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Performance evaluation of waste palm oil diesel as alternative diesel engine fuel

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Abstract

The paper aims to evaluating the performance of palm oil based- waste cooking oil biodiesel as alternative diesel engine fuel. The methodology of the study was experimental. The waste oil was two-step transesterified and chemically analyzed to establish physico-chemical properties of biodiesel. The test fuels were evaluated for brake specific fuel consumption (BSFC) and brake thermal efficiency (ηth) at varying brake power on test rig consisting of Mazda engine coupled with a power take off propeller inserted in the power take off shape to Froude hydraulic dynamometer. The results showed that at all brake power, the BSFC decreased as strength of diesel increased in the blend. At brake power of 15KW, brake specific fuel consumption (kg/KWh) for BD25, BD50, BD75, BD100 and AGO were 0.41, 0.40, 0.38, 0.44 and 0.37 respectively. The brake thermal efficiency, at that instant of brake power of 15KW, were 22.2, 21, 20.8, 23.8 and21.5 for BD25, BD50, BD75, B100 and AGO in that order. As the load increased, brake thermal efficiency (ηth) increased for all the test fuels utilized while the brake specific fuel consumption decreases. These characteristics were closely associated with physico-chemical properties of the biodiesel. In conclusion, waste palm oil biodiesel demonstrated characteristics of lean, cleaner but high performance fuel in IC engine.

Keywords: Biodiesel; Brake specific fuel consumption; Brake thermal efficiency; Test rig; Blends; Dynamometer

1 Introduction

Energy is the hub to socioeconomic development of any society, especially in transportation, industrial and agricultural sectors [1]. Fossil fuel has been acknowledged as a major source of energy for prime movers. Combustion of fossil fuel and disposition of waste have been serious concern to industrial key players and governments due to consequential damage to health, economy, climate and environment. Reducing greenhouse gas emissions has redirected research interest to renewable energy sources. The quest for greener fuels sources has gained wider societal and political interest due to socioeconomic and environmental concerns: reduction in greenhouse emission, biodegradability, sustainability as well as its competitive nature to fossil fuels[2,3].The Koyoto Protocol, and other emerging protocols and conventions, have influenced dynamic national policy framework, and more importantly, rapid technological development, triggering researches and technologies that cut- back emission of dangerous substances to the atmosphere, and still maintain delicate balance between industrialization, economy and environment[4]. Diesel engine was originally designed to run on peanut oil, according to Rudolf Diesel but the exploration of fossil fuel and its suitability to diesel engine, perhaps slowed down the initiative [5-6].[7,8] state that diesel engine can burn biodiesel fuel with little or no modifications.

Many studies on characterization of biodiesel have shown similar physico-chemical properties to fossil fuel, currently in use; inferring similar performance in IC engine. The available information indicates that sunflower, soybean and rapeseed oil look to be the most promising among the vegetable oils reviewed. It was observed that the physico-

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chemical properties vegetable –oil based biodiesel are comparable and meet the requirement of diesel engine combustions [9]. Biodiesel is a derivative of transesterification process from fats or vegetable oil including palm oil [1]. The characteristics of palm-oil diesel (POD) were consistent with researchers on other renewable lipid feedstock. The various work demonstrated that vegetable based- renewable energy is possible with two step transesterification. However, these studies were conducted from virgin vegetable oil except [1] who studied the production of biodiesel from Nigeria restaurant waste cooking oil using blender. Tribological evaluations of performance of this vegetable oil have also been studied. [10] Studied performance and emission characteristics of diesel engine using karanja oil methyl ester and eucalyptus oil fuel blends. [8, 11] analyzed biodiesel from virgin palm oil.

The question of renewable energy from biodiesel seems to have been scientifically and sufficiently answered but not its sustainability. There is a general interest using and producing biodiesel, but the economics have not yet appeared favourable. Obtaining critical mass of feedstock for production and developing sustainable supply chain of virgin vegetable oil places serious cost concern. Vegetable oils could be 75% of the manufacturing cost, making production cost of biodiesel approximately 1.5times higher than diesel [12, 13]. But with waste cooking oil (WCO), the cost compared to virgin vegetable oil could be reduced to 1-2 times, thereby cutting down the manufacturing cost of biodiesel [13]. In Germany and Brazil, alternative to 100% biodiesel concentration is used and it equally reduces CO2 and NOx emission [14, 15]. Annually, it is well documented that many millions of tons of waste cooking oil are collected and utilized in a variety of ways globally [14]. Such oil could have contaminated soil and water. According to United Nations, renewable energy should make economic sense and its technology, global public good[16].The paper aims to utilize palm oil based- waste cooking oil (WCO) in tribological evaluation of biodiesel performance.

2 Material and methods

2.1 Materials

Automobile gas oil (AGO) was purchased from Nigeria National Petroleum Corporation (NNPC) service station. Palm oil based-waste cooking oil (WCO) was procured from Roban food, a reputable big restaurant, with network across eastern region of the country. Wilson Group, Nsukka, Enugu State is the supplier of processed (palm) vegetable cooking oil the enterprise. Other chemicals were bought from Wallace engineering laboratory at Awka, Anambra State.

2.2 Methods

The study was divided into the following segments:

- A two step transesterification.
- Standardization of biodiesel/ blends.
- Characterization of test fuels.
- Experimentation on test rig

The processes were performed at Warri Refinery Petrochemical laboratory, Delta State, according to BIS code [17].

2.3 Experiment Test Rig

Table 1 Methodologies for Determining the Physico- chemical Properties of Test Fuels

S/N	Property	Instrumentation
1	Density @ 25^{0}C (kg/m3)	Analytical Balance (GH-252)
2	@ 15^{o}C (kg/m3)	Analytical Balance (GH-252)
3	Cetane index	Cetane Number Analyser (TP-131)
4	Viscosity (cST) @ 40^{o}C	Viscometer (GD-265D)
5	Calorific value	Calorimeter
6	Sulphur content	XRF Spectrometer
7	Cloud point (^{0}C)	MP 80 Tester

The physico -chemical properties of test fuels were determined using methods on Table1.

Experimental test bed for the study included Mazda engine coupled with a power take off (PTO) propeller inserted in the PTO shape to Froude hydraulic dynamometer. The engine specification is shown on Table 2. Table 3 shows the specification of hydraulic dynamometer.

Table 2 Specification of Test Engine

Engine	**Specification**
Manufacturer	Mazda
Country	Japan, Tokyo
Cylinder	Inline, 4
Displacement	1998cc
Cylinder Bore	93mm
Piston Stroke	102mm
Compression Ratio	16.3:1
Fuel System	Direct Injection
Fuel Type	Diesel (AGO)
Type of Engine	CI
Power Output	75hp
Torque	120N-m

2.4 Experimental Procedure

- To measure brake power, engine was initially run to 20 minutes under no-load condition for stabilization and smooth operations.
- Speed of engine is measured with the help of non-contact digital laser tachometer which displayed speed in rpm (800rpm, 1200rpm, 1600rpm, 2000rpm and 2400rpm).
- Fuel consumption measurement unit has a fuel tank and graduated glass burette of 50 mL capacity. The fuel/ blend, AGO, BD75, BD50, BD25 and B100 sample was filled in 50 mL burette and allowed to pass in the engine.
- The total time required to consume 50 mL fuel is noted.
- The same procedure is repeated for different loading condition to find out the fuel consumption at every load.
- Fuel filter was changed for each test fuel and system bled to ensure accuracy.
- There were three experimental runs for each test fuel. The mean value was computed as test value.
- The computed variables were tabulated and graphed for comparative study.

Table 3 Dynamometer Specification

Dynamometer	**Specification**
Type	Hydraulic dynamometer
Manufacturer	Froude Inc
Location	Worcester, WR 3,USA
Model	EC 26 TC
Maximum Speed, rpm	9000
Torque, Nm	152
Power ,KW	75

The study was empirically guided by theoretical concepts represented in Table 4; to calculate different parameters.

Table 4 Formulae of Important Engine Characteristics

Characteristic	Formula	Unit	Eq.
Brake Power(BP)	$\frac{2\pi NT}{60000}$	$N - m$	1
Fuel Consumption (f_c)	$\frac{V_{cc}}{t}$ x C	(L/h)	2
Brake specific fuel comsumption(BSFC)	$\frac{f_c \text{ x } P}{bp}$	(Kg/KW-h)	3
Brake thermal efficiency (η_{th}	$\frac{K_s}{bsfc \text{ x } HV}$ x 100	(%)	4

3 Results and discussion

3.1 Physico- Chemical Properties of Test Fuels

Table 5 shows physico- chemical properties of test fuels. It was observed that viscosity of biodiesel was lower when compared with AGO. The effect yields greater atomization and efficient spray of the charged gas. Sulphur content (SOx) of 'pure' biodiesel was 0.0013, and found insignificant. Presence of sulphur in blends was traceable to AGO; which increased with blend strength. Calorific value of the fuel decreased as the blend increased. One of the main parameters to determine the characteristics of biodiesel is calorific value. Calorific value has an inverse relationship with BSFC, because a reduction in calorific value is compensated with increased rise in fuel consumption for attainment of power output. Table 5 and Figure 1 reflect the relationship. Apart from calorific value, other parameters that showed similar trend included viscosity, calorific value and density of the various blends; however, there is no relationship between them. Transesterification of some of the virgin oils is reported to have comparable and improved long-term performance.

Table 5 Physico-Chemical Test Values for Test Fuels

S/N	Property	AGO	Biodiesel (B100)	BD75	BD50	BD25
1	Density @ 25^{0}C (kg/m^3)	846.7	906.3	897.5	851.5	849.9
2	@ 15^{o}C (kg/m^3)	850.4	918.2	909.8	863.	845.7
3	Cetane index	52.17	43.27	46.31	48	50.04
4	Kinematic Viscosity (cST) @ 40^{o}C	5.56	3.81	4.32	4.79	4.95
5	Calorific value	44.56	36.95	33.97	31.34	30.85
6	Sulphur content	0.582	0.0013	0.16	0.29	0.425
7	Cloud point (^{0}C)	9	14	10	8	9

3.2 Brake Specific Fuel Consumption

Brake specific fuel consumption (BSFC) is a measure of the fuel efficiency of any engine that burns fuel and produces rotational output. It expresses how efficiently the engine converts fuel supplied into useful work [18]. Table 6 shows brake specific fuel consumption (BSFC) performance of the internal combustion engine.

At a constant brake power, the BSFC decreased as strength of diesel increased in the blend. At brake power of 15KW, BSFC (kg/KWh) for BD25, BD50, and BD75 were 0.41, 0.40 and 0.38 respectively. AGO recorded 0.37 and B100, 044, in BSFC. It was observed that BSFC for biodiesel blend is higher than 'pure' AGO but lower than pure biodiesel. The variation is attributable to higher calorific value, lower density and lower flowability. Varying the engine load also provided a deeper insight in the study of performance characteristics of biodiesel. It is evident, from the study that increasing the engine load from zero to full load reflects a decreasing trend in the BSFC of various test fuels. The performance corroborates the relationship expressed in Eq.3. It infers that brake specific energy consumption also decreases. Figure 1 shows the graphical performance of brake specific fuel consumption of the test fuels at various brake power. There is consistent and comparable behavior of the test fuels. Pure biodiesel (B100) had lower calorific value, lower SOx emission in the physic- chemical analyses than AGO. This is evident in high fuel consumption rate (fc) in B100 than AGO.

Table 6 Engine Performance Result

Brake POWER BP (KW)	Brake Specific Fuel Consumption (BSFC (kg/kwh)					Thermal Efficiency (η_{th}) (%)				
	BD25	BD50	BD75	B100	AGO	BD25	BD50	BD75	B100	AGO
15	0.41	0.40	0.38	0.44	0.37	22.2	21	20.8	23.8	21.5
20	0.33	0.32	0.31	0.35	0.30	25.6	25.2	25	26	24.9
25	0.31	0.29	0.26	0.32	0.25	29.7	29	28.8	30	28.5
30	0.26	0.24	0.22	0.29	0.21	31.9	31.8	31.2	32.1	30.6
35	0.25	0.23	0.21	0.27	0.19	32.5	32.2	32	33	31.9
40	0.23	0.21	0.20	0.26	0.19	33.1	33	32.9	33.5	32.7
45	0.21	0.20	0.19	0.25	0.18	33.7	33.6	33.4	33.9	33.1

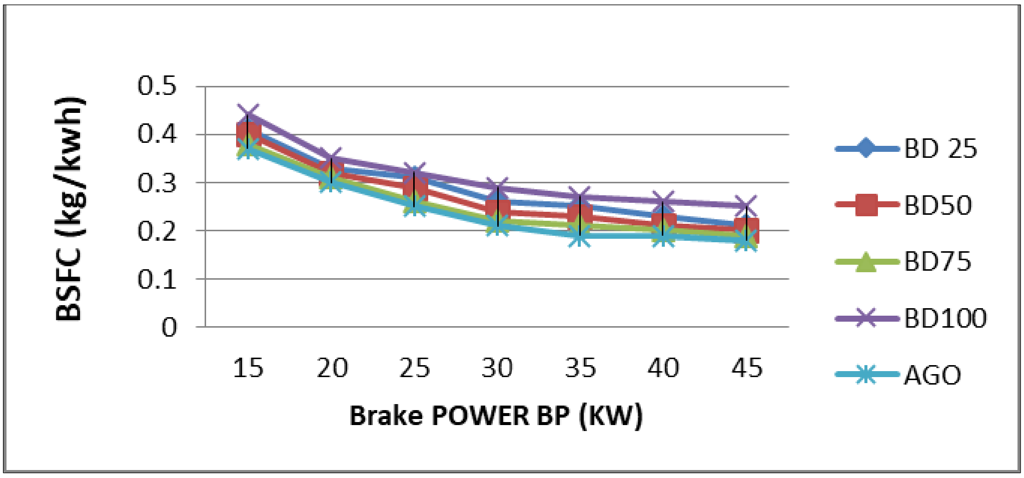

Figure 1 Brake Specific Fuel Consumption of Test Fuels

3.3 Brake Thermal Efficiency

Table 6 shows the brake thermal efficiency performance of the engine. Brake thermal efficiency is a measure of how effective the chemical energy of the fuel is converted to mechanical power or work [19, 20]. From Table 6, at instant of 15KW brake power (BP), BD25, BD50 and BD75 recorded 22.2,21 and 20.8; while B100 and AGO reported 23.8 and 21.5 respectively. B100 recorded better brake thermal efficiency than AGO. The improvement was attributed to the presence of oxygen in the biodiesel fuel which helps in combustion process. But most significant observation was that as the load increased, brake thermal efficiency (η_{th}) increased for all the test fuels. Biodiesel had better brake thermal efficiency than pure diesel fuel. Figure 2 shows the graphical representation of brake thermal efficiency. AGO showed a comparable trend with other test fuels but weaker in brake thermal efficiency. We can conclude that brake thermal efficiency of the test fuels increased with brake power. However, increase in brake thermal efficiency resulted to decrease in fuel power. It has been established that thermal efficiency is the reciprocal of BSFC multiplied by the fuel heating value expressed in Eq.4. The brake thermal efficiency had a contrary trend with BSFC.

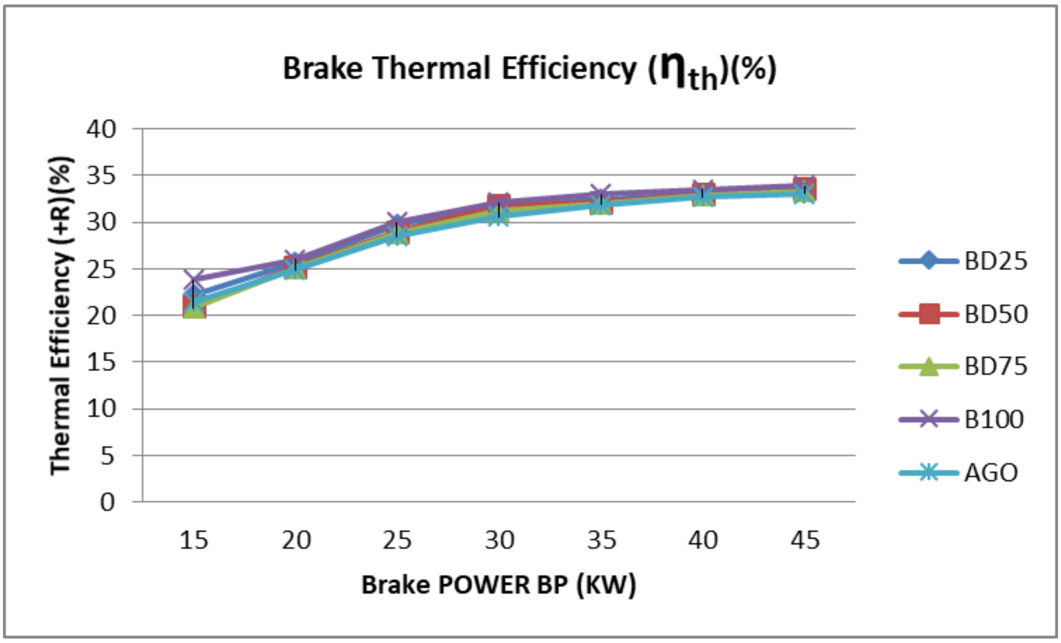

Figure 2 Brake Thermal Efficiency of Test Fuels

Palm oil diesel (POD) obtained from waste cooking oil, had lower calorific value than diesel oil; resulting to high fuel consumption. The brake specific fuel consumption (BSFC) and brake thermal efficiency generally decreased as AGO strength increased in the mixture. For the characteristics studied, biodiesel demonstrated good quality of fuel, but with lean characteristic. It also has greater potential of reducing greenhouse gas emission.

Abbreviations

- AGO: Automobile gas oil (Diesel)
- BDx: Blend of Biodiesel and Diesel
- BP: Brake power
- BSFC: Brake specific fuel consumption
- C: unit constant i.e. 3.6
- HV: gross heating value (kW/kg)
- Ks: unit constant i.e. 3600
- N: engine speed (rpm)
- POD: Palm oil diesel
- T: torque (N-m)
- t: time taken to consume 50 mL fuel (sec)
- Vcc: volume of the fuel consumed (mL)
- WCO: waste cooking oil
- ηth: Brake thermal efficiency

4 Conclusion

The paper has revealed the physico-chemical properties of biodiesel derived from palm oil-based waste cooking oil. It has lower calorific value and lower greenhouse gas emission, hence, a neater and greener fuel than AGO. The tribological evaluation indicated palm oil diesel exhibited higher brake specific fuel consumption and brake thermal efficiency than AGO, with compensation in high fuel consumption. It exhibited characteristic of lean fuel. Finally, the properties of palm oil based- waste cooking oil are comparable with biodiesel from virgin vegetable oil from other lipid feedstock. The utilization of waste vegetable oil would make economic sense as enunciated by United Nations.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflict of interest.

References

[1] Samuel OD, Waheed MA, Bolaji BO, Dario OU. Production of Biodiesel from Nigerian Restaurant Waste Cooking Oil Using Blender. International Journal of Renewable Energy Research. 2013; 3 (4): 56-64.

[2] Amish PV, Subrashisubrahmanyam N, Payal AP. Production of Biodiesel through Transesterification of Jatropha Oil Using KNO3/ Al2O3.Fuel. 2009; 2 (6): 625-628.

[3] Mushtaq A, Sofia R, Mir AK Muhammad Z, Shazia S, Sobia G. Optimization of Base Catalyzed Transesterification of Peanut Oil Biodiesel. African Journal of Biotechnology. 2009; 8 (3): 441-446.

[4] Longman WG, Scott WH. Energy technology in a dynamic world: technology of greener fuel production and adaptation. 2nd Ed. New Delhi: Wiley publisher; 2020.

[5] Viggy CR, Smith MT. Fundametals of thermodynamics: engine cycles and thermal metrics. 1st Ed. Ontario: Prentice-Hall; 2018.

[6] Lapuerta M, Rodríguez-Fernández J, Agudelo, JR. Diesel Particulate Emissions from Used Cooking Oil Biodiesel. Bio-resource Technology. 2008; 99 (4): 731-740.

[7] O'Neil E, Goodman SS, Bradley MD. Biofuel from feedstocks: Applications of industrial biotechnology. 4th Ed. Kansas: Evergreen Publisher; 2020; 156-169.

[8] Kinast JA. Production of Biodiesel from Multiple Feedstock and Properties of Biodiesels and Biodiesel/Diesel Blends, Report 1 in a series of 6. Colorado: National Renewable Energy Laboratory [cited 2019 Jul 18]. Available from https://www.nrel.gov/docs/fy03osti/31460.pdf

[9] Majuski HH, Kalam M. Performance Evaluation of Palm Oil Diesel Blends on Small Engine. Journal of Energy, Heat and Mass Transfer. 2002; (11): 125-132.

[10] Nagwan H, Ranu N, Kumar A, Tewari PC. Performance and Emission Characteristics of Diesel Engine Using Karanja Oil Methyl Ester and Eucalyptus Oil Fuel Blends. Procedia Environmental Science, Engineering and Management. 2019; (4): 553-563.

[11] Majuski HH, Abdulmin M, Sudhir HS. Indirect Injection Diesel Engine Operation on Palm Oil Methyl Ester and its Emission. Proc. Ind. Mech. Eng. Part D: IMechE. 1997; (211): 291-9.

[12] Ma F, Hanna MA. Biodiesel Production: A Review. Bioresour Technol. 1999; 70: 1–15.

[13] Zhang Y, Dube MA, McLean DD, Kates M. Biodiesel Production from Waste Cooking Oil: Economic Assessment and Sensitivity Analysis. Bioresour Technol. 2003; 90: 229-40.

[14] Lele S. Biodiesel and Jathropha Plantation. Res.J-22, Sector 7, Vashi, Navi,Mumbai 400703, India, [cited 2004, jun17]. Available from https://www.coursehero.com/file/49369803/36337539-Bio-Diesel-Book-Dr-Satish-Lelepdf/

[15] Lertsathapornsuk V, Pairintra R, Aryusuk K, Krisnangkura K. Microwave Assisted in Continuous Biodiesel Production from Waste Frying Oil and its Performance in a 100kW Diesel Generator. Fuel. 2008; (89): 1330-1336.

[16] UN. Five Ways to Jump –Start the Renewable Energy Transition. NY: United Nations; [cited 2022, Mar 17]. Available from https://www.un.org/en/climatechange/raising-ambition/renewable-energy-transition

[17] BS 882; Specification for Aggregates from Natural Sources for Concrete. London: British Standards Institute; [cited 1992 Apr 07]. Available from https://www.thenbs.com/PublicationIndex/documents/details?Pub=BSI&DocID=256297

[18] Ashok B, Nathagopal K. Advances in Eco- Fuels for a Sustainable Environment. Cambridge: Woodhead Publishing;[cited 2019 Aug25]. Available from https://www.worldcat.org/title/advances-in-eco-fuels-for-a-sustainable-environment/oclc/1078149475

[19] Dhamodaran G, Krishnam R, Pochareddy YK, Ganeshram AK, Pyarelal HM, Sivasubramanian H. A Comparative Study of Combustion, Emission, and Performance Characteristics of Rice-Bran, Neem, and Cottonseed Oil Biodiesel with Varying Degree of Unsaturation. Fue. 2017; (187): 296- 305.

[20] Raheman H, Ghadge SV. Performance of Diesel Engine with Biodiesel at Varying Compression Ratio and Ignition Timing. Fuel. 2008; 87 (12): 2659-2666.