obtained physicochemical characteristics of the final PAME biodiesel product and compare them to those of the traditional diesel and the ASTM D6751 standard. From this comparison, it can be stated that there is a slight difference in the physicochemical characteristics between the obtained biofuel and the traditional diesel but it still overall respecting the ASTM D6751 standard for biofuels.

Internal combustion engine

A KUBOTA agricultural tractor powered by a traditional four-cylinder diesel engine was used to evaluate the performance of the produced PAME biodiesel derived from the Iraqi oasis and its impact on the overall performance and emissions. The technical specifications of the KUBOTA engine under test are presented in Table 2. Figures 2a and 2b respectively show actual views of the KUBOTA agricultural tractor engine and the hydraulic brake dynamometer used to measure the output torque. The dynamometer is equipped with a torque cell sensor and a magnetic pick-up frequency sensor. The torque cell incorporates a full Wheatstone bridge strain gauge configuration to measure torque during testing, while the magnetic pick-up frequency sensor utilizes a toothed wheel, coil, and iron core assembly to record the engine shaft speed.

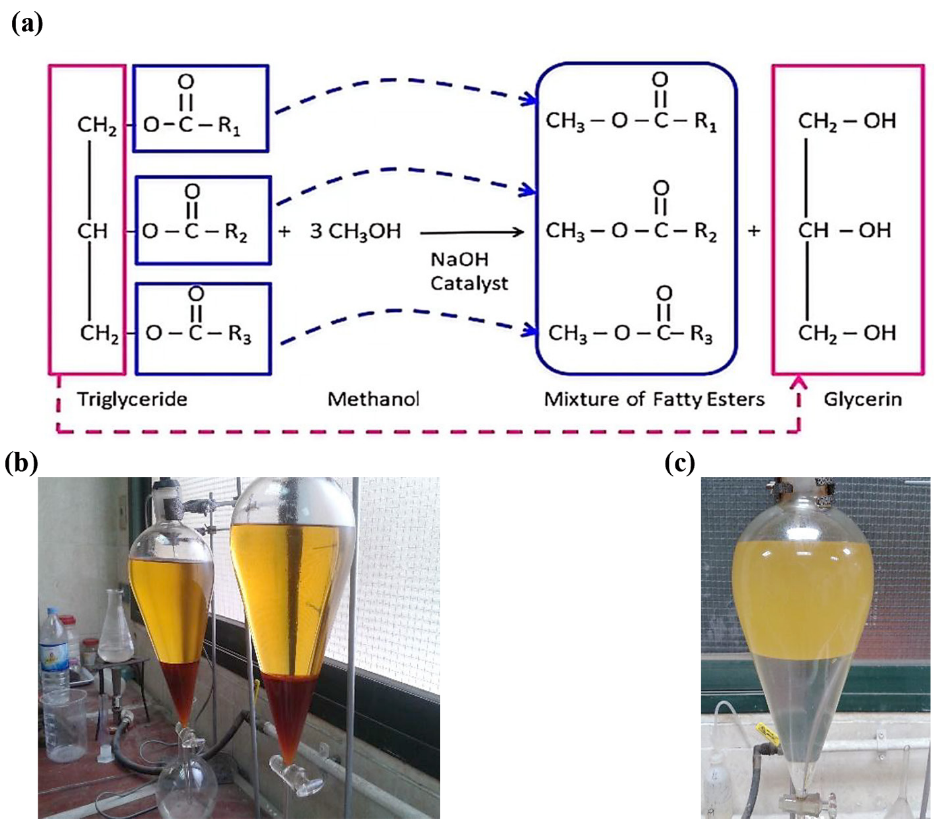


Figure 1. PAME Laboratory-scale production process of PAME biodiesel: (a) transesterification reaction, (b) separation phase, and (c) final product of biodiesel

Table 1. Comparison of physicochemical properties between produced PAME biofuel and conventional diesel

Property	PAME	Diesel	Biofuel ASTM D6751
Flash point (C°)	185	80	130 at least
Pour point (C°)	10	-35 to -15	-15 to 10
Calorific value (MJ·kg^{-1})	39.9	45.6	39-41
Density at 40°C (g·cm^{-3})	0.837	0.848	0.878
Viscosity at 40 °C (g·cm^{-1}·s^{-1})	3.5	4.5	3.5 – 5

Table 2. Technical specifications of the Kubota engine

Type of engine	Four strokes, liquid-cooled diesel
Top speed	3000 rpm
Compression ratio	21.8:1
Number of cylinders	4-cylinder
Bore (mm)	100
Stroke (mm)	120

Computational method

A one-dimensional gas dynamics engine model of the Ricardo Wave environment, which employs a staggered grid finite-volume discretization approach, has been used in this study to describe the engine that is being tested. A variety of applications are required to use the 1-D engine bundle, ranging from model setup to output analysis. This study employed three programs: Wave Solver was used to solve the flow equations, Wave Build GUI was used to model the engine, and Wave Post was used to post-process the findings. Figure 3 shows a simplified view of the developed 1-D engine model created using the Ricardo Wave Build GUI. The current engine model consists of many sub-models for the injector, single cylinder, intake and exhaust ducts, and intake and exhaust valves. This model is probably similar to the 1-D diesel engine model that (Ketata et al., 2023) earlier built. Both conventional diesel and biofuel include "data" files that hold the thermodynamic properties of each fuel.

RESULTS AND DISCUSSION

Brake and indicated torques

Figures 4a and 4b respectively compare the indicated and brake engine torques as dependent on the engine speed between the traditional diesel and the produced PAME biodiesel. From Figure 4b, it is clear that the experimental and predicted brake torques exhibit similar trends for the two tested fuels. The maximum indicated torque value for the produced PAME biofuel is 417.894 N.m at 1600 rpm. The indicated torque value for traditional diesel is 346.514 N.m at 1600 rpm. The minimum indicated torque value for traditional diesel at maximum engine speed is 222.220 Nm, while the minimum indicated

(a) (b)

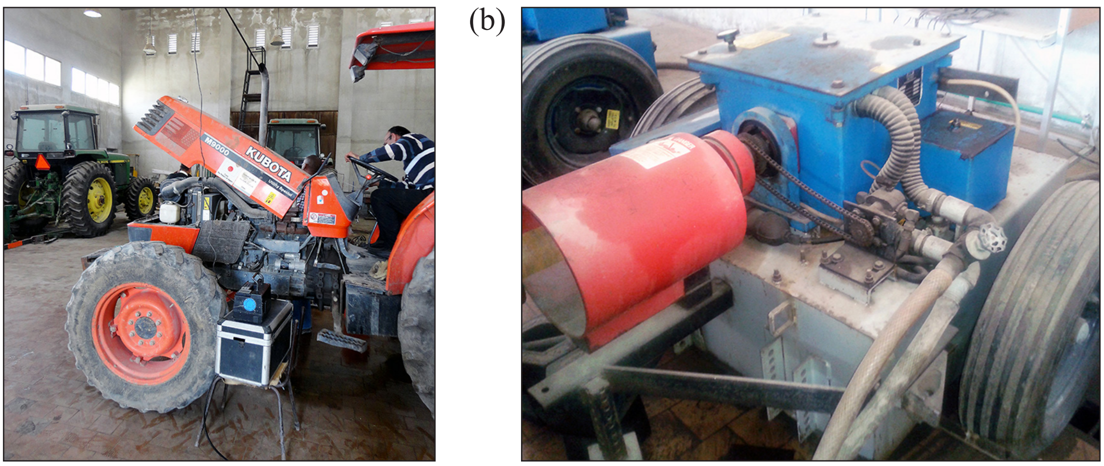


Figure 2. Experimental evaluation of the produced PAME biodiesel: views of the (a) KUBOTA tractor (b) its diesel engine

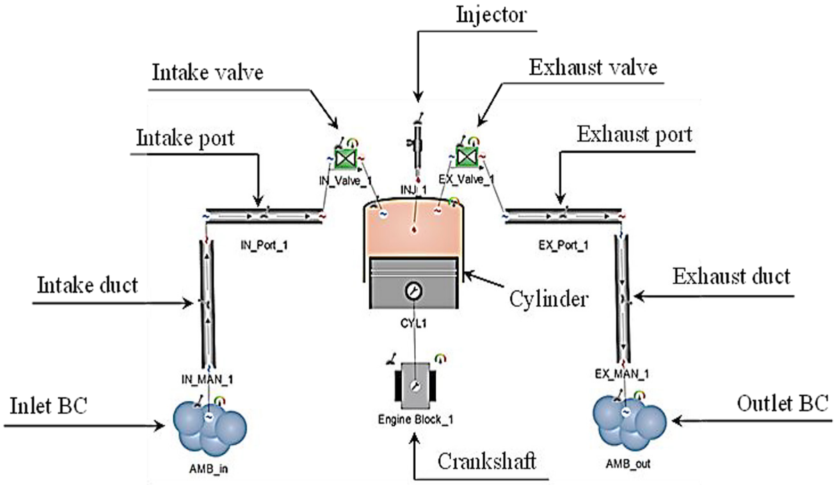


Figure 3. Schematic layout of the 1-D engine model

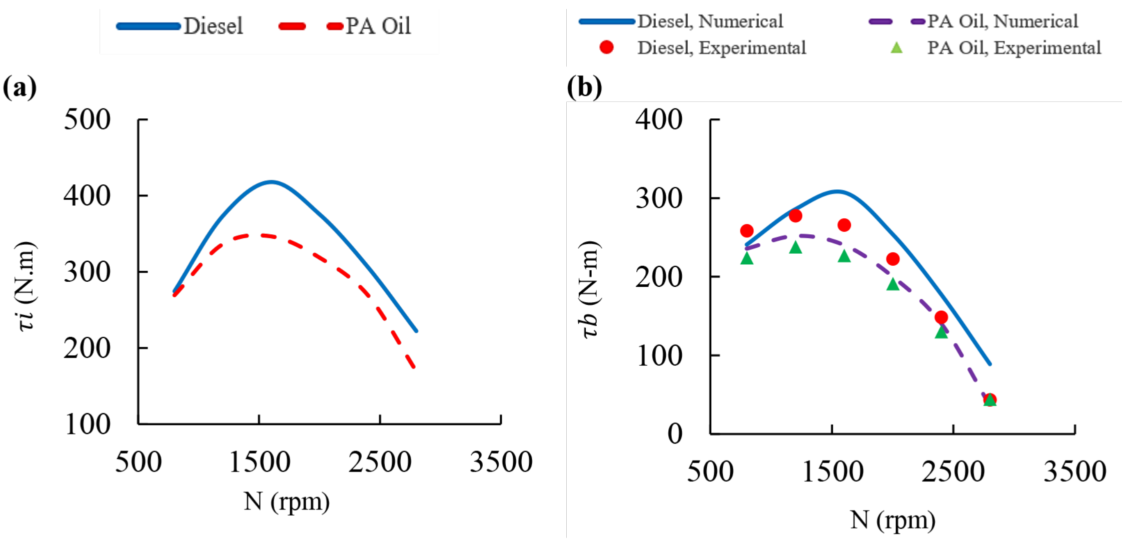


Figure 4. Cycle average (a) indicated and (b) brake torques under different speeds

torque value for PAME biofuel is 169.410 Nm at maximum engine speed as shown in Figure 4a. According to these results, adding more biodiesel to the fuel mixture causes the torque values to slightly decrease. This decrease can be explained by the fact that compared to traditional diesel fuel, the heat content of the fuel mixture decreases with an increasing biodiesel proportion. The increased lubricity and higher oxygen content of biodiesel may reduce friction loss, improving effective braking torque while compensating for the lower calorific value of the fuel (Simsek, 2020). Specifically, in both fuel cases, the brake torque peaks at approximately 1200 rpm within the middle-speed range before declining with higher speeds. This trend can be attributed to decrease volumetric efficiency, resulting in reduced air intake by the engine with increased engine speed. Furthermore, the simulation data shows a slightly higher torque in the traditional diesel case compared to the PAME biofuel case.

Brake and indicated powers

Figure 5 compares the distribution of the indicated power with respect to the engine speed between the traditional diesel and the produced PAME biodiesel. From Figure 5, it is obvious that both experimental and predicted indicated and brake powers have comparable trends for the two tested fuels. This finding validates the accuracy of the one-dimensional computational model. The results show that the brake power values increase with an increasing engine speed. The traditional diesel fuel has a higher specified brake power up to 10% compared to the produced PAME biofuel.

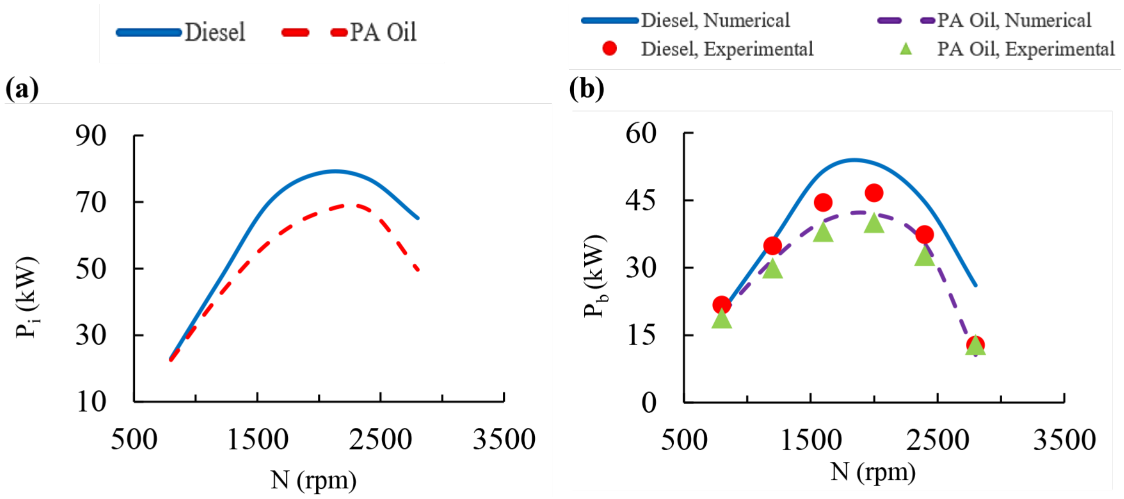
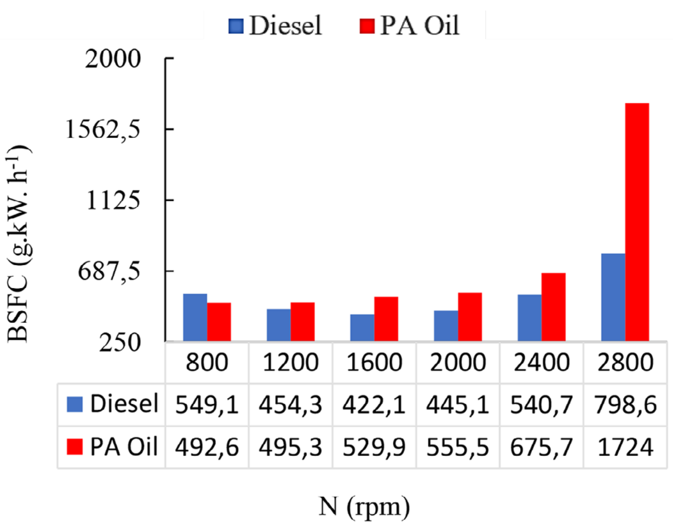


Figure 5. Cycle average (a) indicated and (b) brake powers under different speeds

With traditional diesel fuel, the highest value of the brake power is about 78.6 kW, recorded at an engine speed of 2000 rpm, and the lowest value is about 23.0 kW, recorded under an engine speed of 800 rpm. The indicated brake power of the produced PAME biofuel reaches a maximum value of 67.7 kW under an engine speed of 2400 rpm and a minimum value of 22.6 kW at 800 rpm, as shown in Figure 5a. These results show that the experimental and simulated brake power levels for the two fuels studied show the same trend (Demiray, Ertuğrul Karatay, & Dönmez, 2020). Since the tests pointed that the brake power of the produced PAME biofuel is comparable to that of the conventional biodiesel. Therefore, the possibility of using the produced PAME biofuel instead of the traditional diesel fuel is proposed as a clean fuel alternative.

Brake specific fuel consumption

Figure 6 shows the comparison of the brake-specific fuel consumption (BSFC) for the traditional diesel fuel and the produced PAME biodiesel. As the engine speed increases, the BSFC tends to decrease first and then increase due to poor fuel atomization and traditional diesel fuel air mixing. This causes BSFC to increase at lower engine speeds. Increasing the engine speed can increase the fuel atomization effect, increase the fuel mixing speed, and reduce the BSFC value. However, as the engine speed increases further, the frequency of fresh air entering the cylinder increases, increasing BSFC. The produced PAME biodiesel has the highest BSFC value compared to the conventional diesel. The highest BSFC value is about 1724.3 g.kW.h^{-1}, measured at the



	800	1200	1600	2000	2400	2800
Diesel	549,1	454,3	422,1	445,1	540,7	798,6
PA Oil	492,6	495,3	529,9	555,5	675,7	1724

Figure 6. Comparison of the brake-specific fuel consumption (BSFC) between the conventional diesel and the produced PAME biofuel for the six investigated engine speeds

maximum engine speed of 2800 rpm, and the lowest value is 492.6 g.kW.h^{-1}, measured at an engine speed of 800 rpm. The BSFC of the conventional diesel reaches a maximum of about 798.6 g.kW.h^{-1} at a maximum engine speed of 2800 rpm and the minimum value is about 422.1 g.kW.h^{-1} at an engine speed of 1600 rpm. This is consistent with the previous works (Zheng et al., 2022).

In-cylinder temperature

It is vital to calculate the maximum in-cylinder temperature because it affects the engine's mechanical and thermal stresses, in addition to the engine emissions. Figure 7 depicts the instantaneous change in the in-cylinder temperature concerning the crankshaft angle (CA) for

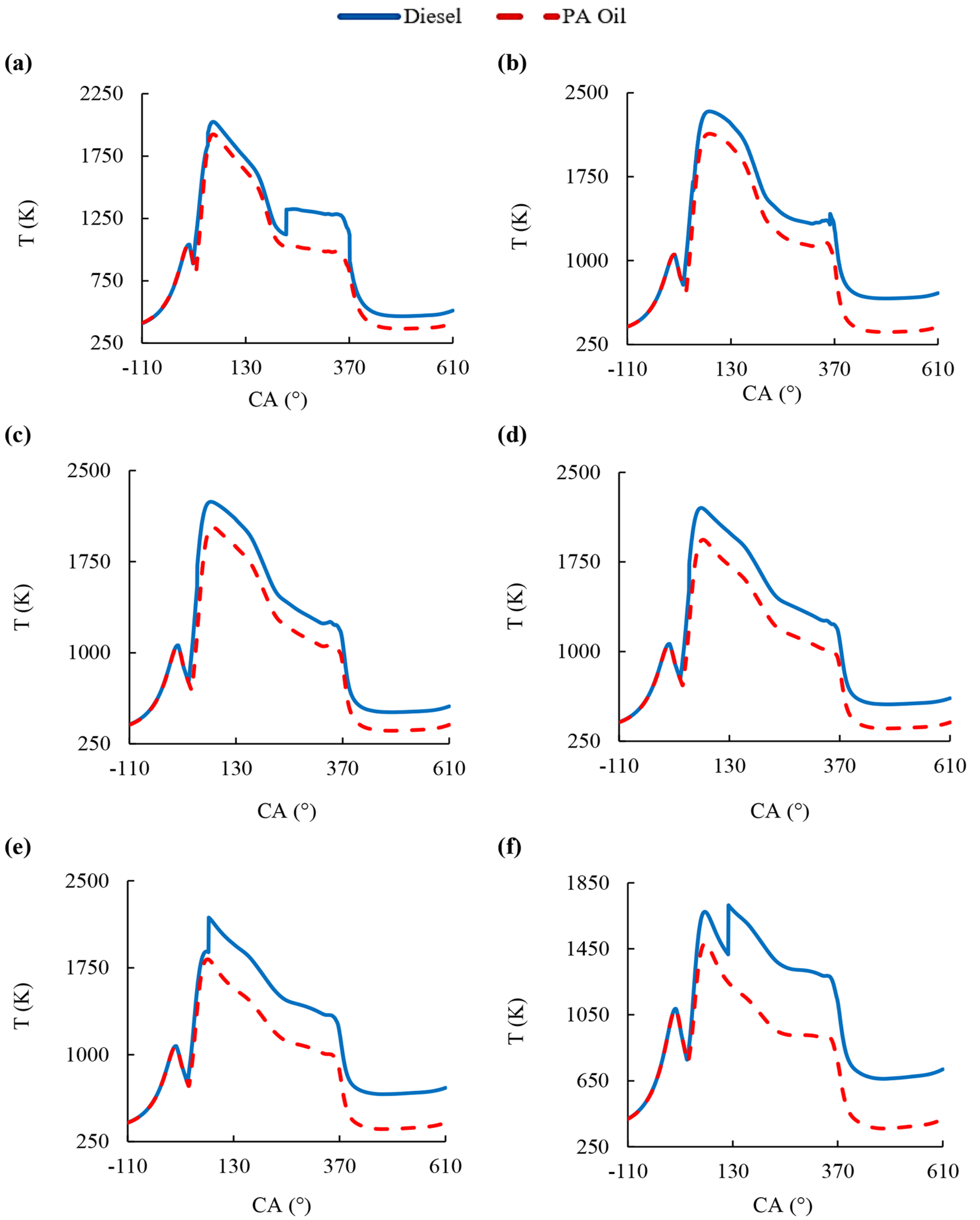


Figure 7. Comparison of in-cylinder temperature *T*(*K*) as a function of *CA*(°) between the traditional diesel and the produced PAME biofuel: (a) 800 rpm, (b) 1200 rpm, (c) 1600 rpm, (d) 2000 rpm, (e) 2400 rpm and (f) 2800 rpm

both the traditional diesel fuel and the produced PAME biodiesel under an engine rotational speed range from 2800 rpm down to idle at 800 rpm. The sudden increase in the temperature with the initiation of combustion is observed in all cases. Noticed that model predictions showed lower temperature values for PAME biofuel compared to traditional diesel fuel. Generally, the lower temperature values for the PAME biofuel can be attributed to the engine running a little 'leaner' and possibly to its higher heat of evaporation and lower calorific value. The in-cylinder temperature and the heat release predictions of the model are well within the range that effectively confirms that the spray dynamics, fuel droplet evaporation, fuel air mixing, ignition delay, and combustion sub-models are reasonably working. The conventional diesel fuel recorded higher combustion temperature compared to the produced PAME biodiesel, where the in-cylinder heat value of the produced PAME biofuel was 2334.1 K at 80.3 deg, while the highest value was for the produced PAME biodiesel was 2134.1 K at 80.5 deg at 1200 rpm engine speed as shown in Figure 7e. This is consistent with the work of Hussain et al. (2025).

Burn duration 90% and 50%

Figure 8 shows the contrast in burn duration of 50% for the conventional diesel and the produced PAME biodiesel as opposed to engine

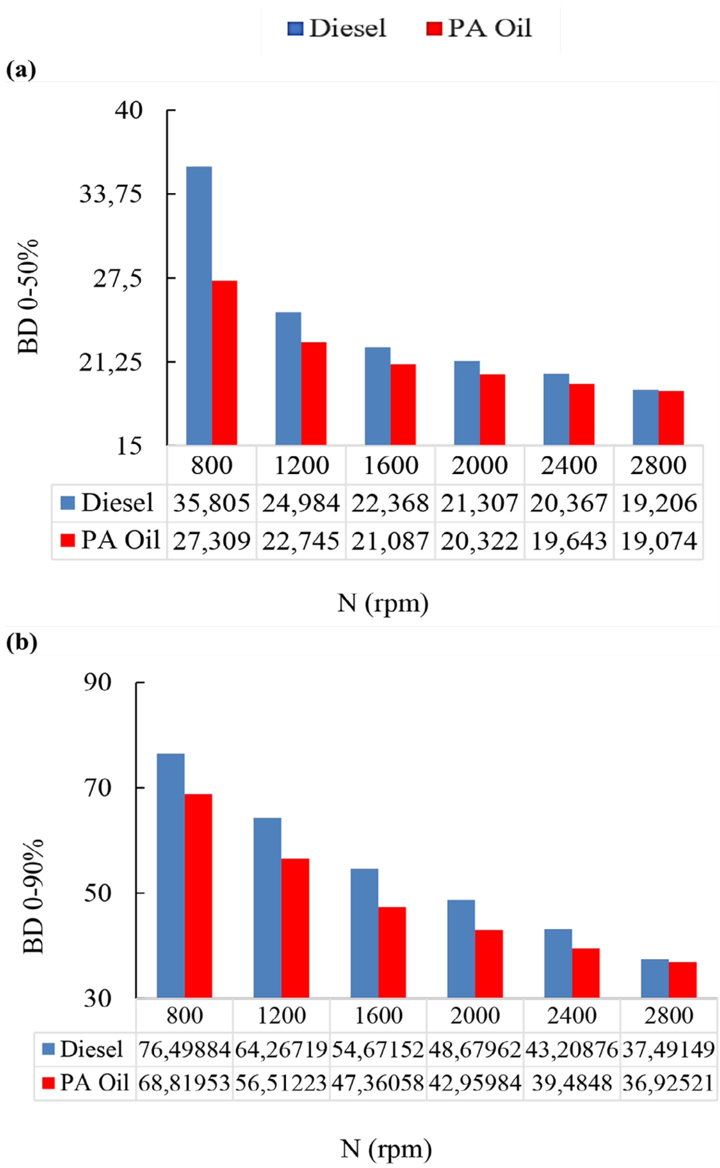


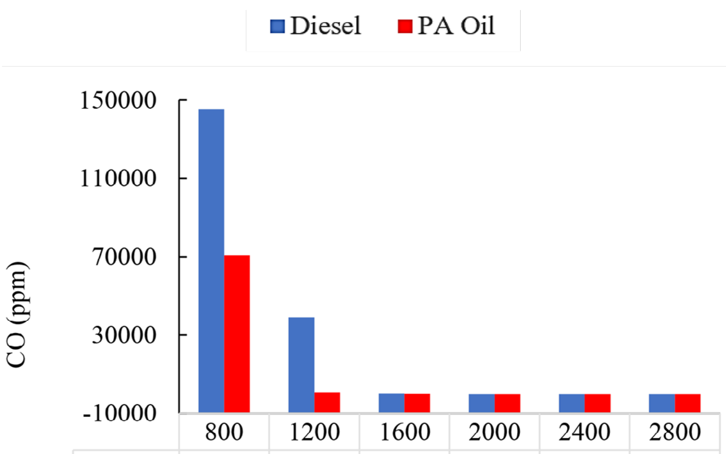
Figure 8. Comparison of (a) 50% and (b) 90% burn durations between the conventional diesel and the produced PAME biofuel for the six investigated engine speeds

rotational speed. The burn length is crucial for improving the engine's performance, enhancing fuel efficiency, decreasing emissions, and making sure of the durability of the engine. The burn duration is a critical parameter that substantially influences the engine efficiency, the overall performance, and the emissions. A shorter burn duration normally leads to more active combustion, as the fuel burns more swiftly and absolutely, converting more of the fuel's energy into beneficial paintings. The biodiesel regularly has a slightly longer burn length as compared to standard diesel because of its better oxygen content material, which could affect combustion timing. The conventional diesel fuel has the highest value registered burn length of 50% of 35.805% recorded at an engine speed of 800 rpm. The lowest value of the burn duration of 50% of 19.206% was recorded for the conventional diesel beneath an engine speed of 2800 rpm. The burn duration of 50% for the produced PAME biodiesel reaches its highest value of 27.31% at an engine speed of 800 rpm, while at a velocity of 2800 rpm, it reaches its lowest value of 19.1% as shown in Figure 8a. The burn duration of 90% of the conventional diesel and the produced PAME biodiesel as opposed to the engine speed. As the burn length of 90% refers to the time it takes the combustion manner to reach 90% completion, this parameter is used to measure the timing and completeness of the combustion technique in an internal combustion engine. A shorter burn period of 90% normally shows extra efficient and managed combustion, which is acceptable for engine overall performance and emissions control. Factors that affect burn duration by 90% are much like people who affect burn period by 50%, as mentioned earlier, and include engine velocity, compression ratio, air-gas combination, ignition timing, and different engine parameters. The traditional diesel is found with the highest value registered a burn duration of 90% of 76.5% recorded at an engine pace of 800 rpm, while the lower value 37.5% for the conventional diesel fuel recorded below an engine speed of 2800 rpm. The 90% burn duration for the produced PAME biodiesel reaches its highest value of 68.82% at an engine speed of 800 rpm. At a lower value of 2800 rpm, the 90% burn duration reaches its lowest value of 36.9%. From these consequences, especially at low engine speeds, the produced PAME biodiesel performs higher burn duration compared to the traditional diesel. This observation can be defined by the reality that the produced PAME biodiesel incorporates more oxygen than the petroleum diesel main to a lower burn period and extra combustion completeness as shown in Figure 8b.

Cycle-average emissions

CO emission

Figure 9 shows the cycle-average carbon oxide (CO) emission for conventional diesel and the produced PAME biodiesel to different engine



	800	1200	1600	2000	2400	2800
Diesel	145549	39118	261,72	37,64	5,5367	1,6048
PA Oil	70809	732,53	72,661	11,492	1,7613	1,159

Figure 9. Comparison of cycle-average CO emission between the conventional diesel and the produced PAME biofuel for the six investigated engine speeds

rotational speeds. The CO emission is a toxic gas, and it significantly influences the surroundings, causing pollution to increase bad human health impacts and may cause death. It has been mentioned that the engine rotational speed affects the CO emission because the in-cylinder temperature decreases whilst engine velocity decreases, inflicting the conversion of carbon monoxide oxidation to carbon dioxide gradually down (Chybowski et al., 2025; Stanescu, Soica, & Leahu, 2025). Therefore, a significant increase in CO emission at low speeds was noticed. Increasing the engine rotational speed ends in a large upward push in gas intake and the in-cylinder temperature.

The conventional diesel recorded the highest carbon monoxide emissions, reaching 145,549ppm compared to the produced PAME biodiesel, where the CO emission reached 70,809 ppm at the engine speed of 800 rpm. The lowest CO emission was for the conventional diesel, which reached 1604 ppm, while the lowest percentage for the conventional PAME biodiesel fuel was about 1159 ppm, both at the maximum engine speed of 2800 rpm. As a deduction, it may be pronounced that the usage of the conventional PAME biodiesel fuel has caused a substantial lower in CO emissions as compared the traditional diesel. These consequences match properly the previous studies paintings of Gad, El-Shafay and Abu Hashish (2021).

CO_2 emission

Figure 10 presents the comparison of cycle-average carbon dioxide (CO_2) emission for the conventional diesel fuel and the produced PAME biodiesel under different engine speeds. From these results, it has been figured out that the CO_2 emission increases at low speeds for the produced PAME biodiesel compared to the traditional diesel, and then it decreases starting from the speed of 1600 rpm. The percentage of CO_2 greatly increases at high temperatures during combustion, as carbon bonds are broken and new bonds are formed with oxygen atoms and release more chemical energy and water (Iacono et al., 2024). Under an engine speed of 1200 rpm, the PAME biofuel recorded the highest value for CO_2 emission, reaching 126,230 ppm, compared to the traditional diesel, which recorded the highest value about 124,511 ppm at an engine speed of 1600 rpm. The lowest recorded value of the CO_2 emission was for the PAME biofuel, which amounted to 56,051 ppm at the engine speed of 2800 rpm, while for the traditional diesel fuel, the lowest recorded value was 51,315 ppm, at the engine speed of 800 rpm.

NO_x emission

Figure 11 shows the distribution of the cycle-average nitrogen oxides (NO_x) emission for both the traditional diesel and the PAME biodiesel under the six investigated engine speeds. The oxides of nitrogen in the fumes discharge incorporate mainly the nitric oxide (NO) and the nitrogen dioxide (NO_2). Particularly, the NO_x arrangement is based upon the temperature inside the chamber, the oxygen concentration, the time for

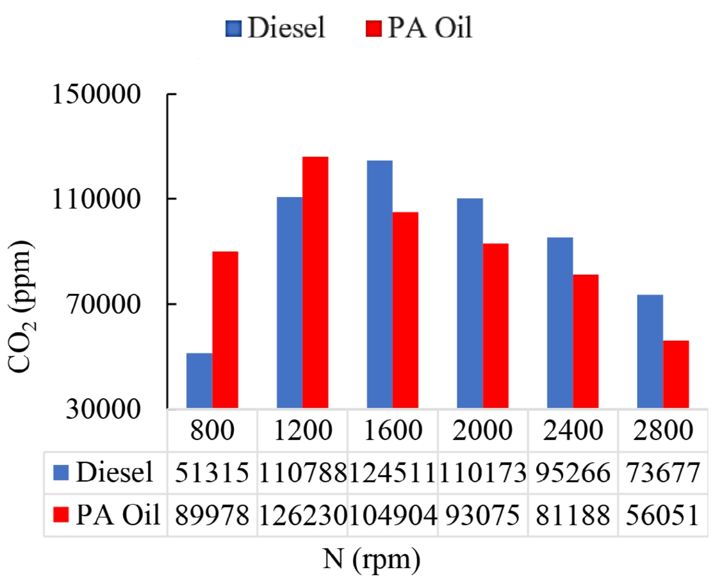
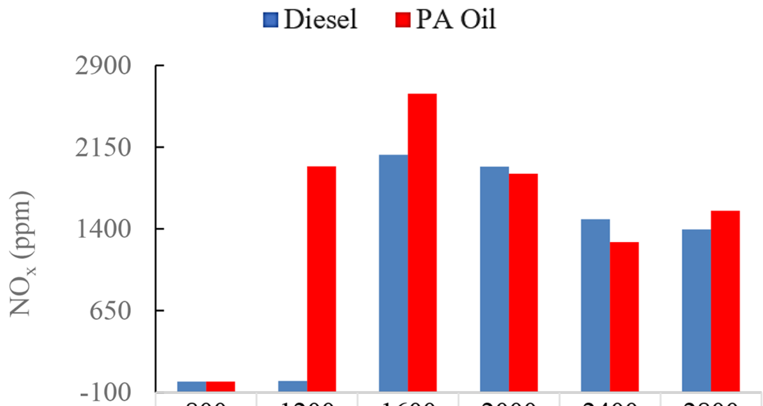


Figure 10. Comparison of cycle-average CO_2 emission between the conventional diesel and the produced PAME biofuel for the six investigated engine speeds



	800	1200	1600	2000	2400	2800
Diesel	0,01262	5,28301	2080,78	1970,18	1488,61	1395,63
PA Oil	0,09141	1974,92	2640,96	1907,02	1279,48	1567,91

N (rpm)

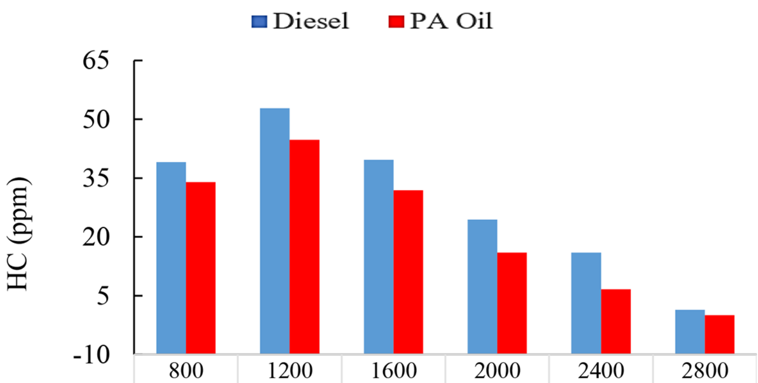
Figure 11. Comparison of cycle-average NOx emission between the conventional diesel and the produced PAME biofuel for the six investigated engine speeds

the reaction to occur, and the equivalence ratio. The NO_x emission returns are special from other emissions from the engine. In fat, the nitrogen oxide is formed due to the oxidation of nitrogen inside the air in the course of the burning of the air-fuel combination in the combustion chamber (Azad et al., 2017).

It depends on the timing of combustion and temperature. The oxygen amount and the in-cylinder temperature are the primary reasons that influence NOx emission. This fact can explain the observation from figure 11 that the produced PAME biodiesel recorded the highest NOx emission, reaching 2640.96 ppm compared to the petroleum diesel, where the NOx emission reached 2080.78 ppm, both at the engine speed of 1600 rpm. The lowest NOx emission was for petroleum diesel, which reached 0.01 ppm, while the lowest percentage for the PAME biodiesel fuel was about 0.09 ppm, both at an engine speed of 800 rpm. This is consistent with the previous research of Patel, Azad and Khan (2019).

Unburned hydrocarbon emission

The emissions of unburned hydrocarbons (HC) for the traditional diesel fuel and the produced PAME biodiesel are shown in Figure 12.



	800	1200	1600	2000	2400	2800
Diesel	39,077644	52,858948	39,656166	24,379066	16,015404	1,4139415
PA Oil	33,985165	44,771427	31,862415	16,005318	6,652137	0,0317968

N (rpm)

Figure 12. Comparison of cycle-average unburned hydrocarbon (HC) emission between the Conventional diesel and the produced PAME biofuel for the six investigated engine speeds

The diesel recorded the highest HC emission, reaching 52.86 ppm compared to the produced PAME biodiesel, where the HC emission reached 44.77 ppm, both at the engine speed of 1200 rpm. The lowest HC emission was for the traditional diesel, which reached 1.41 ppm, while the lowest value for the produced PAME biodiesel was about 0.03 ppm, both at an engine speed of 2800 rpm. The result indicates that the produced PAME biodiesel has the lowest HC emissions because it incorporates extra oxygen, and the combustion charge of this fuel is higher than the traditional diesel. Indeed, the petroleum diesel holds more hydrocarbons, and they have extra HC emissions. This is why the diesel fuel has the highest HC emissions (Zhao et al., 2018).

CONCLUSIONS

In the present work, a new biodiesel, denoted as the PAME biofuel, was produced through the transesterification reaction based on the palm oil extracted from the palms of the Iraqi oasis. Analyses were carried out to figure out the physicochemical properties of the new biodiesel which were compared to those of diesel. The produced PAME biodiesel showed physicochemical properties comparable to diesel that matches with the requirements of the ASTM D6751 norm. This fact has confirmed the ability of the usage of such biofuel in diesel engines as a clean alternative fuel. The produced biofuel is tested with an agricultural Kubota tractor engine. Test data in terms of the brake torque and power were measured and compared to those of the petroleum diesel. Then, these experimental results served as data for the validation of a developed 1-D gas dynamic model of the engine. The gap between numerical and experimental results did not exceed the value of 10% which ensured the validity of the computational method. Based on the gathered results, it has been figured out the following major outcomes:

- As the produced PAME biodiesel is used to feed the engine, there is a 30% decrease in the instantaneous heat release which has an immediate impact on the in-cylinder temperature. This was explained by the fact that the produced PAME biodiesel has a lower calorific value than petroleum diesel.
- Overall, the 50% and 90% burn durations were significantly reduced up to 10% as the produced PAME biodiesel is used to feed the engine in comparison to the petroleum diesel.
- The consumed fuel amount has increased up to about 30% as a result of using the produced PAME biodiesel compared to petroleum diesel for the same output power under low and medium engine speeds. At high engine speeds, the fuel consumption dramatically increased by over 70%.
- Supplying the engine with the produced PAME biodiesel resulted in a reduction of up to 10% in the brake torque and power at medium and high engine speeds, while similar power and torque outputs were observed under idle operating conditions.
- The usage of the produced PAME biodiesel significantly reduces the emissions of carbon monoxide (CO) and carbon dioxide (CO_2) at low engine speeds. Through the oxidation process, the lost amount of CO emissions was transformed into CO_2. As a result, the OAME biofuel's CO emissions were marginally greater than those of the conventional fossil diesel.
- Using the produced PAME biodiesel resulted in a noticeable rise in nitrogen oxide (NOx) emissions, particularly under the idle regime. This finding is explained by the high oxygen concentration of the produced PAME biodiesel.
- The unburned hydrocarbons emission is decreased by up to 25% when using the produced PAME biodiesel compared to petroleum diesel. This fact shows that the combustion of the palm oil biodiesel is more complete than that of the conventional diesel due to its high oxygen content.
- According to this research, the PAME biodiesel, of low cost of production, extracted from the palms of Iraqi oasis can be an ecologically beneficial fuel that can be used in 100% proportion or added to petroleum diesel in small amounts rather than having to totally replace it.

REFERENCES

1. Al-Aseebee, M. D., Ketata, A., Rasool Hasan, H. A., Moussa, O., Driss, Z., Abid, M. S., Naje, A. S., & Hussain, T. H. (2025). Numerical and experimental study of the impact of biofuel generated from waste olive oil on performance and emissions of IC engines. *Journal of Ecological Engineering*, *26*(2). https://doi.org/https://doi.org/10.12911/22998993/195974
2. Al-Aseebee, M. D., Ketata, A., Hasan, H., Moussa, O., Driss, Z., Abid, M. S., Naje, A., & Hussain, T. (2024). Numerical and experimental analyses for performance and emissions assessment of a

four-stroke engine powered by oleic acid methyl ester biofuel made from waste frying oil. *Global NEST Journal*, *26*(8). https://doi.org/https://doi.org/10.30955/gnj.005273

3. Azad, A. K., Rasul, M., Khan, M. M., & Sharma, S. (2017). Macadamia biodiesel as a sustainable and alternative transport fuel in Australia. *Energy Procedia*, *110*, 543-548.
4. Bakri, B., Ketata, A., Driss, S., Benguesmia, H., Driss, Z., & Hamrit, F. (2019). Unsteady investigation of the heat ventilation in a box prototype. *International Journal of Thermal Sciences*, *135*, 285-297.
5. Bhanu Teja, N., Devarajan, Y., Mishra, R., Sivasaravanan, S., & Thanikaivel Murugan, D. (2023). Detailed analysis on sterculia foetida kernel oil as renewable fuel in compression ignition engine. *Biomass Conversion and Biorefinery*, *13*(4), 2959-2970. https://doi.org/https://doi.org/10.1007/s13399-021-01328-w
6. Chybowski, L., Szczepanek, M., Pusty, T., Brożek, P., Pełech, R., & Borowski, P. (2025). Evaluation of the ignition properties of fuels based on oil diesel fuel with the addition of pyrolytic oil from tires. *Energies*, *18*(4), 860. https://doi.org/https://doi.org/10.3390/en18040860
7. Demiray, E., Ertuğrul Karatay, S., & Dönmez, G. (2020). Efficient bioethanol production from pomegranate peels by newly isolated Kluyveromyces marxianus. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *42*(6), 709-718. https://doi.org/ https://doi.org/10.1080/15567036.2019.1600621
8. Gad, M. S., El-Shafay, A. S., & Abu Hashish, H. M. (2021). Assessment of diesel engine performance, emissions and combustion characteristics burning biodiesel blends from jatropha seeds. *Process Safety and Environmental Protection*, *147*, 518-526. https://doi.org/https://doi.org/10.1016/j.psep.2020.11.034
9. Hussain, S. S., Ali, S. A., Husain, D., & Sharma, M. (2025). A machine learning model for the computation of thermophysical properties of WCO biodiesel mixed with multiwalled carbon nanotubes. *Science and Technology for Energy Transition*, *80*, 40. https://doi.org/https://doi.org/10.2516/stet/2025021
10. Iacono, G. E., Gurgacz, F., Bassegio, D., Souza, S. N. d., & Secco, D. (2024). Agricultural tractor engine performance and emissions using biodiesel-ethanol blends. *Engenharia Agrícola*, *44*, e20230089. https://doi.org/https://doi.org/10.1590/1809-4430-Eng.Agric.v44e20230089/2024
11. Ketata, A., Moussa, O., & Driss, Z. (2023). Start of injection timing effect on performance and exhaust emissions of a combustion engine powered by a diesel-oleic acid methyl ester biodiesel blend. *International Journal of Ambient Energy*, *44*(1), 515-526. https://doi.org/https://doi.org/10.1080/01430750.2022.2132286
12. Lomeu, A. A., Mendonça, H. V. d., & Mendes, M. F. (2023). Microalgae as raw material for biodiesel production: perspectives and challenges of the third generation chain. *Engenharia Agrícola*, *43*, e20220087. https://doi.org/http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v43nepe20220087/2023
13. Ojapah, M. M., & Diemuodeke, E. O. (2023). Effect of palm oil biodiesel blends on engine emission and performance characteristics in an internal combustion engine. *Open Journal of Energy Efficiency*, *12*(1), 13-24. https://doi.org/ 10.4236/ojee.2023.121002
14. Osorio-González, C. S., Gómez-Falcon, N., Sandoval-Salas, F., Saini, R., Brar, S. K., & Ramírez, A. A. (2020). Production of biodiesel from castor oil: A review. *Energies*, *13*(10), 2467. https://doi.org/https://doi.org/10.3390/en13102467
15. Patel, S., Azad, A., & Khan, M. (2019). Numerical investigation for predicting diesel engine performance and emission using different fuels. *Energy Procedia*, *160*, 834-841. https://doi.org/https://doi.org/10.1016/j.egypro.2019.02.150
16. Simsek, S. (2020). Effects of biodiesel obtained from Canola, sefflower oils and waste oils on the engine performance and exhaust emissions. *Fuel*, *265*, 117026. https://doi.org/https://doi.org/10.1016/j.fuel.2020.117026
17. Stanescu, R.-C., Soica, A., & Leahu, C.-I. (2025). Influence of Biodiesel from Used Cooking Oil and Sunflower Oil on Engine Efficiency and Emission Profiles. *Energies (19961073)*, *18*(3). https://doi.org/https://doi.org/10.3390/en18030583
18. Torres, D. J. G., de Souza Mendes, A., & Albuquerque, C. (2024). Performance and emissions data of an internal combustion engine operating with different ethanol/water mixtures and compression ratios. *Data in Brief*, *54*, 110390. https://doi.org/https://doi.org/10.1016/j.dib.2024.110390
19. Yaseen, M., Thapa, N., Visetnoi, S., Ali, S., & Saqib, S. E. (2023). Factors determining the farmers' decision for adoption and non-adoption of oil palm cultivation in Northeast Thailand. *Sustainability*, *15*(2), 1595. https://doi.org/ https://doi.org/10.3390/su15021595
20. Zhao, F., Yang, W., Yu, W., Li, H., Sim, Y. Y., Liu, T., & Tay, K. L. (2018). Numerical study of soot particles from low temperature combustion of engine fueled with diesel fuel and unsaturation biodiesel fuels. *Applied energy*, *211*, 187-193. https://doi.org/https://doi.org/10.1016/j.apenergy.2017.11.056
21. Zheng, F., Cho, H. M., & Xu, C. (2022). Effect of biodiesel blended fuel on the performance and emission characteristics of diesel engines–a review. *International Journal of Applied Mechanics and Engineering*, *27*(1), 215-231. https://doi.org/10.2478/ijame-2022-0014