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Study of Performance and Emission Characteristics of Diesel- Biodiesel Blends on Variable Compression Test Rig

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ABSTRACT: The scarcity of petroleum products is forcing renewable energy resources to be more attractive. Biodiesel is an alternative fuel created through the transesterification of vegetable oils and animal fats. The most important biodiesel quality parameters are obtained by paying attention to and making a trade-off between reaction time and temperature. The presence of contaminants in the feedstock, such as water and free fatty acids, or impurities in the final products, such as methanol, free glycerine, or soap, causes difficulties during this process. This research work has developed processes to produce biodiesel from *Jatropha curcas*. The biodiesel was extracted and all the blends were characterized to determine the physicochemical characteristics by the test methods ASTM 6571. The emission characteristics indicate that B_{20} was less than all types of oil samples. The power and torque outputs of B_{20} were found better than all blends next to the baseline diesel fuel. The smell of the smoke of B_{40} was spicy and its smoke density was very little as compared to all types of fuel samples. The novel finding of this study was that increasing the biodiesel in the blend increases brake power, and torque and reduces brake-specific fuel consumption.

KEYWORDS: Biodiesel blends, Emission, Jatropha curcas, Performance, and Transesterification

1. INTRODUCTION

Currently, energy is a critical factor in the development of economic growth for the people who live on this planet (Atabani et al., 2012; Rehman et al., 2019). In the current energy scenario, the transportation sector consumes the lion's share of the energy from fossil fuels and emits a significant amount of carbon dioxide (Wang et al., 2014).The world's energy demand is also continuing to grow. According to (Chhabra et al., 2021) it is forecasted that 60% of the need for energy growth is diesel fuel for the total energy supply in 2035. This growth, in turn, affects the stability of the ecosystem, global climate, and oil reserves. The energy demand of the world has forced many researchers to seek alternative energy solutions (Kumar Shukla et al., 2020). With the recent high and volatile oil prices, various countries are being compelled to devise novel policies to mitigate the impact of these high prices on their economies. The most effective policy in this regard is the diversification of energy supply sources in the transportation sector. Similarly, developing countries such as Ethiopia import all of their petroleum fuel requirements, and their demand for petroleum fuel is increasing rapidly year after year due to their expanding economy and infrastructure. Besides this, clean energy is essential for today's economic development to ensure a sustainable energy source, so clean and renewable energy as a replacement for petro-diesel for compression ignition engines is required (Akram et al., 2022; Hwang et al., 2014). Hence, looking for alternative energy solutions, biodiesel appears to offer the best opportunities (A. Demirbaş et al., 2015; A. H. Demirbaş et al., 2015). Biodiesel is gaining popularity due to its renewable nature, as it has the potential to replace diesel fuel in compression ignition engines without requiring engine modifications. The development of biodiesel in Ethiopia has the potential to bring numerous benefits, including (Amigun et al., 2011; Birhanu & Ayalew, 2017), increased energy supply security through oil diversification and progressive substitution; reduced national oil import expenses; increased agricultural activity, bringing economic benefits to farmers using non-arable lands; and reduced pollution, including greenhouse gas emissions, providing both local and global environmental benefits. Biodiesel is a potentially infinite source of energy for use in diesel engines because it is derived from renewable biological resources. It is derived from waste cooking oil, animal fats, and oilseed crops such as *Jatropha curcas*, palm seeds, soybean, canola, and sunflower, which are particularly useful in the production of biodiesel fuel (Dimian & Rothenberg, 2016). However, non-edible oil from Jatropha, Camellia, and Ricinus is suitable (Bhuiya et al., 2016; A. Demirbaş et al., 2015; Dimian & Rothenberg, 2016). Therefore, for this research purpose, *Jatropha curcas* is chosen for the production of biodiesel because of its local availability. *Jatropha curcas* with high amount of non-edible oil content and capable of growing everywhere, even in non-arable and hilly regions, is a prospective candidate in this respect. It is a drought-resistant shrub that grows to be three to five meters tall and has been designated as a biofuel plant for lowering greenhouse gas emissions (Bailis & Baka, 2010; Suhana Mokhtar et al., 2021). The oil content of *Jatropha curcas* ranges from 30% to 50% of its seed weight (Kumar Shukla et al., 2020). Oil extracted from plant seeds are viscous for the application of diesel engines as fuel. It requires either esterification or transesterification depending on the percentage of free fatty acid profile. The addition of an acid or base catalyst facilitates these reactions (Anastopoulos et al., 2009). Biodiesel has a greater density than petro-diesel and has better spray penetration, which is attributed to its greater density (Chen et al., 2013). However, it has a larger droplet size that leads to poor combustion (Demirbaş et al., 2016). Therefore, to minimize the viscosity and promote good combustion, the oil extracted from *Jatropha curcas* has to be transesterified using base catalyst sodium hydroxide and tested in a variable compression test rig with a different blending ratio of diesel fuel to evaluate its emission and performance characteristics. In addition, this fuel has similar physio-chemical characteristics to diesel oil. It promotes fuel performance and lubricity, which leads to longer engine life (Jha & Schmidt, 2021). According to (Taher et al., 2020), it has a higher cetane number which promotes better ignition properties. Biodiesel is better for the environment than petro-diesel because of its biodegradability and lower emissions of carbon dioxide, sulfur oxides, and volatile matter. On the other hand, due to its cloud point, it does reduce performance in cold climates (Travis, 2012). Furthermore, biodiesel is a long chain fatty acid methyl ester (FAME) with many advantages over petro-diesel, such as lower exhaust emissions and half the ozone-forming potential of petro-diesel (Araújo et al., 2017); better lubricity, high flash point, high cetane number, biodegradability, and domestic origin (Hajjari et al., 2014).

Being a potential alternative fuel source, there is a need to test the suitability of oil produced from *Jatropha curcas* for the operation of four-stroke cycle diesel engines to evaluate its emission and performance characteristics in a variable compression test rig. The main objective of the research work was to produce biodiesel from *Jatropha curcas* seeds, testing the physio-chemical characteristics of the biodiesel and its blends (B_0, B_{10}, B_{20}, B_{40}) and evaluation of its emission and performance characteristics in four-stroke cycle diesel engine.

2. MATERIALS AND METHODS

The methodology used in this work is primarily experimental, involving the production of biodiesel, which includes extraction and transesterification, characterization of the fuel's physio-chemical properties, and testing the biodiesel blends in variable compression test rig for emission and performance characteristics. The extraction and transesterification of biodiesel were carried out in Addis Abeba at the Wondo-Genet Agricultural Research Center Laboratory known as the Essential Oil Research Center (EORC), while the characterization of the biodiesel was carried out at the Ethiopian Petroleum Enterprise (EPE) and the Ethiopian Rural Energy Development and Promotion Center. Emission analyses of biodiesel and blends were performed at Jimma University's Mechanical Engineering department. The chemicals used in the experiment were 99.8 percent pure methanol of analytical grade, and the basic catalyst Potassium Hydroxide (KOH) was in the form of a pellet for the esterification process. The experimental data were analysed using the statistical analysis software SPSS for interpreting the relation between performance and emission parameters.

2.1. Experimental setup and procedures

This research work was completed by four successive phases, which are the production of straight vegetable oil from *Jatropha curcas* seeds, transesterification, characterization of the physic-chemical characteristics of the biodiesel and its blends, and evaluation of its emission and performance characteristics.

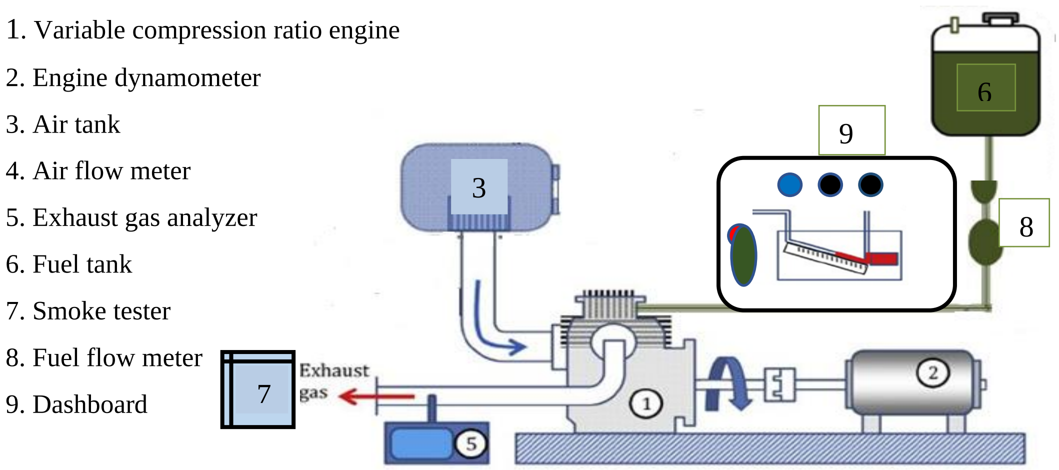

Figure 1. Schematic representation of the experimental setup of Engine Performance and emission testAs shown in (Figure 1), the experimental setup consists of a TD43F variable compression engine test rig model TOOLQUIP 5000 equipped with an engine dynamometer, air tank, airflow meter, exhaust gas analyser, fuel tank smoke tester, fuel flow meter, and dashboard for the measurement of engine torque, power, and rpm.

The compression ratio of the test engine ranges from 5:1 to 18:1. It is normally an aspirated test engine operated by petrol, diesel fuel, propane, or natural gas. The engine is directly connected to a dynamometer. This is used to start the engine and turn it to test the friction power. The engine and dynamometer are both mounted on a rigid steel bed plate that stands free on four vibration isolation feet. The following are the experimental conditions: Seven engine speeds (1000, 1250, 1750, 1500, 2000, and 2500 rpm), a fixed compression ratio of 1:14, and a 210 crank angle BTDC. Diesel number 2 was used as a reference fuel, and B_{10}, B_{20}, and B_{40} were tested for emission and performance characteristics.

3. RESULTS AND DISCUSSION

From the extraction process, the solvent method yielded 22% (v/w) oil, and the combination of the mechanical press and solvent method yielded 33.3% (v/w). Extracting oil from the oilseeds requires the organic solvent hexane, which is preferable to dissolve and extract the oil from its seeds. However, the solvent is expensive, and it requires at least twenty-four hours to dissolve the oil from the seeds. Additionally, separation of the solvent from the oil using Rota-Vapour was required. According to the extraction method observed, the mechanical method of biodiesel extraction has a higher yield and is also more cost-effective and time efficient.

3.1. Fatty acid profile of Jatropha Curcas

Before proceeding to the production of biodiesel, the fatty acid profile of the crude oil extracted from Jatropha curcas was quantified. The fatty acid analysis of Jatropha oil methyl ester was conducted using Varian 3800 model GC equipped with an FID detector. A Varian CP-3800GC equipped with a DB-5 column and FID detector was used for the fatty acid analysis. The quantitative analysis was performed according to the following set of conditions: Column temperature program was set from 130 ˚C for 1 min, and then up to 220 ºC for 20 min at a rate of 15 ºC/min; Nitrogen was used as a carrier gas at a flow rate of 7.0 psi; and the injector and the detector temperatures were set at 250 and 270 ºC, respectively. The result of the fatty acid analysis is summarized below in Table 1.

Table 1. Fatty acid profile of Jatropha Curcas

Oilseed	Palmitic acid (C16:0)	Stearic acid (C18:0)	Oleic acid (C18:1)	Linoleic acid (C18:2)	Linolenic acid (C18:3)
Jatropha oil	6.1	3.9	52.8	33.6	3.3

3.2. Esterification

According to (Singh et al., 2021) Jatropha curcas oil is an appropriate candidate for the production of biodiesel. Because it is none edible and in the long run, it is promising to reduce the consumption of petroleum fuels. The free fatty acid composition of Jatropha Curcas oil was detected by gas chromatography (Model Varian 450 GC). The free fatty acid was found 4.6 % which causes saponification. Therefore, a two-step process of esterification and transesterification was conducted. In this process, the molar ratio of methanol to Jatropha oil was 6:1. 1% (V/Voil) of sulpheric acid was added at 65^0c for 1 hour at a stirring speed of 600RPM. After the reaction is completed, a separator funnel was used to slit the alcohol and sulfuric acid impurities at the upper layer. A water bath of Rota vapor was used to separate the methanol and water from the oil.

3.3. Transesterification

The production of biodiesel from the esterification reaction is qualitatively analyzed by Fourier transform infrared spectroscopy (FTIR). It is accurate, reliable, faster than similar methods of measurement, and economical. It accommodates libraries of infrared bands for component analysis. The conversion of the straight vegetable oil of Jatropha oil to methyl ester was evaluated and monitored by the intensity of C=O ester stretch at wave number (1742cm^{-1}) and this showed a strong ester which indicated the formation of biodiesel as shown in figure 2.

Figure 2. Fourier Transform Infrared spectroscopy for jatropha curcas methyl ester.

3.4. The side product glycerin

When crude oil is converted into biodiesel, the amount of oil transesterified is 97 percent pure biodiesel. The glycerine collected accounted for 18.75 percent of the crude oil transesterified volume.

3.5. Results of the blends of physio-chemical properties.

The pysico-chemical properties of the oil after transesterification were tested by the ASTM D6751 test method. All parameters were obtained in the standard range which defines the oil to be biodiesel as shown in (Table 2).

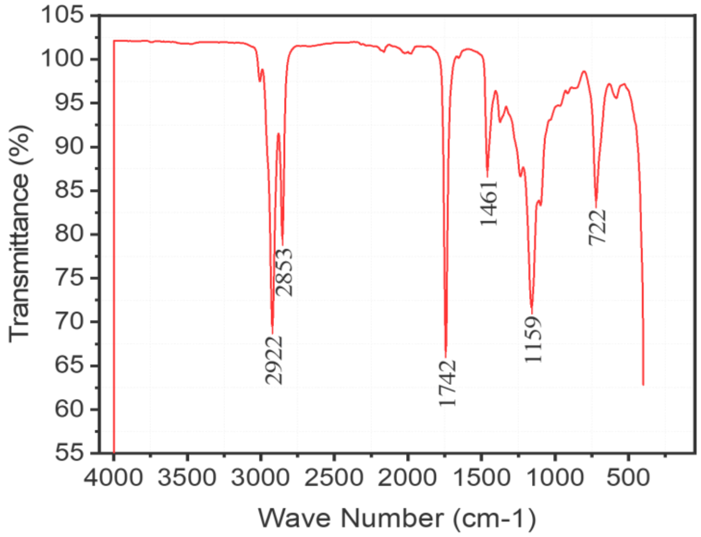

Figure 3. Emission of, a) CO, b) CO2 c) HC and d) NOX vs. Engine speed

Table 2. Parameters of the oil samples after characterization

No	Property	Tests ASTM	Limit 6751-07b	Test Result B40	B20	B1O	B0
1.	Density@15⁰c,g/ml	D1298	Report	0.869	0.8556	0.8616	0.8474
2.	Density@20⁰c,g/l	D1298	Report	0.855	0.8522	0.8582	0.8440
3.	Distillation% V	D86	-	-	-	-	-
	IBP⁰C		-	184.5	182.5	184.5	176
	10%, recovered		-	228	217	215	220
	40%recovered		-	302	281.5	275.5	282.5
	50%recovered		-	316.5	298	287.5	292.5
	90%recovered		Max360⁰C	356	49	349	349
	95%recovered			364.5	361	366.5	352
	100%recovered			-	-	-	-
	FBP		Max390	367.5	362	366.5	352
4	Flashpoint(PMCC)	D93	100M	78.8	76.8	74.8	71.8
5.	Cu-Strip-corrosion	D130	Max3	1a	1a	1a	1a
6.	Cloud point, ⁰C	D2500	Report	0	- 1	- 1	0
7.	Pour point, ⁰C	D97	Repot	< - 8	< - 8	< - 8	< - 8
8.	Kinematic viscosity	D445	1.9__ 6	3.828	3.5116	3.2865	3.1637
9.	Cetane Index	D976	Min47.0	51.34	51.127	47.56	52.905
10	ASTM colour	D1500	Max =3	1<x<1.5	1<x<1.5	1<x<1.5	1
11	Water, seg In, %V	D2709	Max0.03	<0.025	<0.025	<0.025	<0.025
12	Acidity, mg KOH/g	D974	0.5	0.113	0.0534	0.0327	0.0106
13	Ash content, mass%	D482	Max0.01	0.006	0.0006	0.0006	0.0001
14	Calorific value, Cal/g	__	Report	10,31.13	10,619.4	10696.18	11,111.3

The flash point for biodiesel and diesel were 173.80°C and 71.80°C respectively. Hence, biodiesel is safe from fire hazards and custody transfer. The cloud point of biodiesel is 7⁰C, which is greater than that of diesel fuel, which is 0⁰C. Therefore, it is advised to utilize it at temperatures over 7⁰C. The biodiesel and diesel had initial boiling points of 298⁰C and 176⁰C, respectively. Because biodiesel has a greater initial boiling point, starting engines with it at a lower temperature result in increased fuel consumption. Additionally, it was found that the emission of unburned hydrocarbons was rising at decreasing engine speeds. The copper strip corrosion of biodiesel and diesel fuel was found to be [1b] and [1a], respectively, as shown in (Table 2). As a result, the degree of corrosiveness of biodiesel to fuel system components is nearly the same. The kinematic viscosity of biodiesel produced from *Jatropha curcas* and diesel fuel was found to be 5.12mm^2/s and 3.16mm^2/s, respectively. The cetane indexes of biodiesel and diesel fuel were 47.13 and 52.9, respectively. Hence, biodiesel requires more advanced injection timing than diesel fuel for proper combustion. The water and segment of the biodiesel measured was less than 0.025 percent volume. Hence, there is no trouble with or fouling fuel system components if biodiesel is used. The total acidity of biodiesel and diesel fuel is 0.1686 mg KOH/g and 0.0106 mg KOH/g, respectively, which is within the permissible limit. The higher heating value of the biodiesel and diesel fuel are (40.26 kJ/Kg) and (46.44 kJ/Kg), respectively.

3.6. Evaluation of combustion and emission of diesel-biodiesel blended fuel

The variation in carbon monoxide emissions with biodiesel blends as compared to pure diesel fuel is depicted in (Figure 3a). Biodiesel blending reduced carbon monoxide (CO) emissions compared with diesel fuel blending owing to its higher oxygen content (Ruhul et al., 2016). In this study, the carbon monoxide emissions were decreased slightly at low engine speeds as the biodiesel ratio decreased. Furthermore, the carbon monoxide emission increased at higher engine speeds as the ratio of biodiesel in the blend increased, except for B_{20} which is less than the baseline diesel fuel starting from ideal speed to maximum speed.

In an ideal world, the combustion of a hydrocarbon fuel would produce only carbon dioxide and water. Besides that, carbon dioxide occurs naturally in the atmosphere. (Figure 3c) depicted the effect of different mixing ratios of diesel-biodiesel blends with diesel fuel on carbon dioxide emissions. When the biodiesel amount in the blend increased, the carbon dioxide emission slightly increased. However, as seen in (Figures 3a and 3c, when the biodiesel concentration increased, the carbon monoxide and unburned hydrocarbon increased in the exhaust gas. The carbon dioxide concentration has shown in (Figure 3b) an opposite characteristic of carbon monoxide and unburned hydrocarbon. Moreover, this is due to the improved combustion process as the result of the oxygen content of the biodiesel in the blends.

As a previous study indicated diesel engines operated by Jatropha biodiesel decreases HC when compared to diesel fuel (Ganapathy et al., 2011). The influence of different blends of unburned hydrocarbon (HC) emission is seen in (Figure 3c) as the biodiesel ratio increased, unburned hydrocarbon (HC) decreased for all engine speeds. As engine speed increases, the concentration of unburned hydrocarbons decreases. This experiment found that the minimum hydrocarbon emissions for B_0, B_{10}, B_{20}, and B_{40} are 73, 72, 55, and 62 ppm, respectively. When biodiesel is mixed with petroleum diesel, it adds oxygen to the combustion process, resulting in improved combustion. Besides that, there is a decrease in hydrocarbon (HC) emission for all blended fuels as engine speed increases, indicating that the mixing of the fuel to the compressed air improves as the turbulence effect increases at higher engine speeds. This resulted in more complete combustion and lower hydrocarbon emissions.

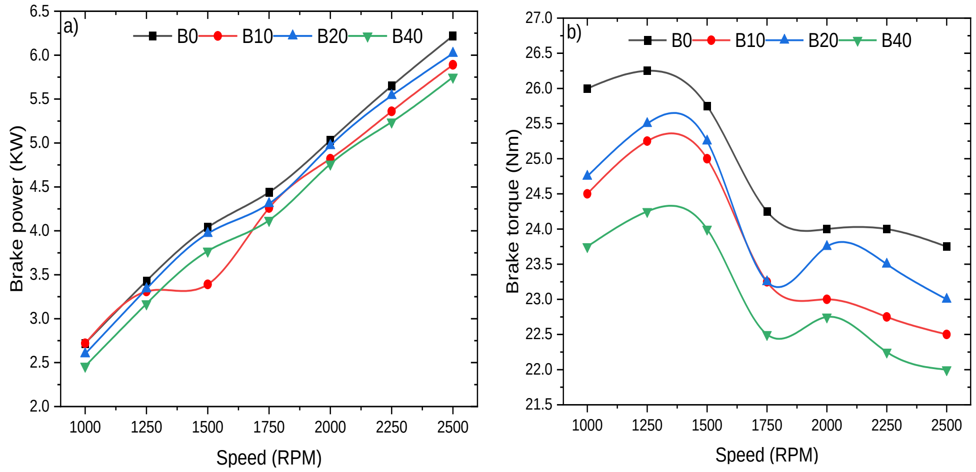

Figure 4: a) Brake power, and b) Brake torque vs. engine speed

The NO_x concentration through tile pipe of the engine indicated that, the baseline fuel has maximum concentration starting from ideal speed to maximum speed. Specially from intermediate speed range 1775 rpm to 2275rpm records maximum concentration NO_x. Moreover, as the biodiesel blend ratio increased the NO_x concentration decreased as indicated on figure 3d.

3.7. Evaluation of power, torque, and fuel consumption

As shown on (Figures 4a, 4b and 4c), the power and torque output of the test engine using different blends of biodiesel [B_0, B_{10}, B_{20}, B_{40}] under full rack setting from the idle speed to the maximum speed of the test engine at an interval of 250 rpm. The power and torque curve patterns of the fuel blends against speed appeared to be similar to the conventional diesel fuel. The lower calorific value of the biodiesel causes a slight reduction in power and torque. Other researchers hypothesized that using additives could optimize combustion behaviour and improve engine performance. The engine's brake power output was calculated using the engine torque gauge and rpm reading of the engine dynamo meter, which measures the displacement of a spring that balances the force generated by the dynamo meter casing as it attempts to turn with the engine when driving against the brake. The TD43F engine test rig uses an electrical dynamometer, which places a load on the engine and the power is dissipated in the resistor network. Therefore, brake power and brake torque are related by (equation 1) (Dimitrov et al., 2021), were simultaneously read from the meters, and shown for all types of fuel (B_0, B_{10}, B_{20}, B_{40}) on the (Figure 4).

$$P_b = \frac{2\pi N T_b}{60000}[KW] \quad (1)$$

Where $P_b = \omega \times T$ (KW), brake power, $\omega = \frac{2\pi N}{60}$ rad/sec, angular velocity of crankshaft

N = *rpm* of Engine and T_b= Torque of the engine in N-m(Figures 4a and 4b) shown are the power and torque output of the test engine using different blends of biodiesel (B0, B10, B20, and B40). Under full rack, setting it was tested from idle speed, which is 1000 rpm, to the maximum engine speed at an interval of 250 rpm. Previous research reports showed that as the percentage of biodiesel increased in the blends, the brake power decreased (Ruhul et al., 2016), similarly this research result showed that as the percentage of biodiesel increased in the blends, the brake power, and brake torque decreased because of the lower calorific value and higher viscosity of the biodiesel. The fuel consumption decreased from B0 to B40 as the percentage volume of the biodiesel in the blend increased. In addition, the fuel consumption increased from lower speed to higher engine speed for all fuel samples. The fuel consumption of B20 as indicated on figure 4c was with the lowest BSFC when compared to other biodiesel-diesel blend.

The engine performance test results for conventional diesel fuel and biodiesel blends are shown in the (Figures 5a to 5d), where (Figure 5a) is for the performance curve of the baseline diesel fuel and the (Figures 5b to 5d) are for the performance curves of the blends B10, B2O, and B40 respectively.

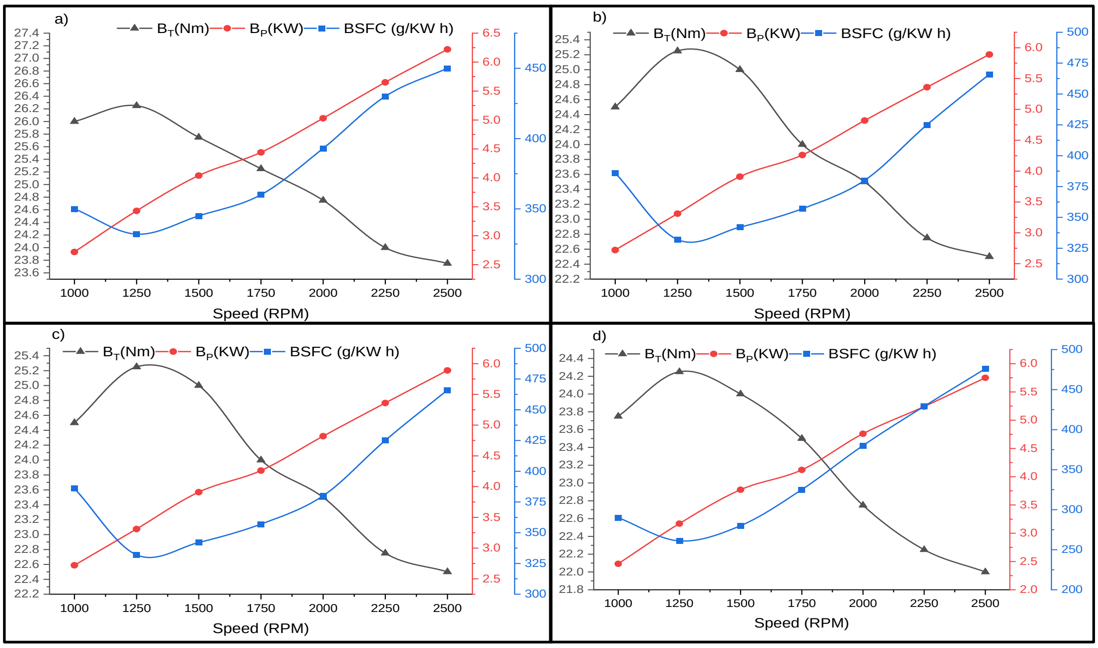

Figure 5. Performance Curve of: a) B0, b) B10, c) B20, and d) B40 vs. engine speed

The fuel consumption decreased from B_0 to B_{40} as the percentage volume of the biodiesel in the blend increased. In addition, the fuel consumption increased from lower speed to higher engine speed for all fuel samples. However, starting from the intermediate speed to the maximum speed range of the test engine, it was smoothly operated. The fuel consumption of the B_{20} was found the least of the other fuel samples, hence it was more economical. The lower calorific value of the biodiesel accounts for the slight decrease in power and torque.

3.2.1. Measurement of fuel consumption

The fuel consumption in a given interval of time was measured in terms of volume. The TD43F Variable compression engine has vessels with suitable capacities of 8ml, 16ml, and 32ml that are connected to the main fuel tank and supplied fuel to the engine during testing. The vessel was filled and then disconnected from the fuel tank via a valve. A stopwatch was used to time how long it took to empty the vessel. The fuel consumption of the engine was calculated by dividing the volume of the vessel by the time. Total fuel consumption (TFC) is the amount of fuel consumed by the engine per unit of time. Generally, it is expressed in Kg/h (Dimitrov et al., 2021).

$$T_{fc} = \frac{x}{t} \times 3.6 \times sg \left[Kg/h\right] \quad (2)$$

Where x =fuel consumed in cm^3, t = time in seconds, and $s.g$ = specific gravity of the fuel. Specific fuel consumption is a useful criterion of economic power production.

Thus, brake-specific fuel consumption is defined as the amount of fuel consumed per unit of time to generate unit brake power output (Dimitrov et al., 2021).

$$BSFC = \frac{\text{Total consumption of fuel(mass / time)}}{\text{brake power}} [Kg/Kwh] \quad (3)$$

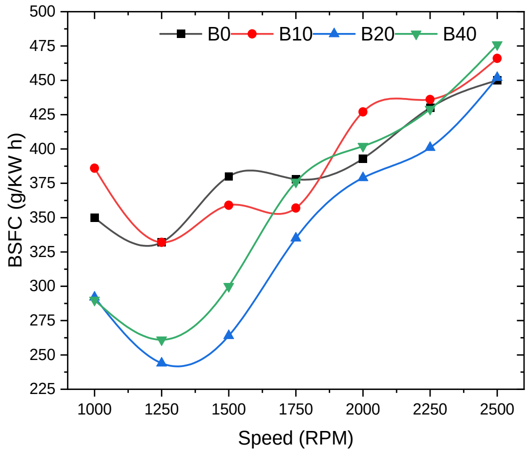

Figure 6: Brake-specific fuel consumption curves

As a previous study indicated Jatropha biodiesel operation decreases BSFC when compared to diesel fuel (Ganapathy et al., 2011). The TFC of B_{40} was better than all blends of the oil samples ranging from 1250-2000 rpm as indicated in (Figure 6a). However, at engine speeds higher than 2000 rpm to the maximum engine speed B_{20} and B_{40} were better respectively. Similarly, the brake fuel consumption and TFC curves showed the same trend in the performance curves as indicated in (Figure 6b).

3.8. Efficiency

3.8.1. Thermal efficiency

It is the ratio of brake power (Pb) or indicated power (Pi) to heat energy of supplied fuel over the same time interval. The efficiency based on brake power is known as brake thermal efficiency, and it is represented by (Dimitrov et al., 2021).

$$B_{th} = \frac{P_b}{m_f \times cv} \times 100\% \quad (4)$$

Where, m_f= mass flow rate of fuel *(kg/s) and* C_V = calorific value of fuel in *kJ/Kg*

In addition, the efficiency based on indicated power of the engine is called indicated thermal efficiency (Dimitrov et al., 2021).

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$$I_{\eta th} = \frac{P_I}{m_f \times cv} \times 100\% \quad (5)$$

As a previous study indicated Jatropha biodiesel operation increases brake thermal efficiency when compared to diesel fuel (Ganapathy et al., 2011). The brake thermal efficiency of B_{20} as shown in (Figure 7a) was maximum from 1250 rpm to 1800 rpm when compared to other diesel-biodiesel blends. However, at intermediate engine speeds, brake thermal efficiency tends to decline in the following orders: B_{20}, B_{40}, B_{10}, and B_0.

The mechanical efficiency shown in (Figure 7b) indicated that B20 was better at lower engine speeds ranging from idle to 1200 rpm than all blends of oils in the experiment. However, B_{40} has the least mechanical efficiency at intermediate speeds. From the mechanical efficiency curves of the fuel blends, it was seen that the mechanical efficiency decreased from B_0 to B_{40}. However, the biodiesel blends are observed to have good lubricating properties at lower engine speeds as the mechanical efficiency increased from the rated engine speed of 1000 to 1250 rpm. Hence biodiesel blends must preferably be used for constant and low-speed engines

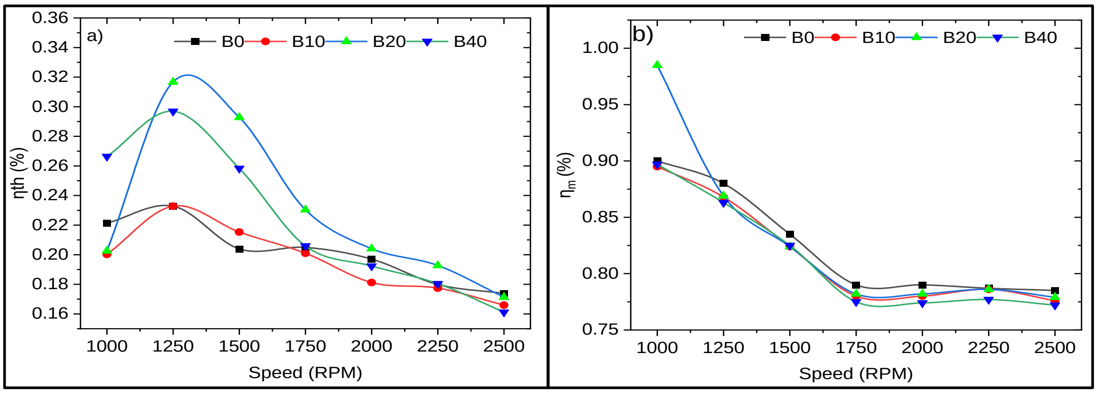

Figure 7: a) Brake thermal efficiency b) mechanical efficiency vs engine speed

One Way ANOVA (Analysis of Variance) for F Test

Table 3. ANOVA table for performance, efficiency, and emission characteristics

		Sum of Squares	df	Mean Square	F	Sig.
Brake Torque	Between Groups	610442.497	6	101740.416	1.006	.434
	Within Groups	4247853.839	42	101139.377		
	Total	4858296.337	48			
Brake Power	Between Groups	2.046	6	.341	.192	.977
	Within Groups	74.556	42	1.775		
	Total	76.602	48			
BSFC	Between Groups	64262.531	6	10710.422	1.469	.212
	Within Groups	306167.714	42	7289.707		
	Total	370430.245	48			
CO	Between Groups	.057	6	.010	2.771	.023
	Within Groups	.145	42	.003		
	Total	.202	48			
HC	Between Groups	5217.061	6	869.510	1.392	.240
	Within Groups	26233.429	42	624.605		
	Total	31450.490	48			
CO_2	Between Groups	42.259	6	7.043	4.480	.001
	Within Groups	66.029	42	1.572		
	Total	108.288	48			
NO_X	Between Groups	22.471	6	3.745	14.352	.000
	Within Groups	10.960	42	.261		
	Total	33.430	48			
η_{th}	Between Groups	.007	6	.001	.313	.927
	Within Groups	.147	42	.004		
	Total	.154	48			
η_m	Between Groups	.119	6	.020	1.267	.293
	Within Groups	.657	42	.016		
	Total	.776	48			

The results of the ANOVA analysis (Table 3) show whether there is a statistically significant difference between performance, efficiency, and emission characteristics. The significance values for CO, CO_2, and excess NO_X were (F (6, 42) = 2.771, p = 0.023), (F (6, 42) = 4.480, p = 0.001), and (F (6, 42) = 14.352, p = 0.000), all of which were less than 0.05. As a result, there is a statistically significant difference in the mean of CO, CO_2, and excess NO_X between biofuel blends. Furthermore, there was no significant difference in the mean HC of the biofuel blends at (F (6, 42) =1.392, p = 0.24). In terms of performance, there was no statistically significant difference between the biodiesel blends of brake torque, brake power, and BSFC at (F (6, 42) = 1.006, p =.434), (F (6, 42) = 0.192, p = 0.977), and (F (6, 42) =1.469, p = 0.212). Furthermore, there was no statistically significant difference between the biofuel blends in terms of thermal and mechanical efficiency (F (6, 42) = 0.313, p = 0.927) and (F (6, 42) = 1.27, p = 0.293).

4. CONCLUSIONS AND RECOMMENDATIONS

The objective of the study was to assess the emission and performance characteristics of *Jatropha curcas*-derived biodiesel in variable compression engine. The fuel injection timing used in this study was 21^0 BTDC and a compression ratio of 1:14. Solvent and mechanical pressing were used to produce biodiesel. The mechanical extraction method has a higher yield, cost-effectiveness, and time-saving with an average yield of 33.3%. The flash point of biodiesel is higher than diesel fuel, which is less susceptible to fire hazards and fuel custody transfer. The cloud point of biodiesel is 7^0c, which is greater than the cloud point of diesel fuel, which is 0^0c and has to be reported to customers. As the percentage of biodiesel grew, the brake power, fuel usage, and emissions reduced. The brake power of the blend B_{20} was greater than that of all other types of blends. Moreover, the mechanical efficiency was slightly increased. Therefore, for optimum functioning with larger ratios of biodiesel blends, the rated idle speed must be adjusted to fast idle. As a result, we recommend other researchers assess the emission and performance characteristics of biodiesel produced from *Jatropha curcas* in existing diesel engines with varying compression ratios and injection timing.

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DATA AVAILABILITY STATEMENT

Data will be made available on request.

DECLARATION OF INTEREST'S STATEMENT

The authors declare no conflict of interest.

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