https://doi.org/10.14669/AM/193804

INVESTIGATIONS ON THE PERFORMANCE OF A SINGLE-CYLINDER DIESEL ENGINE POWERED BY BIODIESEL DERIVED FROM PALM OIL AND ANTIOXIDANT ADDITIVES

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Abstract

Fossil fuel supplies are being depleted and environmental pollution is increasing due to the transportation and industry sectors' growing intensification. Biodiesel is a cheap, abundant, and environmentally beneficial fuel source that may be used. This study aims to reduce pollution in diesel engines by adding L-ascorbic acid, an antioxidant, to palm oil biodiesel (PB20, 20% palm biodiesel and 80% diesel). Solvent extraction was used to obtain palm oil from the discarded palm. Alkali transesterification was used to turn palm oil into biodiesel. There are samples of biodiesel that contain 90% biodiesel with 10% L-ascorbic acid (PB20L10), and 95% biodiesel with 5% L-ascorbic acid (PB20L5), varying the amount of antioxidant ingredient added. The results of the experimental study show that, in comparison to diesel fuel and PB20, the oxides of nitrogen emissions from PB20L5 and PB20L10 are much lower. The brake thermal efficiency (BTE) is also reduced with an antioxidant added to biodiesel in comparison with PB20. Additionally, PB20 emissions increased modestly when antioxidant ingredient was added.

Keywords: antioxidant additive; palm oil; diesel; biodiesel; performance; emissions

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https://doi.org/10.14669/AM/193804

1. Introduction

Petroleum derivatives constitute a significant contributor to the daily rise in energy consumption, especially in the transportation sector. Compression ignition engines once preferred diesel over petrol due to its increased efficiency and reduced pollutants [1]. Different fuels have been created and utilised in an effort to find a superior liquid petroleum substitute. Among the various fuels, biodiesel is one that is growing in popularity daily [2]. Assessed a trial using mango seed oil to lower NOX emissions. Mango seed oil is a type of biodiesel that is made from the leftovers of mango fruit. They looked into the biodiesel using several antioxidant kinds [3]. According to the authors, there are several categories of antioxidants, including natural, synthetic, and biological antioxidants. A recent ASTM report examined tamarind biodiesel and its blends based on their physical and chemical characteristics [4]. A majority of the tamarind biodiesel's attributes were similar to those of diesel fuel and well within the ASTM standards. In order to study the performance and emission characteristics of the diesel engine, several fuel injection timings were examined in [5]. Regardless of load circumstances, the researchers discovered that retarded fuel injection time reduced tailpipe emissions more than other fuel injection timings. In a study that used rice bran oil biodiesel in a diesel engine, researchers used two monophenolic antioxidant additives. They found that both antioxidants significantly decreased the emissions of NOx [6]. The authors [7] conducted research on biodiesel from neem oil by producing three blends (B10, B15, B20) and testing them on a diesel engine. They evaluated engine performance and emissions compared to pure diesel. The best brake thermal efficiency (27.73%) was achieved with B15 at full load. The blends significantly reduced CO, HC, and smoke emissions but increased NOx emissions. The results indicate that neem-based biodiesel is an effective and eco-friendly alternative fuel. The authors [8] conducted experimental research on biodiesel made from palm oil with an antioxidant additive (butylated hydroxytoluene). They tested biodiesel blends (P20, P20BHT5, P20BHT10) in a single-cylinder diesel engine, evaluating performance and emissions. Adding antioxidants reduced NOx emissions by up to 32.7% but increased CO, HC, and smoke emissions. Brake thermal efficiency decreased slightly with antioxidant use. The study highlights the potential of palm oil biodiesel with antioxidants as an eco-friendly diesel alternative. The authors [9] investigated the performance and emission characteristics of a low-heat-rejection (LHR) diesel engine running on biodiesel blends with an antioxidant additive. They used biodiesels from mango seed oil, mahua oil, and pongamia oil, combined with L-ascorbic acid to reduce nitrogen oxide (NOx) emissions. Experimental results showed improved brake thermal efficiency and reduced CO, HC, and smoke emissions. However, NOx emissions increased due to higher combustion temperatures. Adding antioxidants mitigated this issue, making the biodiesel blends more suitable for diesel engines.

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2. Materials and Methods

2.1. Test fuel preparation

A lab was considered during the creation of the experimental tools. A magnetic stirrer, thermometer, and reflux condenser were all included in the 2000 ml flask used for trans-esterification. The flask held 1000 cc of hot oil at 65°C. After treating the heated oil with a 255 ml methanol solution, 13.10 g of potassium hydroxide was added. After two hours, the liquid and the glycerol layer were separated using a different funnel [10]. A warm solution containing 5% acetic acid was used twice to treat the methyl esters, as shown in Table 1. Any remaining alcohol and water were removed from the ester by drying it at 100°C. Figure 1 displays the results of the Fourier transformed infrared (FTIR) analysis, which reveal the bonding type and functional group chemicals in the extracted palm oil.

Tab. 1. Test fuel characteristics

S.no	Properties	Diesel	PB20	PB20L5	PB20L10
1	Viscosity at 40°C (cSt)	3.7	5.9	5.9	6.0
2	Density (kg/m³)	831	875	863	848
3	Fire point (°C)	69	83	82	84
4	Flash point (°C)	73	78	83	85
5	Cetane number	44	53	50	48
6	Calorific value (kJ/kg)	42 634	40 243	39 587	39 458

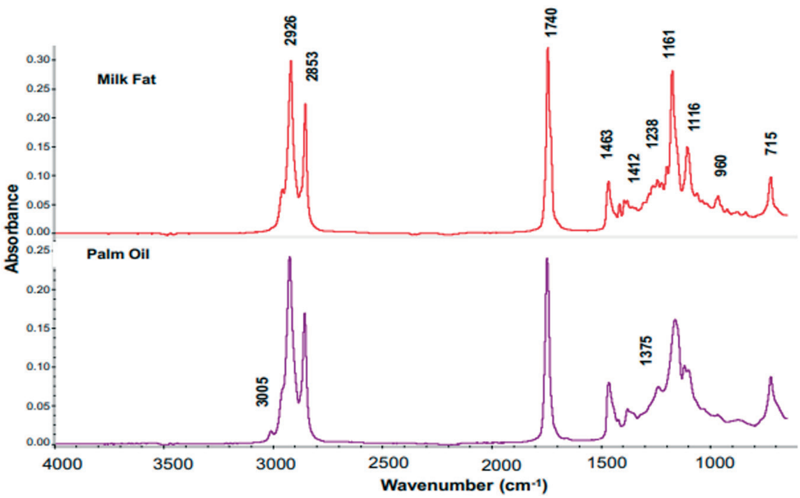

Fig. 1. Wavenumber region 4000–650 cm^{-1} of milk fat and palm oil FTIR spectra

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2.2. Experimental work

The engine is made up of one cylinder and accelerates at 1500 revs per minute. An engine test bench is shown in Figure 2. Table 2 provides detailed specifications of the test engine used in the experiment. The crankshaft of the test engine and an eddy current dynamometer are used to adjust the load in this experiment. Fuel consumption was measured with a burette and stopwatch. For the measurements of HC, CO, and NOx emissions, AVL 444 di-gas analyzers were used. K-type thermocouples were used for monitoring exhaust gas temperatures. As shown in Table 3, exhaust smoke opacity was measured with an AVL 437C.

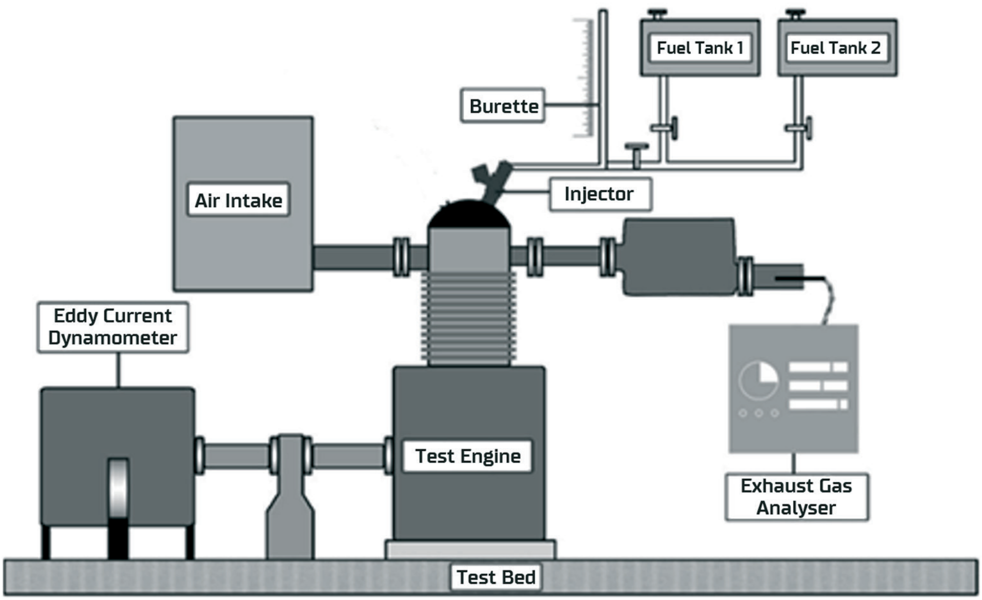

Fig. 2. Bench for testing engines

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Tab. 2. Research Engine Specifications

Make	Kirloskar TV – I
Rated brake power	5.2 kW
Bore & Stroke	87.5 mm & 110 mm
Injection timing	23°before TDC
Compression ratio	17.5:1
Injection Pressure	220 bar
Speed	1500 rpm
Injection type	Mechanical injection system

Tab. 3. Uncertainty of various parameters

Parameters	Uncertainty [%]
Speed	0.2
Pressure	0.4
Temperature	0.2
Crank angle	0.2
Oxides of Nitrogen	0.9
Carbon Monoxide	0.04
Unburnt Hydrocarbon	0.13
Load	0.3
Brake thermal efficiency	0.6
Brake Specific Fuel Consumption	0.7

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3. Results and discussion

3.1. Brake Thermal Efficiency (BTE)

Figure 3 shows variations in BTE with braking power for PB20, PB20L5, and PB20L10 diesel engines. It is discovered that for all tested fuels, increasing braking power results in an increase in BTE. The highest BTE for diesel, PB20, PB20L5, and PB20L10 was reported to be 29.4%, 28.5%, 27.3%, and 26.7% at peak power output. At all power levels, BTE was reduced when PB20 fuel was used instead of diesel fuel. The PB20 fuel's high density, high viscosity, and low calorific value cause worse combustion inside the cylinder, which might contribute to reduced thermal efficiency. BTE at all loads is modestly reduced by adding an antioxidant ingredient to PB20 fuel. Biodiesel combustion might be inadequate due to antioxidant chemicals used in biodiesel [11].

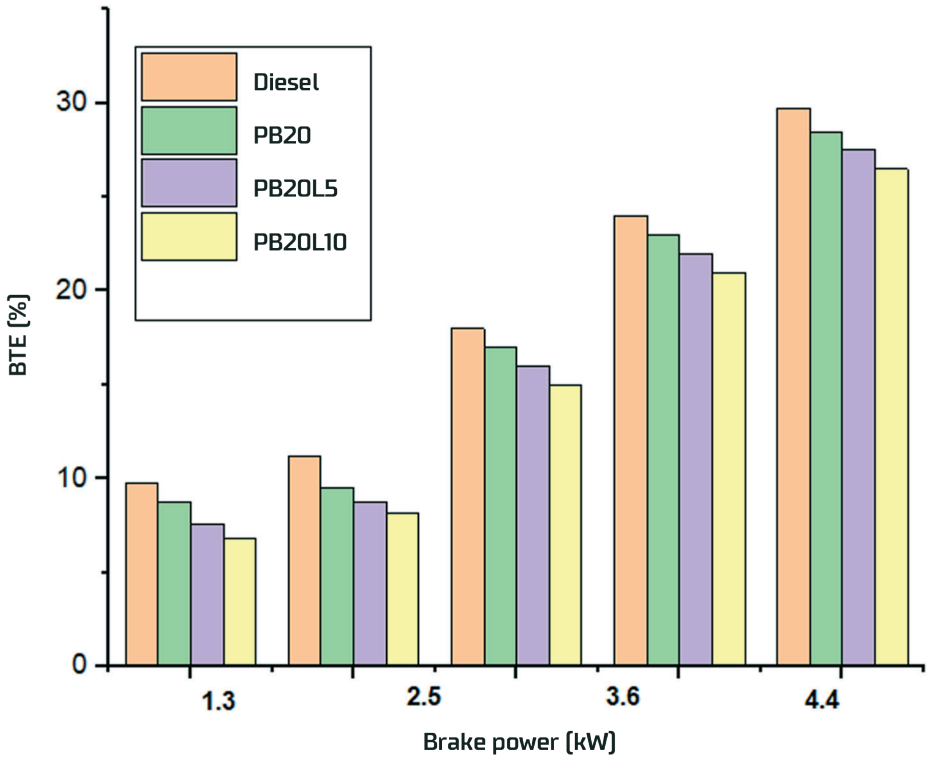

Fig. 3. A variation of the BTE with braking power

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3.2 Brake Specific Energy Consumption

The BSEC is shown in Figure 4 with respect to braking power for diesel, PB20, PB20L5, and PB20L10. It appears that diesel, PB20, PB20L5, and PB20L10 have BSECs of 12.5, 14.3, 15.2, and 16.3 kJ/kWh, respectively, as a function of maximum braking power. The BSEC of neat PB20 is higher than that of diesel fuel. At all loads, biodiesel with antioxidants has a slightly higher BSEC. As a result, more additive mixtures of biodiesel may have been used to compensate for incomplete combustion's loss of power [12].

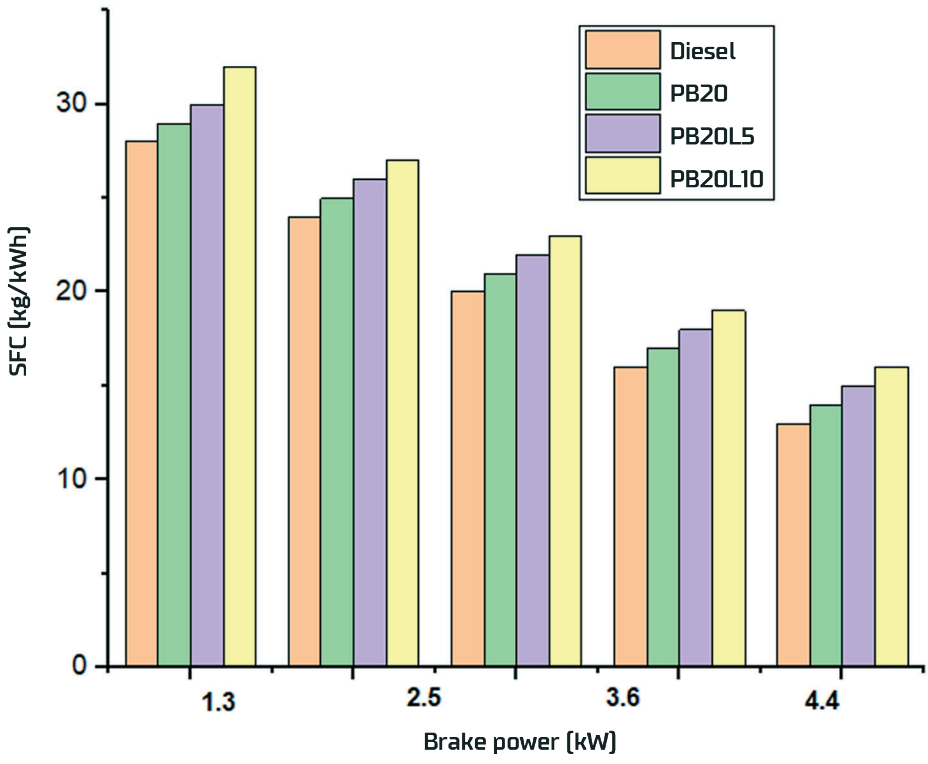

Fig. 4. A brake-powered variation of BSEC

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3.3 Oxides of Nitrogen Emission

A comparison of NOx emissions of diesel engine, PB20, PB20L5, and PB20L10 is shown in Figure 5. A maximum load of 563 ppm resulted in NOx emissions from diesel, PB20, PB20L5, and PB20L10 fuels, respectively. In all loads, PB20 fuel's NOx emissions were significantly higher than diesel's. In addition to producing elevated NOx emissions, biodiesel has a high oxygen content. The combination of biodiesel and antioxidants, however, results in reduced NOx emissions at all brake pressures. As a result of antioxidants lowering combustion temperatures in the cylinders, NOx emissions may be reduced [13].

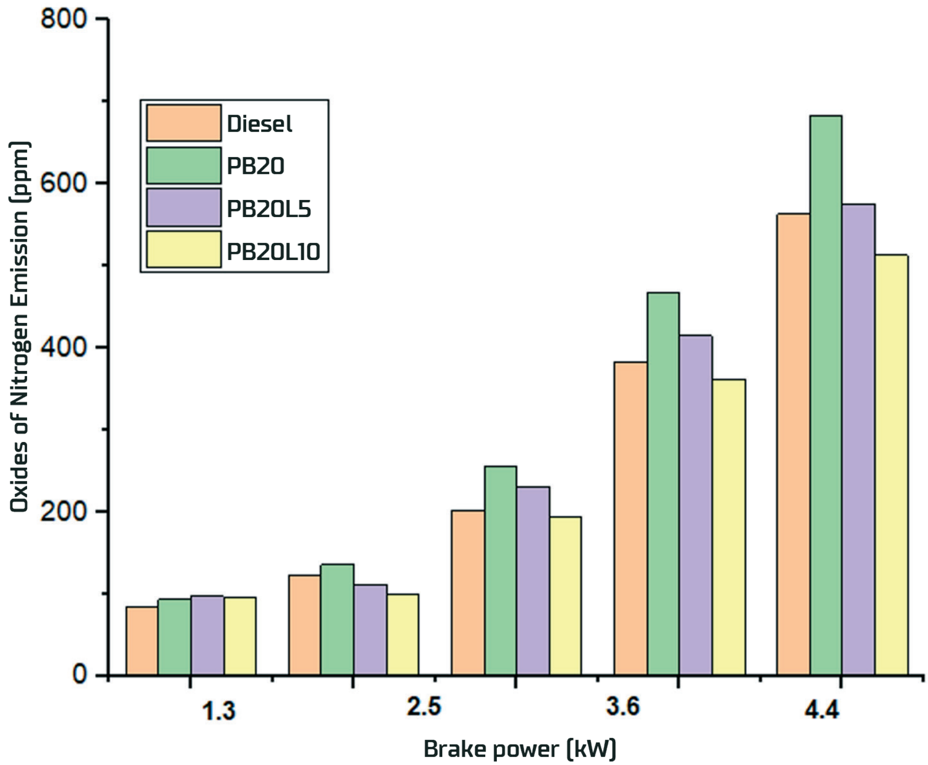

Fig. 5. The effect of brake power on NOx

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3.4. Carbon Monoxide Emission

Diesel engines emit CO primarily from incomplete combustion of fuel and too much air. In Figure 6, CO emissions are shown to vary with braking power for biodiesel mixed with antioxidant additives, diesel fuel, and biodiesel. Diesel, PB20, PB20L5, and PB20L10 fuels were found to have CO emissions of 0.064%, 0.058%, 0.060%, and 0.062% under maximum load conditions. When PB20 is used at peak load, CO emissions are found to be lower than for any other test fuel. It might be because the PB20 fuel has a high oxygen percentage. Antioxidant additions to PB20 result in a small increase in CO emission at all brake powers. CO_2 emissions rise due to the slowdown of oxidation between carbon and oxygen caused by antioxidant compounds [14].

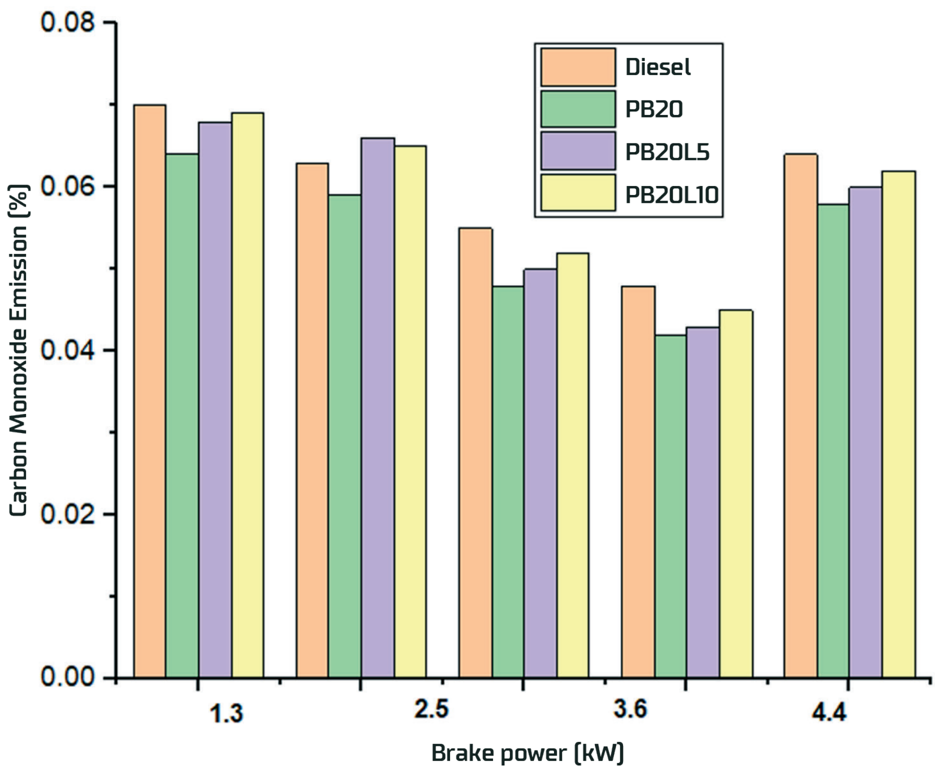

Fig. 6. CO variation with brake power

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3.5. Hydrocarbon emission

All gasoline samples were analyzed for hydrocarbon emissions based on their braking power as shown in Figure 7. For diesel, PB20, PB20L5, and PB20L10, maximum HC emissions were 63 parts per million. At all power outputs, PB20 exhibits steadily lower HC emissions than other test fuels. This may be mostly caused by the biodiesel molecules completely burning in the presence of additional oxygen, raising the combustion chamber's flame temperature. When comparing HC emissions for PB20L5 and PB20L10 fuels to PB20 at all braking power, a considerable increase is seen. Biodiesel contains antioxidant additives that lower the oxygen content and reduce hydrocarbon emissions by reducing reactive free radical production [15, 16].

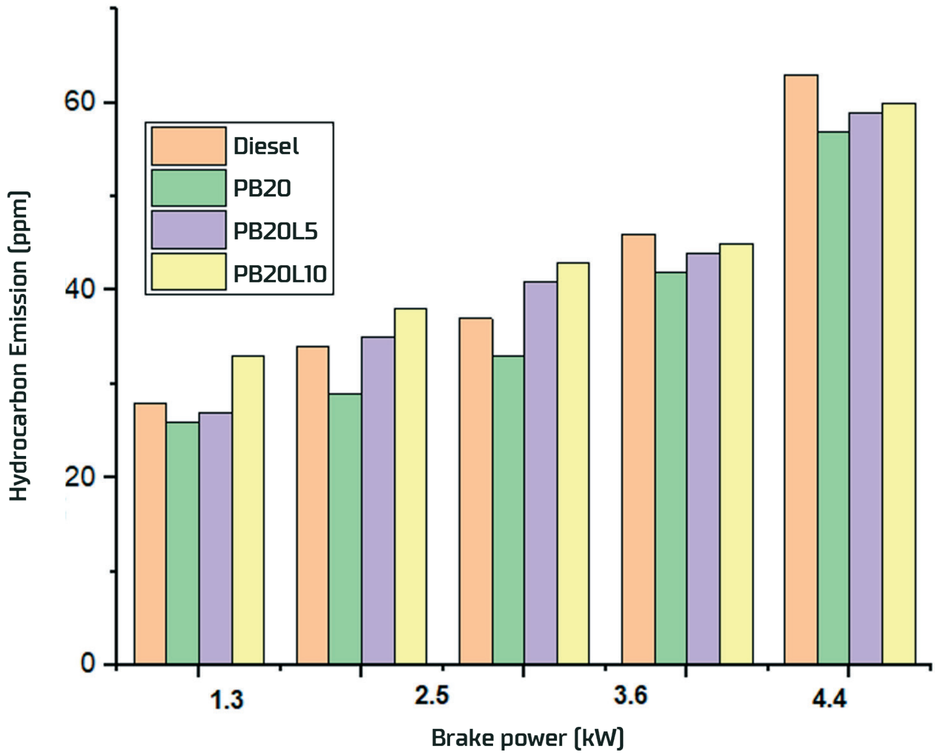

Fig. 7. The effect of brake power on HC

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3.6. Smoke emission

A variation in smoke emissions is shown in Figure 8 for fuels evaluated with engine braking power. Each fuel tested showed an increase in smoke produced with increased braking power for each fuel. In Figure 8, smoke emission values are depicted for diesel, PB20, PB20L5, and PB20L10, which are respectively 74%, 65%, 68%, and 70%. When PB20 was compared with diesel, we observed a slight decrease in smoke opacity. This decrease is brought about by the PB20 fuel's higher oxygen concentration, which leads to full combustion and soot oxidation. On the other hand, PB20's antioxidant ingredient adds a tiny amount of smoke emission. In biodiesel, antioxidant additives produce hydroxyl radicals, which decrease the oxidation process. The result is incomplete combustion and increased smoke emissions [17, 18, 19].

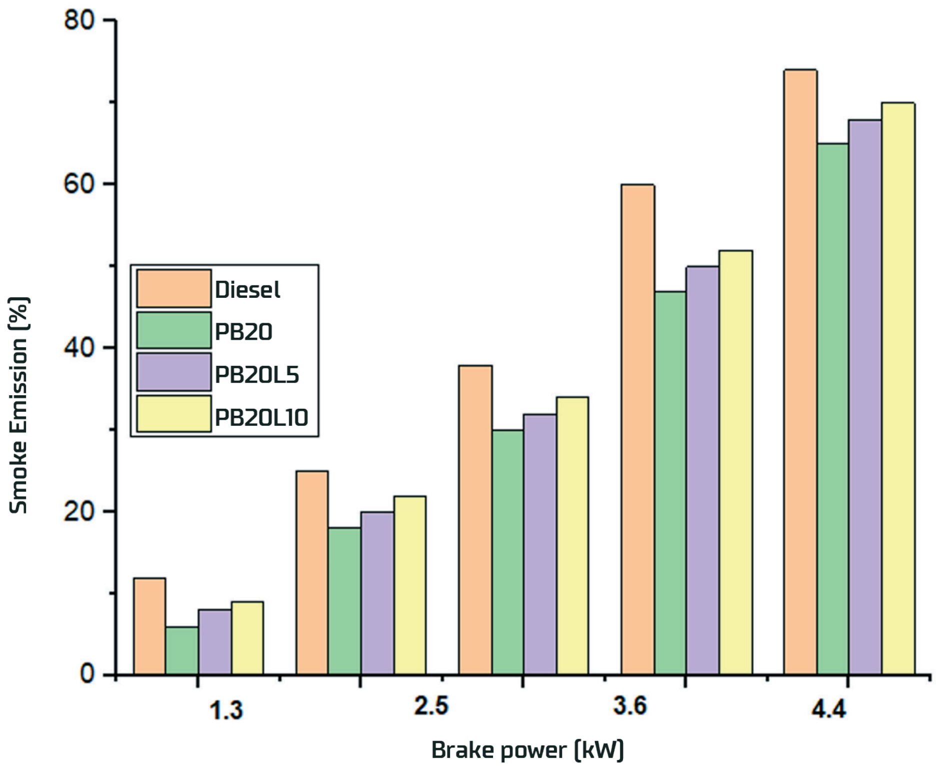

Fig. 8. Effects of brake power on smoke emission

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4. Conclusion

In the presence of antioxidant chemicals, orange peel oil biodiesel has been investigated for its performance and emission characteristics. Following are the primary findings derived from the collected data:

1. One possible substitute fuel for diesel engines is biodiesel made from palm waste.

2. Diesel fuel exhibits lower NOx emissions than PB20. Comparing PB20L5 and PB20L10 to PB20 fuel, the highest reduction in NOx emissions is determined to be 20.2% and 33.4%, respectively.

3. Antioxidant additive addition to PB20 biodiesel results in a small rise in CO and HC emissions at all braking power levels. On the other hand, clean PB20 biodiesel produces less CO and HC emissions.

4. When antioxidant additives were added to biodiesel, smoke emission was found to rise; however, when PB20 fuel was used alone instead of diesel, smoke emission was shown to drastically decrease.

5. The BTE for PB20L5 and PB20L10 is 2.1% and 3.3% lower than that of PB20 biodiesel at maximum braking power, respectively. The BSEC is 4.1% higher than that of PB20 biodiesel at maximum braking power.

5. Reference

[1] Ahmed MM, Pali HS, Khan MM. Experimental analysis of diesel/biodiesel blends with a nano additive for the performance and emission characteristics of CI Engine. International Journal of Engine Research. 2023;24(11):4500–4508. https://doi.org/10.1177/14680874221132958.

[2] Ali MH, Abdullah A, Yasin MHM. Effect of BHA and BHT antioxidant additives on engine performance and emission of a CI engine fueled with a palm oil methyl ester-diesel fuel blend. AIP Conference Proceedings. 2019;2059(1):02005. https://doi.org/10.1063/1.5085994.

[3] Gnanasikamani B, Bharathy S, Suresh Kumar K, Marimuthu C. Ecological influence of addition of antioxidant and incorporation of selective catalytic reduction on NO emission in off-road engines powered by waste plastic oil blend. Environmental Progress & Sustainable Energy. 2019;39(4)e13383. https://doi.org/10.1002/ep.13383.

[4] Raju DV, Kishore PS, Yamini K. Experimental Studies on Four Stroke Diesel Engine Fuelled with Tamarind Seed Oil as Potential Alternate Fuel for Sustainable Green Environment. European Journal of Sustainable Development Research. 2018;2(1):1–10. doi.org/10.20897/ejosdr/78489.

[5] Raju DV, Venu H, Subramani L, Kishore PS, Prasanna PL, Kumar DV. An experimental assessment of prospective oxygenated additives on the diverse characteristics of diesel engine powered with waste tamarind biodiesel. Energy. 2020;203:117821. https://doi.org/10.1016/j.energy.2020.117821.

https://doi.org/10.14669/AM/193804

[6] Raju DV, Kishore PS, Nanthagopal K, Ashok B. An experimental study on the effect of nanoparticles with novel tamarind seed methyl ester for diesel engine applications. Energy Conversion and Management. 2018;164:655–666. https://doi.org/10.1016/j.enconman.2018.03.032.

[7] Dhande DY, Navale SJ. Experimental investigations on the performance and emissions of compression ignition engine fuelled with lower blends of neem-based biodiesel. The Archives of Automotive Engineering – Archiwum Motoryzacji. 2024;103(1):57–76. https://doi.org/10.14669/AM/186109.

[8] Harigaran A, Balu P. An experimental study on the performance and emission characteristics of a single-cylinder diesel engine running on biodiesel made from palm oil and antioxidant additive. International Journal of Ambient Energy. 2023;44(1):1076–1080. https://doi.org/10.1080/01430750.2022.2162577.

[9] Venkatesan EP, Rajendran S, Murugan M, Medapati SR, Ramachandra Murthy KVS, Alwetaishi M, et al. Performance and Emission Analysis of Biodiesel Blends in a Low Heat Rejection Engine with an Antioxidant Additive: An Experimental Study. ACS Omega. 2023;8(40):36686–36699. https://doi.org/10.1021/acsomega.3c02742.

[10] Mahmud MI, Cho HM. A review on characteristics, advantages and limitations of palm oil biofuel. International Journal of Global Warming. 2018;14(1):81–96. https://doi.org/10.1504/IJGW.2018.088646.

[11] Harun Kumar M, Dhana Raju V, Kishore PS, Venu H. Influence of Injection Timing on the Performance, Combustion and Emission Characteristics of Diesel Engine Powered with Tamarind Seed Biodiesel Blend. International Journal of Ambient Energy. 2020;41(9):1007–1015. https://doi.org/10.1080/01430750.2018.1501741.

[12] Reddy SNK, Wani MM. A Comprehensive Review on Effects of Nanoparticles-antioxidant Additives-biodiesel Blends on Performance and Emissions of Diesel Engine. Applied Science and Engineering Progress. 2020;13(4):002. https://doi.org/10.14416/J.ASEP.2020.06.002.

[13] Ashok B, Nanthagopal K, Jeevanantham AK, Bhowmick P, Malhotra D, Agarwal P. 2017. An Assessment of Calophyllum Inophyllum Biodiesel Fuelled Diesel Engine Characteristics Using Novel Antioxidant Additives. Energy Conversion and Management. 2017;148:935–943. https://doi.org/10.1016/j.enconman.2017.06.049.

[14] Gupta S, Sharma MP. Impact of binary blends of biodiesels on fuel quality, engine performance and emission characteristics. Clean Energy. 2026;7(2):417–425. https://doi.org/10.1093/ce/zkad002.

[15] Simhadri K, Rao PS, Paswan M. Improving the combustion and emission performance of a diesel engine with TiO2 nanoparticle blended Mahua biodiesel at different injection pressures. International Journal of Thermofluids. 2024;21:100563. https://doi.org/10.1016/j.ijft.2024.100563.

[16] Ganesan N, Masimalai S. Experimental investigation on a performance and emission characteristics of single cylinder diesel engine powered by waste orange peel oil biodiesel blended with antioxidant additive. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. 2019;42(11):1412–1423. https://doi.org/10.1080/15567036.2019.1604856.

[17] Reddy SNK, Wani MM. An investigation on the performance and emission studies on diesel engine by addition of nanoparticles and antioxidants as additives in biodiesel blends. International Review of Applied Sciences and Engineering. 2021;12(2):111–118. https://doi.org/10.1556/1848.2020.00157.

[18] Ramalingam S, Ganesan P, Murugasan E. Effect of antioxidant additives on performance and emission behavior of biodiesel fueled DI diesel engine. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. 2019;42(9),1085–1096. https://doi.org/10.1080/15567036.2019.1602219.

[19] Zhang Y, Zhong Y, Lu S, Zhang Z, Tan D. A Comprehensive Review of the Properties, Performance, Combustion, and Emissions of the Diesel Engine Fueled with Different Generations of Biodiesel. Processes. 2022;10(6):1178. https://doi.org/10.3390/pr10061178.