



Maejo International Journal of Energy and Environmental Communication

Journal homepage: <https://ph02.tci-thaijo.org/index.php/MIJEEC>



ARTICLE

Experimental investigation of a small agricultural diesel engine performance using community biodiesel from wild trees

Nigran Homdoun*, Kittikorn Sasujit, Natthawud Dussadee, Rameshprabu Ramaraj

School of Renewable Energy, Maejo University, Chiang Mai and 50290, Thailand

ARTICLE INFO

Article history:

Received 28 November 2019

Received in revised form

04 January 2020

Accepted 07 January 2020

Keywords:

Wild tree biodiesel

Diesel fuel

Small diesel engine

Exhaust emission

ABSTRACT

The increasing consumption and demand for fossil fuels have more significance than before alarm above its lessening rate and for that reason, stimulated the actions are needed to challenge the issue with an efficient and less polluting alternative fuel for diesel. This study evaluated the performance of an 8.2 kW small diesel engine using three fuels, namely diesel, waste cooking oil biodiesel and wild tree biodiesel, such as granadilla oil biodiesel (GBD) and tung oil biodiesel (TBD). The experimental engine was tested at 1,500 rpm of constant engine speed and 20–80% of engine load. The specific fuel consumption, brake specific energy consumption, brake mean sufficient pressure, brake thermal efficiency, exhaust emission and temperature were evaluated. It was found that the small diesel engine worked well using wild trees biodiesel. The brake means effective pressures were lower by 5–8% and thermal brake efficiency was decreased in the range of 9–15%, compared with diesel fuel. The exhaust emission was lower than Thailand's industrial standard and slightly higher than waste cooking oil biodiesel and diesel fuel operation. The operation of biodiesel from wild trees is suitable for farmers and is considered feasible for local communities in the future.

1. Introduction

Global energy demand for the past five decades is rising aberrantly and it has become a vital concern for the researchers to confirm energy safety and environmental security (Ramaraj et al., 2016). Moreover, fossil fuel use has been related to some disturbing environmental problems such as global warming and climate change (Chuanchai and Ramaraj, 2018). Renewable fuels for substitute energy sources have been paid massive responsiveness in recent years (Van Tran et al., 2019; Sittisom et al., 2019). Biodiesel has been gaining worldwide popularity as an alternative energy source (Unpaprom et al., 2015). Also, energy is

essential in developing the social and economic aspects of Thailand. The country imported crude oil more than 85% of the domestic crude oil demand (Sutabutr, 2012). However, the Royal Thai Government wishes to step up its efforts to increase the share of renewable energy in the country to 30% in 2036 (Sitdhiweij, 2016). Biodiesel is an alternative energy that the Royal Thai Government supports with the production target of 14 million liters/day, while the current production is only 6.5 million liters/day and all raw materials are derived from oil palm (Nupung et al., 2018; Heo et al., 2019). In northern Thailand, most people are employed in the agricultural sector and the income of households is lower than in other regions. Using diesel fuel in

* Corresponding author.

E-mail address: nigranghd@gmail.com (Nigran Homdoun)

agricultural diesel engines for soil preparation and harvesting process accounted for more than 70% of energy consumption in the domestic rice production (Chaichana et al., 2014). Previously, attempts were made to use jatropha or oil palm to replace the fossil fuels with high interest, but recently it was found that the plants produced relatively low yields and had high operating costs, thus leading to the delay in development (Prueksakorn et al., 2010). While oil palm had a conflict with food crops and the proportion used to produce energy fuels was limited (Adeyemi et al., 2011).

Nomenclature and abbreviation

GBD	Granadilla Oil Biodiesel
TBD	Tung Oil Biodiesel
WBD	Waste Cooking Oil Biodiesel
KOH	Potassium Hydroxide
CO	Carbon monoxide
HC	Hydrocarbon
rpm	Rate speed
kW	Engine rate

Alternatively, local communities may adopt local oil crops to produce biodiesel. An example was from passion fruit, a tropical fruit plant widely grown in northern Thailand (Tippayawong and Chumjai, 2012). Household industry, the fiber pulp and passion fruit juice will be produced into fruit juice while the seeds will be discarded and that was found to have high oil content in a range of 19-30% by weight, which may be used to produce biodiesel (Iha et al., 2018). The tung tree is a species of Vernicia in the spurge family native to southern China, Laos, Myanmar and Vietnam. As of 2009, there were over 500,000 tung trees planted in northern Thailand due to their economic usefulness in the further (Wongchai, 2017). Currently, the production of tung trees occurred in local communities. Experiments with tung tree oil mixing with diesel were not successful due to high viscosity, low spraying characteristics and incomplete combustion (Jaichandar and Annamalai, 2011). Adopting the transesterification process and testing with the agricultural engine offer an alternative way to expand the use of this plant.



Fig. 1. (a) the seeds of passion fruit; (b) tung for biodiesel production.

Waste cooking oil is available from households and restaurants. The households waste cooking oil in Thailand was more than 100 million liters/year with northern Thailand has an average of more than 5.5 million liters/year (Siriwardhana et al., 2009). Generally, waste cooking oil can be used to produce biodiesel well, but the production cost was high (Yu et al., 2013). Applying directly to a diesel engine, the brake power, torque and thermal efficiency of the biodiesel engine were lower than those from the diesel engine;

at the same time, fuel and energy consumption were higher (Buyukkaya, 2010; Raheman et al., 2013). The carbon monoxide (CO), hydrocarbon (HC) and particulate matter using pure biodiesel were slightly lower than diesel (Qasim et al., 2017; Verma and Sharma, 2015) while NO_x was higher (Raheman et al., 2013).

For biodiesel blend with diesel, the engine performance was similar to pure diesel fuel; however, these fuels showed higher engine performance than pure biodiesel operation (Adaileh and Alqdah, 2012). The heating value of fuel was a significant factor for increasing or decreasing engine performance and that depends on the proportions in the mixture (Ali et al., 2015). However, the viscosity and density of fuel affected injection, combustion and power output (Srithar et al., 2017).

The CO, HC and particle matter of biodiesel operation was lower than diesel fuel operation while the NO_x was slightly higher than diesel mode (Adaileh and Alqdah 2012; Qasim et al., 2017; Verma and Sharma 2017). The objective of this work is to evaluate the performance of a small agricultural diesel engine using community biodiesel from the passion fruit seeds, tung oil tree seeds and waste cooking oil.

2. Materials and methods

2.1. Production and properties of biodiesel

This experiment used a small diesel engine to test engine performance by using wild tree biodiesel, waste cooking oil biodiesel and diesel (Fig. 1.). The wild tree biodiesel was converted from granadilla oil and tung oil by using the transesterification process.

Table 1

Combustion properties of diesel and three biodiesel fuels.

Property	Method				Method
	Diesel	WBD	GBD	TBD	
Density @ 15 °C (kg/m ³)	850	873	910	885.5	ASTM D-1298
Viscosity @ 40°C (cSt)	2.87	4.3	5.9	7.86	ASTM D-445
Specific gravity @ 15.6/15.6 (°C)	0.854	0.857	0.989	0.895	ASTM D-1298
Flash point (°C)	76	171	94	196	ASTM D-93
Pour point (°C)	3.1	4.2	-8	-15	ASTM D-6749
Acid Value (mgKOH/g)	-	0.20	0.31	0.43	ASTM D-664
Ash (wt%)	-	0.009	0.0806	0.0097	ASTM D-482
Heating value (MJ/kg)	46.80	40.99	37.27	42.33	ASTM D-240

In production, granadilla oil and waste cooking oil were placed with methanol (methanol/oil molar ratio = 6) (Samuel and Gulum,

2019) and catalyzed by 1.02 wt% potassium hydroxide (KOH), while tung oil used methanol (8:1) and 1.0 wt% potassium hydroxide in a jacketed reactor at 65°C, using a 700 rpm motor to circulate in a water bath for about 60 min, after which the mixture was poured into a separation funnel, the liquid started to separate out into layers after 12 h. The bottom layer will be glycerol and impurities, whereas the top layer was granadilla oil biodiesel, tung oil biodiesel and the waste cooking oil biodiesel. The methyl ester separated from glycerol was washed with distilled water to remove the entrained impurities and glycerine. An analysis of chemical and combustion properties was carried out at the National Center of Excellence of Environmental and Hazardous Waste Management, Thammasat University and the Institute of Product Quality and Standardization, Maejo University. The detailed physico-chemical properties are in Table 1.

2.2. Experimental apparatus and procedure

Fig. 2. shows the experimental configuration of the small diesel engine using wild tree biodiesel. The experiment was carried out on an 8.2 kW, Kubota ET11, four-stroke, horizontal, single-cylinder, naturally aspirated and water-cooled engine. The details of the small diesel engine's specifications are given in Table 2. In general, the engine is used widely in agricultural farms for water pumping, walking tractor and application as another power resource (Das et al., 2011). The power and torque of the small diesel engine were used with an eddy current dynamometer and 5 kW heater was adjusted for the loaded test on the operation. The airflow into the engine was measured using Lutron YK-80 flow meters installed before the intake manifold.

Biodiesel and diesel consumption were conducted gravimetrically on consumed fuel measured in grams (g) with a comparison of operation time (s) and engine speed was measured with a digital tachometer model Digicon DT-246L.

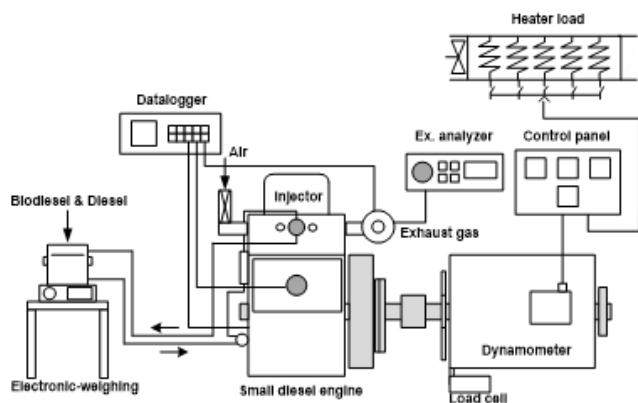


Fig. 2. Schematic of investigation of the operation of a small diesel engine.

The exhaust emission of the small engine was carried out measuring CO, HC and black smoke. The exhaust gas analyzer of

CO and HC used a Koen model KEG 200 with measuring CO in a range of 0.00–9.99% and resolution 0.01% while HC in the range of 0–9999 ppm and resolution 1 ppm, and repeatability of better than 2%. The diesel particulate matter was measured using Heshbon model HBN 1500B within the range of 0–100% and resolution 0.1%. The temperature of engine cooling, exhaust, oil lubricant and ambient used a k-type thermocouple recorded by data logger in real-time. The biodiesels operated with the small diesel engine in this work were tung oil biodiesel (TBD), granadilla oil biodiesel (GBD), waste cooking oil biodiesel (WBD) and diesel. The speed of the engine was tested at a constant 1500 rpm. Moreover, the engine loads were adjusted between 20 and 80% or 1 and 4 kW, respectively. The exhaust emissions of the engine measured CO, unburned HC (UHC), diesel particulate matter, exhaust temperature, and engine noise for every load and type of fuel.

All the measurements were performed three times, and the arithmetic mean of these three readings was employed for calculation and analysis. The data analysis calculated the brake mean effective pressure (P_b), specific fuel consumption (m'), brake specific energy consumption (b_{sec}) and brake thermal efficiency (BTE). The experiments of the engine test run were carried out in fair, constant ambient conditions, and before the test runs for all engines, it was needed to check the oil lubricant, water cooling and fuel then start the engine and warm up with diesel for 10 minutes. After that, the engine was switched to biodiesel mode. However, after finishing the tests in biodiesel mode, the fuel was always switched back to diesel again. In diesel mode, it was usually tested.

Table 2

Small diesel engine specifications.

Engine supplier/model Type	Kubota/ET11 Indirect injected, 4 stroke, single cylinder mechanical injector
Rate speed (rpm)	1800
Engine rate (kW)	8.2 (11 HP)
Bore (mm)	92
Stroke (mm)	90
Cubic capacity (cm ³)	598
Combustion chamber	Swirl
Compression ratio	21:1
Injection pressure (bar)	200
Injection timing (°btdc)	23

2.3. Engine performance analysis

The data analysis of the small diesel engine using three biodiesel and diesel consisted of specific fuel consumption, brake specific

energy consumption, brake mean effective pressure and brake thermal efficiency. The specific fuel consumption is the amount of fuel consumed by an engine for each unit of power output. The value of specific fuel consumption can be calculated using the following relation (Wood et al., 2015):

$$SFC = \frac{\dot{m}}{P_b} \quad (1)$$

When $\dot{m}$: is the fuel consumption (kg/h) and P_b : is brake power (kW). Brake specific energy consumption (b_{sec}) is the ratio of energy obtained by burning fuel for an hour to the actual energy or brake power obtained at the output shaft, given by (Homdoun et al., 2011a):

$$b_{sec} = \frac{\dot{m} \times L_{HV}}{P_b} \quad (2)$$

Where L_{HV} : is the low heating value of diesel fuel (kJ/kg). The brake means effective pressure is a calculation of the engine cylinder pressure that would give the measured brake horsepower. For this work, it was calculated using the following equation (Tongorn, 2017).

$$BMEP = \frac{P_b}{LANK} \quad (3)$$

When L is the length of the stroke (m), A is the area of the piston head (m^2), N is the number of power strokes and K is the number of cylinders. The brake thermal efficiency is defined as the brake power of a small diesel engine as a function of the thermal input from the biodiesel and diesel. The brake thermal efficiency was evaluated using the following equation (Tongorn, 2017).

$$BTE = \frac{P_b}{\dot{m} \times L_{HV}} \quad (4)$$

3. Results and discussion

3.1. Specific fuel consumption

Biodiesel can be produced from any material that contains fatty acids, be they linked to other molecules or present as free fatty acids. Various vegetable fats and oils, animal fats, waste greases and edible oil processing wastes can be used as feedstock for biodiesel production (Samuel and Gulum, 2019).

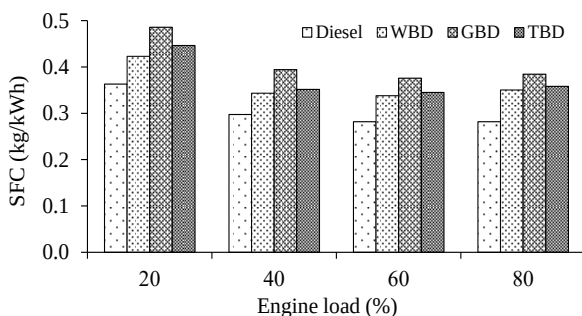


Fig. 3. Specific fuel consumption variation with engine loads.

Commonly, biodiesel can be used instead of diesel fuel that was accepted to operate with the internal combustion engine. Fig. 3. Express that the specific fuel consumption of diesel and all biodiesels at various engine loads. The operation of all biodiesels with the small diesel engine was observed to be higher than the diesel operation.

In particular, granadilla and tung oil biodiesel had higher specific fuel consumption and then waste cooking oil biodiesel. The higher fuel consumption of wild tree biodiesel was caused by the low heating value of the fuel, which produced a low energy input to the engine (Singh et al., 2007) and resulted in higher fuel consumption (Khot et al. 2013). However, the density of the fuel is another factor affecting fuel consumption; the density of biodiesel is higher and supplies more biodiesel to compensate for the lower heating value (Xue et al., 2011). The maximum specific fuel consumption of granadilla oil biodiesel was about 0.486 kg/kWh at 20% of engine load while diesel operation was about 0.363 kg/kWh. The minimum of specific fuel consumption occurred between 60 and 80% engine load and that was about 0.282 kg/kWh.

3.2. Brake specific energy consumption

All brake specific energy consumptions at various engine loads are displayed in Fig. 4. The brake specific energy consumption decreased with increased engine loads until reaching a minimum, which corresponded to 40–60% of the engine load. However, the brake specific energy consumption was trended to slightly increase with increased engine loads with all biodiesel and diesel modes. Comparing the brake specific energy consumption on typical fuel operation of wild tree biodiesel was found to be higher than diesel, followed by granadilla oil, Tung oil, waste cooking oil biodiesel, which was highest.

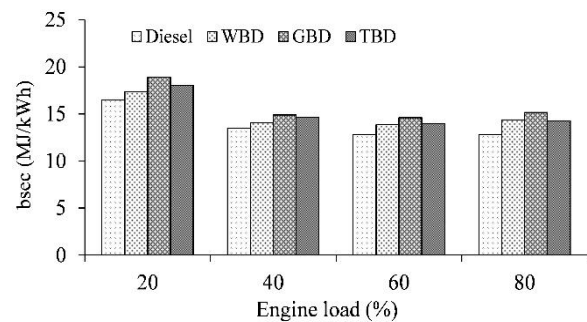


Fig. 4 Brake specific energy consumption variation with engine loads.

The higher brake specific energy consumption of wild tree biodiesel was due to the high viscosity of the fuel, resulting in larger fuel droplet size and low spray from the injector with incomplete combustion (Kumar et al., 2015), which finally led to high specific energy consumption. Lower specific energy consumption of granadilla and tung oil biodiesel was obtained, 13.9 MJ/kWh and 14.60 MJ/kWh, respectively, while for diesel operations, it was about 12.7 MJ/kWh at 60% of the load.

3.3. Brake mean effective pressure

Fig. 5. shows the brake mean effective pressure of the small diesel engine as operated on all biodiesels and diesel. The operation with diesel on the small diesel engine gave higher brake mean effective pressure while the wild tree biodiesels were lower. Biodiesel from granadilla oil gave lower brake mean effective pressure than tung oil biodiesel. However, that was lower than waste cooking oil biodiesel and diesel in a range of 5–8%. The engine torque and brake power were low due to their low calorific value and high viscosity. The high viscosity affected the fuel injection quality with low combustion efficiency and led to high fuel consumption (Ayeter et al., 2015).

The brake mean effective pressure was increased on highest engine loads because the work in the expansion of stroke power exceeded the work in the compression stroke, which was the main reason for the increase in brake mean effective pressure (Homdoun et al., 2015). The maximum brake mean effective pressures of granadilla oil, tung oil and waste cooking oil biodiesel were 633 kPa, 660 kPa and 667 kPa, respectively, while for diesel mode it was 688 kPa. Nw

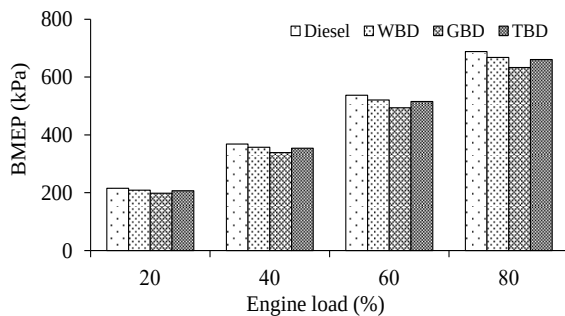


Fig. 5. Brake mean effective pressure of small diesel engine variation with engine loads.

3.4. Brake thermal efficiency

The brake thermal efficiencies of the small diesel engine measured on all biodiesel and diesel operations are shown in Fig. 6. It was found that the brake thermal efficiency increased with increased engine loads. The use of wild tree biodiesel and waste cooking oil biodiesel tended to decrease with increased engine loads.

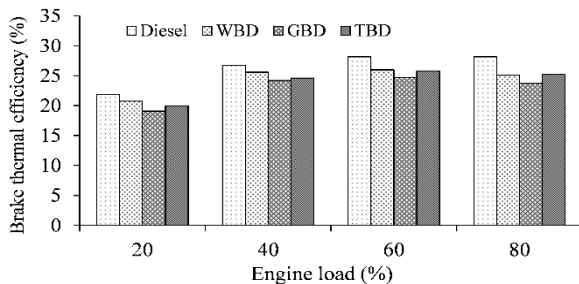


Fig. 6. Brake thermal efficiency of small diesel engine variation with engine loads

The higher brake specific energy consumption of wild tree biodiesel was due to the high viscosity of the fuel, resulting in larger fuel droplet size and low spray from the injector with incomplete combustion (Kumar et al., 2015), which finally led to high specific energy consumption. Lower specific energy consumption of granadilla and tung oil biodiesel was obtained, 13.9 MJ/kWh and 14.60 MJ/kWh, respectively, while for diesel operations, it was about 12.7 MJ/kWh at 60% of the load.

The reduction of brake thermal efficiency was due to the reduced availability of oxygen (Yadav et al., 2014) and led to poor combustion. The small diesel engine was operated on diesel had higher brake thermal efficiency than all other biodiesel modes. It is caused by the combined effect of higher viscosity, higher density and lower calorific value (Savariraj et al., 2011). The maximum brake thermal efficiency was obtained at 60% of the engine load. The highest thermal efficiency of diesel and waste cooking oil biodiesel was 28.16 and 25.05%, respectively, while granadilla and tung oil biodiesel was 25.79% and 24.65%, respectively.

3.5. Exhaust emissions

Carbon monoxide is a colorless, odorless and tasteless gas that is slightly less dense than air. It is toxic to hemoglobin animals when encountered in concentrations above about 35 ppm. Fig. 7. confirm that the variation of CO with engine loads. The CO was lower at 20–40% of engine load while it increased with increased engine load between 60 and 80% due to insufficient oxygen to complete the combustion.

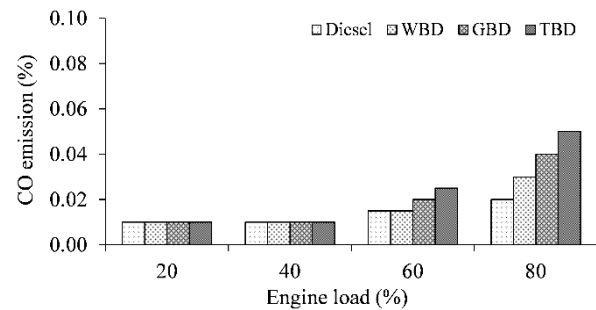


Fig. 7. CO of small diesel engine variation with engine loads.

The use of wild tree biodiesel produced higher CO than diesel and waste cooking oil biodiesel due to the polymerization that takes place at the core of the spray. This also caused a concentration of the spray core and decreased the penetration rate. Low volatility polymers affected the atomization process and the mixing of air and fuel, causing a locally rich mixture, which led to difficulty in atomization and vaporization (Savariraj et al., 2011). The CO emission of wild tree biodiesel operations was in a range of 0.04–0.05%, while diesel mode was less than 0.02%, with calculated between 20–30%. The CO emission of all biodiesel and diesel was acceptable, owing to being below Thailand's industrial standard, which is set at about 4.5% (Homdoun et al., 2011b).

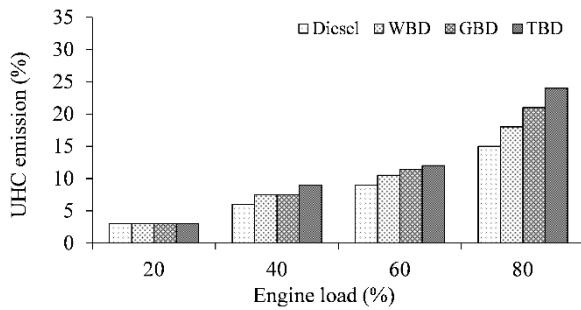


Fig. 8. CO of small diesel engine variation with engine loads

Unburned Hydrocarbons are the HC emitted after petroleum is burned in an engine. Fig. 8. presents the variation of UHC with engine loads operating on biodiesel and diesel modes. The UHC's of wild tree and waste cooking oil biodiesel was observed to be higher than diesel mode. In general, the UHCs of Thailand's standard industry emissions were less than 1000 ppm while the engine operated on biodiesel and diesel modes produced in a range of 3–24 ppm. At maximum load, it was observed to increase the UHC because, at the minimum load, the lower cylinder pressure and temperatures experienced were caused by the lower rate of burning (Sreedhar and Prasad, 2015). This feature resulted in higher UHC emissions.

Diesel particulate matter is the particulate component of diesel exhaust, which includes diesel soot and aerosols. Figure 9 shows the variation of diesel particulate matter with engine loads operating with all biodiesels and diesel.

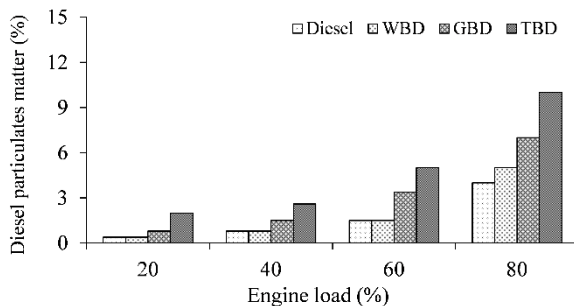


Fig. 9. Diesel particulate matter of small diesel engine variation with engine loads.

The appearance of diesel particulate matter was similar; UHC increased with increased engine loads. The wild tree and waste cooking oil biodiesel were higher than diesel due to the more massive molecular structure, double bonds in the waste cooking oil chemical structure and higher viscosity of tung oil biodiesel (Mishra et al., 2016). These factors led to higher diesel particulate matter resulting in incomplete and sluggish combustion (Saluja and Kumar, 2017; Samuel and Gulum, 2019). The wild tree biodiesel produced diesel particulate matter between 7 and 10% at maximum load. This is lower than Thailand's industrial standard, which is set at less than 50%.

3.6. Exhaust temperature

Fig. 10. indicates the exhaust temperature of the small diesel engine on biodiesel and diesel mode. The exhaust temperature of the engine increased with increased engine load. The use of biodiesel with the small diesel engine produced exhaust temperatures lower than diesel due to fuel properties such as the heating value, cetane number, viscosity and oxygen content (Gu et al., 2013).

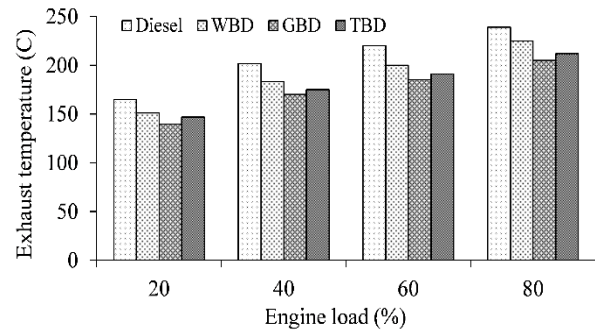


Fig. 10. Exhaust temperature of the small diesel engine in biodiesel and diesel modes.

Naturally, the exhaust temperatures of diesel and biodiesel were obtained in a range 140–280 °C (Pandey et al., 2012) while the exhaust temperature in this work was between 140 and 240°C.

3.7. Engine noise emission

Engine noise is the energy produced from vibration and movement of gas particles into the atmosphere. Engine noise higher than standard is a nuisance, disturbing and may be harmful to health. Fig. 11. demonstrates the engine noise of the small diesel engine in biodiesel and diesel modes. The engine noise increased with increased engine load. Which the overview of that was lower than Thailand's noise standard, and that was about ≤ 115 dB (Lertsawat, 2009). The use of diesel produced lower engine noise than biodiesel due to combustion knock (Siavasha et al., 2015). The engine noise on using biodiesel was obtained in a range of 90–96 dB while diesel mode between 80 and 93 dB.

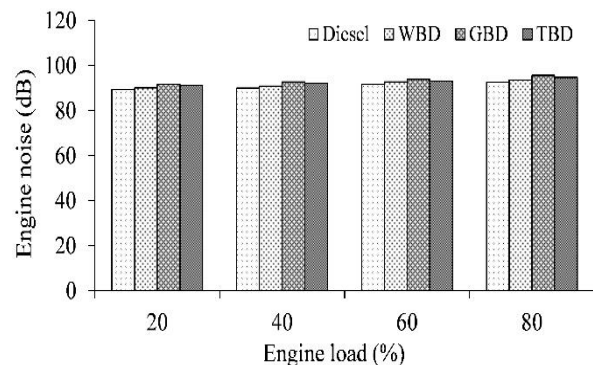


Fig. 11. Engine noise of the small diesel engine in biodiesel and diesel modes.

5. Conclusions

The small diesel engine operated on wild tree biodiesel appeared to work well, but slightly lower than diesel engine operation. It may be suitable for farmers in the north of Thailand. Based on this study, the following conclusions were summarized.

The specific fuel and energy consumption of the small diesel engine operated on wild tree biodiesel were higher than diesel fuel and waste cooking oil biodiesel. The brake mean effective pressure of the small diesel engine was reduced by 5–8% when operating on wild tree biodiesel, while the brake thermal efficiency was decreased in a range of 9–15%, compared to diesel operation. The CO, UHC and particulate matter emissions of the small diesel engine operated on wild tree biodiesel were within the Thailand's industrial standard and slightly higher than those from diesel operation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors would like to thank the School of Renewable Energy, Energy Research Center, Maejo University, for providing the test facilities, as well as the National Science and Technology Development Agency for financial support.

References

- Adaileh, W. M. & AlQdah, K. S. 2012. Performance of diesel engine fuelled by a biodiesel extracted from a waste cooking oil. *Energy Procedia* 18, 1317-1334.
- Adeyemi, N. A., Mohiuddin, A. K. & Jameel, A. T. 2011. Biodiesel production: a mini review. *International Energy Journal* 12, 15-28.
- Ali, O. M., Mamat, R., Najafi, G., Yusaf, T., & Safieddin Ardebili, S. M. 2015. Optimization of biodiesel-diesel blended fuel properties and engine performance with ether additive using statistical analysis and response surface methods. *Energies* 8(12), 14136-14150.
- Ayeter, G. K., Sunnu, A. & Parbey, J. 2015. Effect of biodiesel production parameters on viscosity and yield of methyl esters: *Jatropha curcas*, *Elaeis guineensis* and *Cocos nucifera*. *Alexandria Engineering Journal* 54, 1285-1290.
- Buyukkaya, E. 2010. Effects of biodiesel on a DI diesel engine performance, emission and combustion characteristics. *Fuel* 89, 3099-3105.
- Chaichana, T., Phethuayluk, S., Tepnual, T., & Yaibok, T. 2014. Energy consumption analysis for Sangyod rice production. *Energy Procedia*, 52, 126-30.
- Chuanchai, A., & Ramaraj, R. 2018. Sustainability assessment of biogas production from buffalo grass and dung: biogas purification and bio-fertilizer. *3 Biotech* 8(3), 151.
- Khot, B. K., Patil, P. S., & Hebbal, O. 2013. Experimental investigation of performance and combustion characteristics on a single cylinder LHR engine using diesel and multi-blend biodiesel. *Journal of Research in Engineering and Technology* 2, 120-124.
- Das, D. K., Dash, S. P. & Ghosal, M. K. 2011. Performance study of a diesel engine by using producer gas from selected agricultural residues on dual-fuel mode of dieselcum-producer gas. *Proceedings of World Renewable Energy Congress*, Linköping, Sweden.
- Gu, X., Li, G., Jiang, X., Huang, Z. & Lee, C. F. 2013. Experimental study on the performance of and emissions from a low-speed light-duty diesel engine fueled with n-butanol–diesel and isobutanol–diesel blends. *Journal of Automobile Engineering* 2, 261-271.
- Heo, S. & Choi, J. W. 2019. Potential and environmental impacts of liquid biofuel from agricultural residues in Thailand. *Sustainability* 6, 1-14.
- Homdoun, N., Sasujit, K. & Dussadee N, 2011a. Performance of diesel generator with biodiesel from on highland community. *The 22nd Conference on Mechanical Engineering Network of Thailand*, Krabi, Thailand.
- Homdoun, N., Sasujit, K. & Dussadee N, 2011b. Performance of agriculture water pumping derive biomass energy as fuel. *The 11th Conference of Heat and Mass Transfer in Thermal Equipment*, Chiang Mai, Thailand.
- Homdoun, N., Tippayawong, N. & Dussadee, N. 2015. Performance investigation of a modified small engine fueled with producer gas. *Maejo International Journal of Science and Technology* 9, 10-20.
- Iha, O. K., Martins, G. B., Ehlert, E., Montenegro, M. A., Sucupira, R. R., & Suarez, P. A. 2018. Extraction and characterization of passion fruit and guava oils from industrial residual seeds and their application as biofuels. *Journal of the Brazilian Chemical Society* 29(10), 2089-2095.
- Jaichandar, S. & Annamalai, K. 2011. The status of biodiesel as an alternative fuel for diesel engine – An overview. *Journal of Sustainable Energy & Environment* 2, 71-75.
- Kumar, K. S., Prasada Rao, B. V. V. & Babu, N. H. 2015. Experimental studies on a single cylinder 4-stroke diesel engine run with biodiesel (PaME) at different injection pressures. *International Advanced Research Journal in Science, Engineering and Technology* 2, 98-101.
- Lertsawat, K. 2009. Environmental Noise Regulations in Thailand. *Inter-Noise-2009 Innovations in Practical Noise Control*, Canada 23-26.
- Mishra, C., Kumar, N., Mishra, P. & Kar, B. 2016. In-cylinder combustion and emission characteristics of an agricultural diesel engine fuelled with blends of diesel and oxidative stabilized Calophyllum methyl ester. *SAE Technical Paper* 280140.
- Npueng, S., Oosterveer, P., & Mol, A. P. 2018. Implementing a palm oil - based biodiesel policy: The case of Thailand. *Energy Science & Engineering* 6(6), 643-657.
- Samuel, O. D., & Gulum, M. (2019). Mechanical and corrosion properties of brass exposed to waste sunflower oil biodiesel-diesel fuel blends. *Chemical Engineering Communications*, 206(5), 682-694.
- Prueksakorn, K., Gheewala, S. H., Malakul, P., & Bonnet, S. 2010. Energy analysis of *Jatropha* plantation systems for biodiesel production in Thailand. *Energy for Sustainable Development* 14(1), 1-5.
- Pandey, S., Sharma, A. & Sahoo, P. K. 2012. Experimental investigation on the performance and emission characteristics of a diesel engine fueled with ethanol, diesel and *jatropha* based biodiesel blends. *International Journal of Advancements in Engineering and Technology* 4, 341-353.
- Qasim, M., Ansari, T. M. & Hussain M. 2017. Combustion, performance, and emission evaluation of a diesel engine with

- biodiesel like fuel blends derived from a mixture of Pakistani waste canola and waste transformer oils. *Energies* 10, 1-16.
- Raheman, H., Jena, P. C. & Jadav, S. S. 2013. Performance of a diesel engine with blends of biodiesel (from a mixture of oils) and high-speed diesel. *International Journal of Energy and Environmental Engineering* 4, 1-9.
- Ramaraj, R., Unpaprom, Y., & Dussadee, N. (2016). Cultivation of green microalga, *Chlorella vulgaris* for biogas purification. *International Journal of New Technology and Research* 2(3), 117-122
- Saluja, R. K. & Kumar, V. 2017. Assessment of effect of load and injection timing on the performance of diesel engine running on diesel-biodiesel blends. *International Journal of Renewable Energy Research* 7, 200-213.
- Savariraj, S., Ganapathy, T. & Saravanan, C. G. 2011. Experimental investigation of performance and emission characteristics of Mahua biodiesel in diesel engine. *International Scholarly Research Network* 405182, 1-6.
- Siavasha, N. K., Najafi, G., Hasanbeigib, R. & Ghobadiana, B. 2015. Acoustic analysis of a single cylinder diesel engine using biodiesel fuel blends. *Energy Procedia* 75, 893-899.
- Singh, R. N., Singh, S. P. & Pathak, B. S. 2007. Investigations on operation of CI engine using producer gas and rice bran oil in mixed fuel mode. *Renewable Energy* 32, 1565-1580.
- Siriwardhana, M., Opathella, G. K. C. & Jha, M. K. 2009. Bio-diesel: Initiatives, potential and prospects in Thailand: A review. *Energy Policy* 37, 554-559.
- Sitdhiwej, C., 2016. Renewable energy law and policy in Thailand. *Renewable Energy Law and Policy Review* 2, 184-189.
- Sittisom, P., Gotore, O., Ramaraj, R., Van Tran, G., Unpaprom, Y., & Itayama T. 2019. Membrane fouling issues in anaerobic membrane bioreactors (AnMBRs) for biogas production. *Maejo International Journal of Energy and Environmental Communication* 1(2), 15-19.
- Sreedhar, C. & Prasad, B. D. 2015. Performance evaluation of four - stroke single cylinder DI diesel engine using different blends of diesel and grape seed biodiesel. *International Journal of Engineering and Innovative Technology* 4, 255-261.
- Srithar, K., Balasubramanian, K. A., Pavendan, V. & Kumar, B. A. 2017. Experimental investigations on mixing of two biodiesels blended with diesel as alternative fuel for diesel engines. *Journal of King Saud University – Engineering Sciences* 29 50–56.
- Sutabutr, T. 2012. Alternative energy development plan: AEDP 2012-2021. *International Journal of Renewable Energy* 7, 1-10.
- Tippayawong, N. & Chumjai, P. 2012. Characterization and Performance of Biofuel from Passion Fruit Processing Residues. *The World Congress on Engineering and Computer Science*. San Francisco, USA.
- Tongorn, S. 2007. Study on advanced injection timing on a dual fuel diesel engine with producer gas for power generation. Master Thesis, King Mongkut's University of Technology North Bangkok, Thailand.
- Van Tran, G., Unpaprom, Y., & Ramaraj, R. 2019. Effects of co-substrate concentrations on the anaerobic co-digestion of common reed and cow dung. *Asian Journal of Applied Research for Community Development and Empowerment* 3(1), 28-32.
- Verma, P. & Sharma, M.P. 2015. Performance and emission characteristics of biodiesel fuelled diesel engines. *International Journal of Renewable Energy Research* 5: 245-250.
- Unpaprom, Y., Tipnee, S., & Ramaraj, R. 2015. Biodiesel from green alga *Scenedesmus acuminatus*. *International Journal of Sustainable and Green Energy* 4(1), 1-6.
- Wongchai, W. 2017. Biodiesel production from tung oil and its effects on diesel engine performance and emission characteristics. *The Journal of King Mongkut's University of Technology North Bangkok* 27, 667-680.
- Wood, B. M., Kirwan, K., Maggs, S., Meredith, J., & Coles, S. R. 2015. Study of combustion performance of biodiesel for potential application in motorsport. *Journal of Cleaner Production* 93, 167-173.
- Xue, J., Grift, T. E., & Hansen, A. C. (2011). Effect of biodiesel on engine performances and emissions. *Renewable and Sustainable Energy Reviews* 15(2), 1098-1116.
- Yadav, V. S., Soni, S. L. & Sharma, D. 2014. Engine performance of optimized hydrogen fueled direct injection engine. *Energy* 65, 116-122.
- Yu, C. Y., Huang, L. Y., Kuan, I., & Lee, S. L. (2013). Optimized production of biodiesel from waste cooking oil by lipase immobilized on magnetic nanoparticles. *International Journal of Molecular Sciences* 14(12), 24074-24086.