BOOK CHAPTER | Alternative Engineering Desigsn
dx.doi.org/10.22624/AIMS/REBK2022-P14

Performance Evaluation of Vegetable-based Waste Cooking Oil Biodiesel as Alternative Diesel Engine Fuel

[1]Ugwuanyi Uchenna Barnabas, [2]Adeniyi John Ayodele, [3]Eze Onyeka John, [4]Aka Christian Chikezie, [5]Obasi Oka & [6]Onah Thomas
[1,2,3,5]Federal College of Dental Technology and Therapy, Enugu, [4,6]Enugu State University of Science and Technology, ENUGU.
Email: [1]ugwuanyiuchenna17@gmail.com, [2]adeniyiayodele@fedcodtten.edu.ng
https://scholar.google.com/citations?hl=en&authuser=2&user=NdEv5M4AAAAJ

ABSTRACT

Many researches had attempted characterization of biodiesel to determine its appropriateness as fuel for internal combustion engine. The paper aimed at evaluating the performance of vegetable –based waste cooking oil biodiesel as alternative diesel engine fuel. The methodology of the study was experimental. The waste oil was transesterified and chemical analyses performed to establish physico-chemical properties of diesel, 'pure' biodiesel and blends. The test fuels were evaluated for brake specific fuel consumption and brake thermal efficiency (η_{th}) 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 were that at all 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 while automobile gas oil and pure biodiesel recorded 21.5 and 23.8 in that order. The brake thermal efficiency had a contrary trend with BSFC. However, as the load increased, brake thermal efficiency (η_{th}) increased for all the test fuels utilized. In conclusion, biodiesel has demonstrated features of lean fuel, but exhibited high performance in IC engine. The technology could support agricultural value chain and boost socioeconomic development of Africa.

Keywords: Biodiesel, Brake Fuel Consumption, Efficiency, Test Rig, Blends, Dynamometer

Energy is the hub to socioeconomic development of our society (Samuel, Waheed, Bolaji & Dario, 2013). Fossil fuel has been acknowledged as source of energy 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.Climate change, increase in pump price and carcinogenic effect of emissions have redirected research interest to renewable energy sources.

The quest for greener fuels sources has gained wide societal and political interest due to reduction in greenhouse emission, biodegradability, sustainability as well as its competitive nature to fossil fuels and food supply(Amishi,Subrashisubrahmanyam & Payal, 2009; Mushtag,Sofia, Mir, Muhammad, Shazia & Sobia,2009).The Koyoto Protocol, and other emerging protocols and conventions, have influenced rapid technological development and dynamic national policy framework, triggering researches, policies and technologies that cut- back emission of dangerous substances to the atmosphere.

Most researches focus on transportation sector with interest on solar and electric prime movers. Industrial and agricultural needs have not been sufficiently addressed. Diesel engines dominate agricultural value chain (Utlu & Kocak, 2008). 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 (Gerpen, Shanks, Pruszko, Clements & Knothe, 2004; Lapuerta, Rodriguez & Agudelo, 2008). Kinast (2003) states that diesel engine can burn biodiesel fuel with no modifications.

Biodiesel is a derivative of transesterification process from vegetable oil or fats (Samuel et. al., 2013). ASTM defines biodiesel as mono alkyl ester of long chain fatty acid derivable form renewable lipid feedstock (Raheman & Ghadge, 2008). But the draw-back on the use of the technology is cost. Vegetable oils could be 75% of the manufacturing cost, making production cost of biodiesel approximately 1.5times higher than diesel (Ma &Hanna, 1999; Zhang, Dube, McLean & Kate, 2003).

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 (Zhang et. al., 2003).

Annually, it is well documented that many millions of tons of waste cooking oil are collected and utilized in a variety of ways globally (Lele, 2004). Such oil could have contaminated soil and water. But Africa, and specifically Nigeria, could benefit more. It is an agrarian continent with potential for sustainable lipid feedstock from vegetable oils, hence, should be strategic government initiative of environmental management and technological advancement. Samuel, et. al., (2013) studied the production of biodiesel from Nigeria restaurant waste cooking oil using blender. Therefore, the research is aimed at evaluating the performance of biodiesel and blends. In Germany and Brazil, alternative to 100% biodiesel concentration is used (Lele, 2004, Lertsathrapornsuk, Pairintra, Aryusuk & Krisnangkura, 2008) and it equally reduces CO2 and NOx emission.

Material and Methods

Material

Automobile gas oil (AGO) was purchased from Nigeria National Petroleum Corporation (NNPC) service station. Waste cooking oil (WCO) was procured form Roban Food, a reputable big restaurant that patronizes Wilson Group, Nsukka, Enugu State on Solive (vegetable) oil. Other chemicals were bought from Wallace engineering laboratory at Awka, Anambra State.

Methods

Transesterification, blend composition and characterization of test fuels were performed at Warri Refinery Petrochemical laboratory, Delta State. The experimentation was performed on engine test rig to determine two key performance indicators: brake specific fuel consumption (BSFC) and brake thermal efficiency (η_{th}) at varying brake power (BHP). The test fuels for experimentation were AGO, BD100 and blends: BD25, BD50 and BD 75. BDx indicated xvol% of biodiesel in the composition. The experimentation and physico-chemical analyses on Table 2.1 of biodiesel followed standard procedure on BIS code.

Experiment Test Rig.

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 2.1 .Table 2.2 shows the specification of hydraulic dynamometer.

Table2.1: Methodologies for Determining the Physico- chemical Properties of Test Fuels.

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

Table 2.2: 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

The CI engine was started to steam up to stability at 70℃. The rack is adjusted to optimum position and the fuel test carried out. The parameters measured were brake specific fuel consumption and thermal efficiency for each grade of fuel at different engine loads and different speeds (800rpm, 1200rpm, 1600rpm, 2000rpm and 2400rpm). There were three experimental runs for each test fuel. The mean value was computed as test value. Fuel filter was changed for each test fuel and system bled to ensure accuracy. The computed variables were tabulated and graphed for comparative study.

Table 2.3: 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

Results

Physico- Chemical Properties of Test Fuels

Table 3.1 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 found insignificant, 0.0013. Presence of sulphur in blends was traceable to AGO; which increased with blend strength. Calorific value of the fuel decreased as the blend increased.

Table 3.1: Physico-Chemical Test Values for Biodiesel

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°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°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

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 (Ashok & Nathagopal, 2019). Figure 2.1shows the BSFC of pure and blends test fuels. 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, BD75 were 0.41, 0.40 and 0.38 respectively. AGO also had better value than B100 in BSFC. 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 2.1 and Figure 2.1 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.

It was observed that BSFC for biodiesel is higher than 'pure' AGO; due 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. It infers that brake specific energy consumption also decreases.

Brake Thermal Efficiency

Brake thermal efficiency is a measure of how effective the chemical energy of the fuel is converted to mechanical power or work, according to (Dhamodaran, Krishnan, Pochareddy, Ganeshram, Pyarelal & Sivasubramanian, 2017). It has been established that thermal efficiency is the reciprocal of BSFC multiplied by the fuel heating value. Figure 3.2 shows the brake thermal efficiency. The brake thermal efficiency had a contrary trend with BSFC. 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. The improvement was attributed to the presence of oxygen in the biodiesel fuel which helps in combustion process.

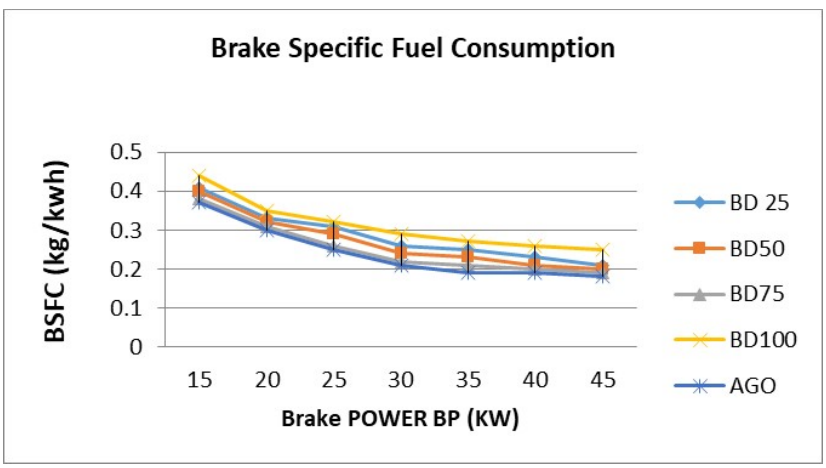

Figure 3.1: Brake Specific Fuel Consumption of Test Fuels.

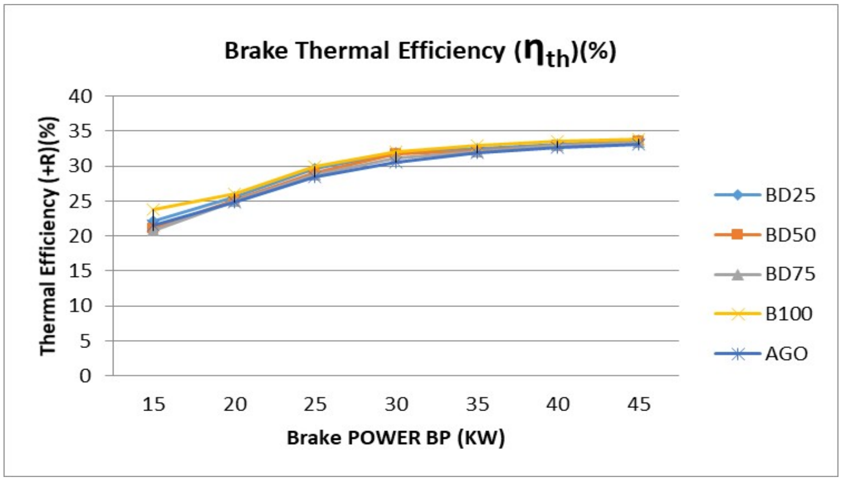

Figure 3.2: Brake Thermal Efficiency of Test Fuels

Conclusion

The study revealed that physico-chemical properties of biodiesel have significant effect on brake specific fuel consumption (BSFC) of test fuels. It was observed that BSFC for biodiesel is higher than 'pure' AGO; due to higher calorific value, lower density and lower flowability. Biodiesel had better brake thermal efficiency (η_{th}) than pure diesel fuel. In conclusion, although, biodiesel has demonstrated features of lean fuel, but exhibited high performance in IC engine. Barring other considerations, biodiesel could serve Africa agriculture value chain more to boost our socioeconomic development.

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