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Determination of Operational Parameters of Cape Verde Biodiesel Fuel Blends in Compression Ignition Engine

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Abstract

Transportation and electric power generation are essential elements of a modern, mechanized agricultural system that can ensure adequate food supply. Yet, this crucial sector, which drives national development, faces a dual challenge: the high cost and environmental unfriendliness of conventional fuels used for transport and power production. In this work, several blends of Cape Verde biodiesel—80/20%, 60/40%, 40/60%, 20/80%, and 100%—were tested on a laboratory-scale, single-cylinder, direct-injection diesel engine under hybrid operation, to assess short-term performance and determine key operational parameters at four load conditions. The Cape Verde biodiesel complied with EN, BIS, and Brazilian biodiesel standards. The results showed that conventional diesel (reference fuel) delivered better performance than the Cape Verde biodiesel blends in terms of brake specific fuel consumption, brake thermal efficiency, and air–fuel ratio. Conversely, the Cape Verde biodiesel blends exhibited improved performance in engine and exhaust gas temperatures. Diesel and the B20 blend recorded almost identical values for brake power and volumetric efficiency. In addition, B100 produced the lowest engine temperature among all biodiesel blends and diesel fuel. Overall, B20 emerged as a promising candidate to replace conventional diesel, provided that long-term performance, combustion, and emissions studies confirm no issues related to engine starting, wear, compatibility with engine components, or catastrophic failure.

Keywords: Diesel, Cape Verde biodiesel, brake power, brake specific fuel consumption, exhaust gas temperature

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FEDERAL POLYTECHNIC, MUBI-NIGERIA

1.0 Introduction

Ongoing efforts are aimed at reducing the negative environmental impact of diesel-powered machinery by employing cleaner fuels. Non-edible vegetable oils have demonstrated potential as substitutes for conventional diesel. [1] highlighted B25 jatropha oil methyl ester as a viable diesel engine fuel due to its comparable performance and emission characteristics. [2] reported that the J20 jatropha biodiesel blend caused no significant changes in brake thermal efficiency and brake specific fuel consumption. Win [3] found good agreement between theoretical and experimental performance results for a jatropha oil–based B20 blend.

[4], using a Student's t-test to compare jatropha and castor biodiesel blends, concluded that fuel type had no significant effect on performance and emissions up to 20% biodiesel content. [5] observed that J25 and J50 jatropha biodiesel blends yielded higher mechanical efficiency than other blends, with slightly higher CO and lower CO_2 emissions relative to diesel. Karthick et al. [6] evaluated jatropha biodiesel blends in a fully instrumented, single-cylinder, direct-injection diesel engine and reported that brake thermal efficiency increased with applied load.

[7] obtained performance results for jatropha methyl ester blends that were close to those of conventional diesel and concluded that these fuels could power existing diesel engines without modification. [8] investigated brake specific fuel consumption, thermal efficiency, and emissions for jatropha biodiesel and found comparable brake power for diesel and jatropha blends, along with reduced CO, CO_2, and HC emissions for biodiesel. [9] conducted tests on a four-stroke, single-cylinder, water-cooled diesel engine using jatropha–diesel blends and recorded higher indicated power for the blends than for pure diesel.

[10] improved biodiesel viscosity and density by blending jatropha and castor oils, achieving better engine operation and brake specific fuel consumption for B20. [11] reported that Neem biodiesel (NB10) produced better engine performance and emission characteristics than other biodiesel blends. [12] showed that up to 20% jatropha biodiesel in diesel yields compatible performance parameters with reduced emissions. [13] observed reductions in in-cylinder peak pressure, temperature, heat release rate, and ignition delay when using jatropha blends. [14] demonstrated that blends of jatropha biodiesel with ultra-low-sulfur diesel can result in negligible NOx emissions.

This study aims to determine whether the operational parameters of a compression ignition engine running on Cape Verde biodiesel blends are suitable, and to compare them with those obtained for a diesel reference fuel.

2.0 Materials

Test rig: The experiments were performed on a Petter AA1, TD114 single-cylinder, two-stroke, horizontal diesel engine with a compression ratio of 17:1, maximum torque of 8.2 Nm at 3600 rpm, and maximum brake power of 2.6 kW at 3600 rpm. The fuel injection timing ranged from 24° to 33° BTDC. The engine was coupled to the necessary instrumentation and auxiliary units.

3.0 Methodology

Performance parameters were calculated using standard equations given by Eastop (1993).

3.1 Power Developed

The brake power developed by the engine is expressed as:

$$P = \frac{2\pi NT}{60} \quad (1)$$

where

N = engine speed (rev/min)
T = torque (N·m)

3.2 Air Consumption Measurement

The mass flow rate of air in kg/hr is given by:

$$Ma = 2.98\sqrt{\frac{P}{T}\text{hmm}} \quad (2)$$

where
P = pressure (mbar)
T = temperature (K)

3.3 Measurement of Fuel Consumption

Fuel consumption was determined by timing, t, for the engine to consume 8 ml of fuel. The mass flow rate in kg/hr is:

$$Mf = \frac{28.8 \times S_{gf}}{t}, \text{ kg}/hr \ (3)$$

where

Sgf = specific gravity of the fuel
t = time to consume a fixed fuel volume

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FEDERAL POLYTECHNIC, MUBI-NIGERIA

3.4 Measurement of Air–Fuel Ratio

The air–fuel ratio is obtained from the ratio of air and fuel mass flow rates:

$\frac{A}{F} = \frac{M_a}{M_f}$ (4)

3.5 Brake Specific Fuel Consumption

Brake specific fuel consumption (b.s.f.c.), in g/kWh, is defined as the fuel mass flow rate divided by brake power:

Brake specific fuel consumption, $\text{b.s.f.c} = \frac{M_f}{P_b} \times 10^3$ g/kwh (5)

where

Pb = brake power

3.6 Heat Percentage Loss in Exhaust

The percentage of input heat lost with the exhaust gases is:

$$\text{percenatge heat loss in exhaust} = \frac{\left(M_a \times M_f\right) \times C_p \times \Delta t \times 100}{M_f \times H} \quad (6)$$

where
H = calorific value of fuel (kJ/kg)
Δt = difference between exhaust and ambient temperatures
Cp = specific heat of exhaust gases

3.7 Correction of Brake Power to Standard Conditions

Measured brake power was corrected to standard atmospheric pressure and temperature using:

$$P_B\left(\text{Corrected}\right) = P_B\left(\text{Measured}\right) \times \frac{749\text{mmHg}}{P_o} \times \frac{273 + t_o}{273 + t_s} \quad (7)$$

where

subscript ‘s’ = standard conditions
subscript ‘o’ = observed conditions

3.8 Brake Thermal Efficiency

Overall brake thermal efficiency is given by:

$$\eta_b = \frac{P_b}{M_f \times H} \times 3600 \quad (8)$$

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FEDERAL POLYTECHNIC, MUBI-NIGERIA

3.9 Volumetric Efficiency

For a two-stroke engine, volumetric efficiency is:

$$\eta_v = \frac{M_a}{60N} \times \frac{1}{V_s \rho_a} \quad (9)$$

where

V_s = swept volume (m^3)
ρ_a = density of air (kg/m^3)

4.0 Experimental Procedure

The objective of the experiment was to determine the operational parameters of a compression ignition engine operating on Cape Verde biodiesel. The engine was configured for hybrid use, covering both automotive and generator applications. Each fuel blend was evaluated over a short-term test lasting two hours. Torque and engine speed were manually controlled, and the following parameters were recorded: engine temperature, fuel consumption, exhaust temperature, and developed power. The engine speed ranged between 2200 and 2500 rpm. The engine was first operated on conventional diesel, the reference fuel, and then on each of the jatropha biodiesel blends. After each fuel test, the engine was serviced, fresh lubricating oil was added, and the fuel system was flushed before introducing the next blend. Cape Verde biodiesel oil was sourced from the National Research Institute for Chemical Technology (NARICT), Zaria, Kaduna State, Nigeria. The engine specifications and fuel properties are summarized in Tables 1 and 2, respectively.

Table 1
Diesel Engine Specifications

S/No	Parameters	Value
1	Ambient temperature, °C	32
2	Engine bore, mm	70
3	Engine stroke, mm	57
4	H_2, mm of water	35.8
5	Density of air, kg/m^3	1.1548
6	Quantity of fuel consumed, ml	8
7	Swept volume, m^3	2.19×10^{-4}

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FEDERAL POLYTECHNIC, MUBI-NIGERIA

Table 2: Properties of Biodiesel Jatropha

S/No	Fuel Properties	ASTM *Ps* 975 diesel	ASTM 121 Biodiesel	Biodiesel Jatropha Produced in NARICT
1	Aniline point, °C	_	_	27
2	Specific gravity at 60˚F	0.85	0.88	0.88
3	API gravity	_	_	29.1
4	Carbon Residue, Wt%	<0.35	0.05	1.21
5	Kinematic viscosity at 40^0C, Cst	1.3-4.1	1.90-6.0	5.82
6	Colour			>1.0
7	Diesel index			23.5
8	Calorific value, KJ/kg	45	41	44
9	Flash point, °C	60-80^0C	-100 to 170˚C	133
10	Cloud point, °C	-5 to 5^0C	-3 to 12˚C	-3

(Source: NARICT)

5.0 Results and Discussion

5.1 Brake Power

Brake power increased with torque and engine speed for both diesel and all Cape Verde biodiesel blends. The B20 and B40 blends produced brake power values close to diesel, whereas B60 showed a marked decrease. Higher Cape Verde biodiesel content in B80 and B100 caused further reductions in brake power. The brake power curves for B80 and B100 were almost superimposed, indicating similar output. These findings are consistent with [15], who reported overlapping brake power curves for B80 and B100 when a

ISSN: 2971-7760 | VOL 6, ISS 1 | 22 JULY 2026
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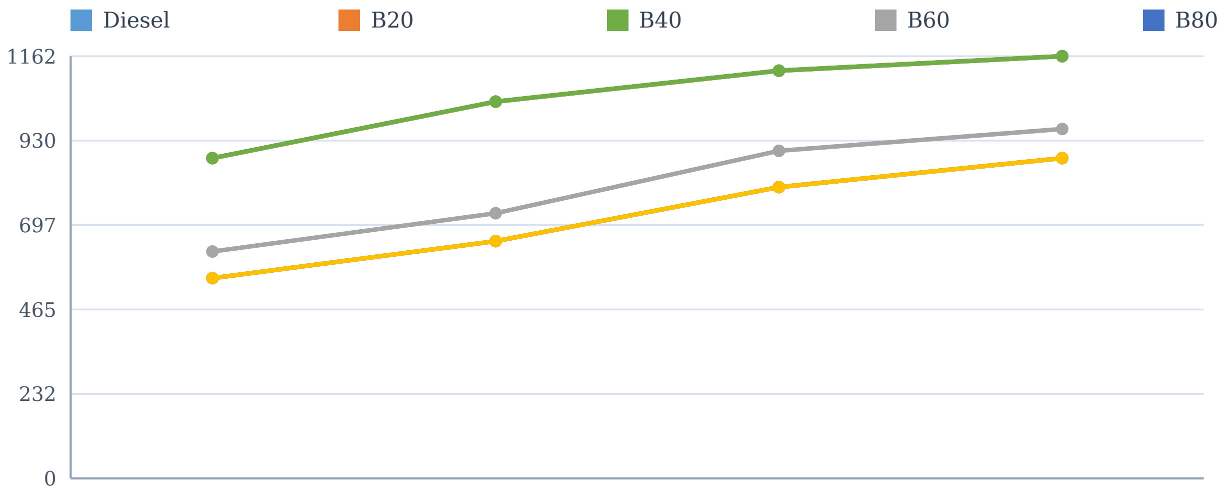
FEDERAL POLYTECHNIC, MUBI-NIGERIA

compression ignition engine was run as a ship or generator engine. [16] likewise found that diesel produced higher brake power than all tested Cape Verde biodiesel blends in automotive applications.

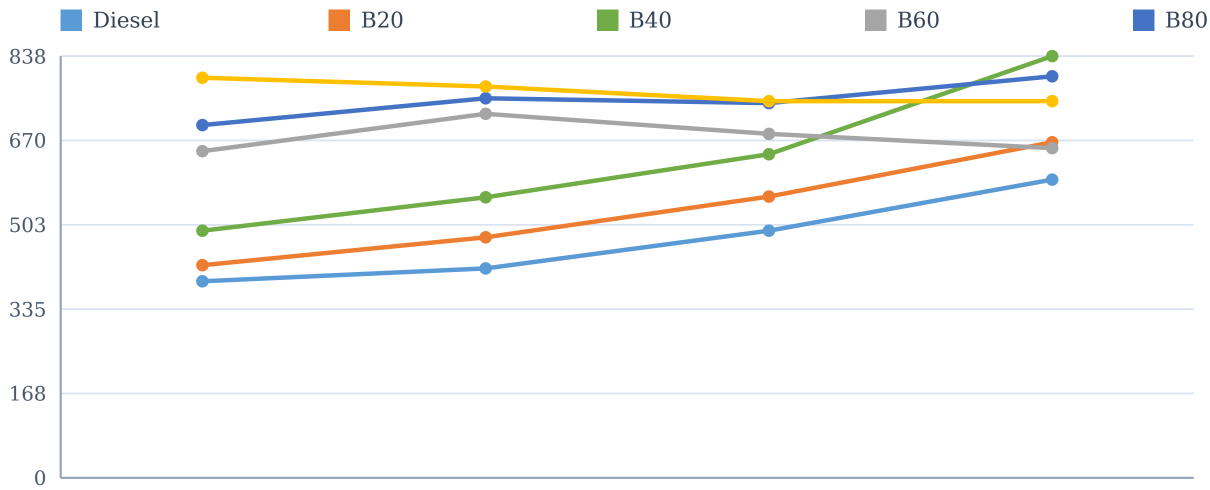
Figure 1: Variation of Brake Power against Torque for Diesel and Tested Blends



5.2 Brake Specific Fuel Consumption

Brake specific fuel consumption increased markedly for diesel, B20, and B40 across all load conditions but remained nearly constant for B80 beyond 5.4 Nm. For B100, fuel consumption decreased with increasing engine load. Overall, fuel consumption rose as the proportion of biodiesel increased at all loads. At the maximum torque of 5.8 Nm, B40 displayed higher fuel consumption than B60, B80, and B100. Among all Cape Verde biodiesel blends, B20 yielded the lowest brake specific fuel consumption at every load. This contrasts with [16], who found that B100 had the minimum brake specific fuel consumption in automotive operation, but aligns with the results of [17].

Figure 2: Variation of Brake Specific Fuel Consumption against Torque for Diesel and Tested Blends



5.3 Brake Thermal Efficiency

Diesel, B20, and B40 all showed a decreasing trend in brake thermal efficiency as load increased. This indicates a reduction in efficiency as more biodiesel was added to the diesel–biodiesel blends, especially B20 and B60. B60, B80, and B100 had very similar brake thermal efficiencies over all load conditions, except at 5.8 Nm, where B100 slightly outperformed B60 and B80 and matched B20. At lower loads, diesel, B20, and B40 clearly exhibited higher brake thermal efficiencies than the higher-percentage Cape Verde biodiesel blends. The maximum brake thermal efficiency among the biodiesel blends was 19.70% for B20, compared with 23.63% for diesel. [18] obtained 16.17% and 22.28% for similar biodiesel and diesel tests in automotive applications. B100 showed marginally lower thermal efficiency than all other Cape Verde biodiesel blends and diesel, in agreement with [1] and [19].

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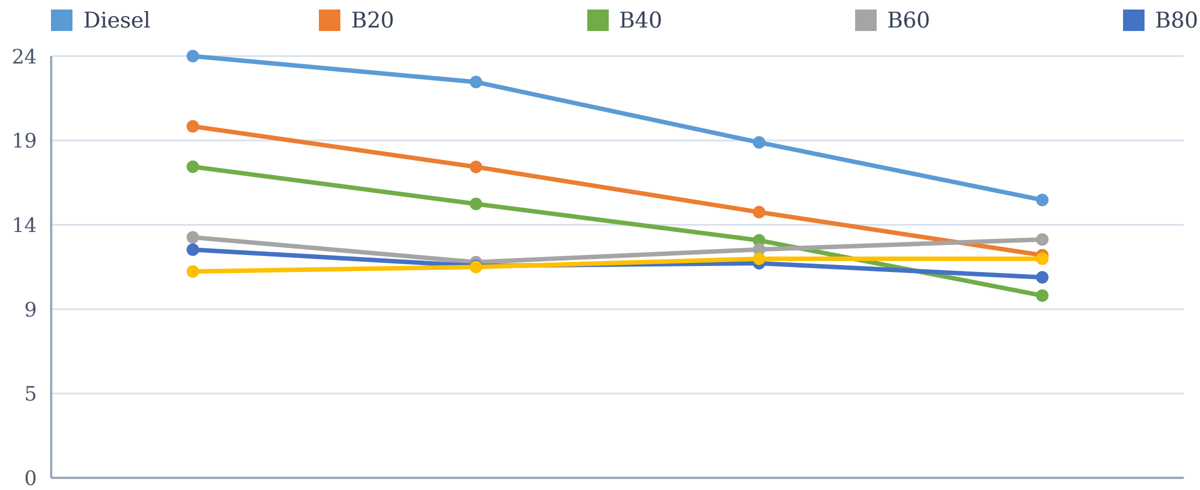
Figure 3: Variation of Brake Thermal Efficiency against Torque for Diesel and Tested Blends



5.4 Engine and Exhaust Gas Temperatures

Diesel consistently produced the highest engine temperatures at all loads compared to the Cape Verde biodiesel blends. For the biodiesel blends, B20 and B40 exhibited nearly identical engine temperature profiles, as did B60 and B80. B100 provided the lowest engine temperature across all load conditions (Figure 4). Regarding exhaust gas temperature, diesel again recorded the highest values. Among the Cape Verde biodiesel blends, B80 yielded the lowest exhaust flue gas temperature, followed by B60, with B40 and B100 showing similar exhaust temperatures. Lower exhaust gas temperatures indicate reduced loss of useful heat through the exhaust, which is beneficial for engine efficiency. These outcomes agree with [18] but contradict [20], who reported higher exhaust temperatures for biodiesel blends than for diesel.

ISSN: 2971-7760 | VOL 6, ISS 1 | 22 JULY 2026
https://doi.org/10.5281/zenodo.21492735
FEDERAL POLYTECHNIC, MUBI-NIGERIA

Figure 4: Variation of Engine Temperature against Torque for Diesel and Tested Blends

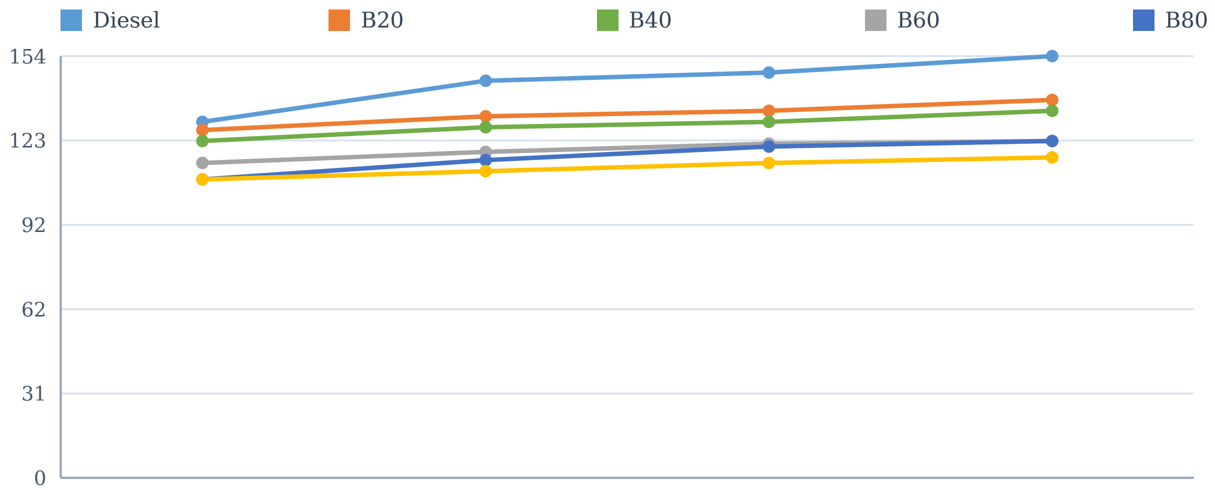
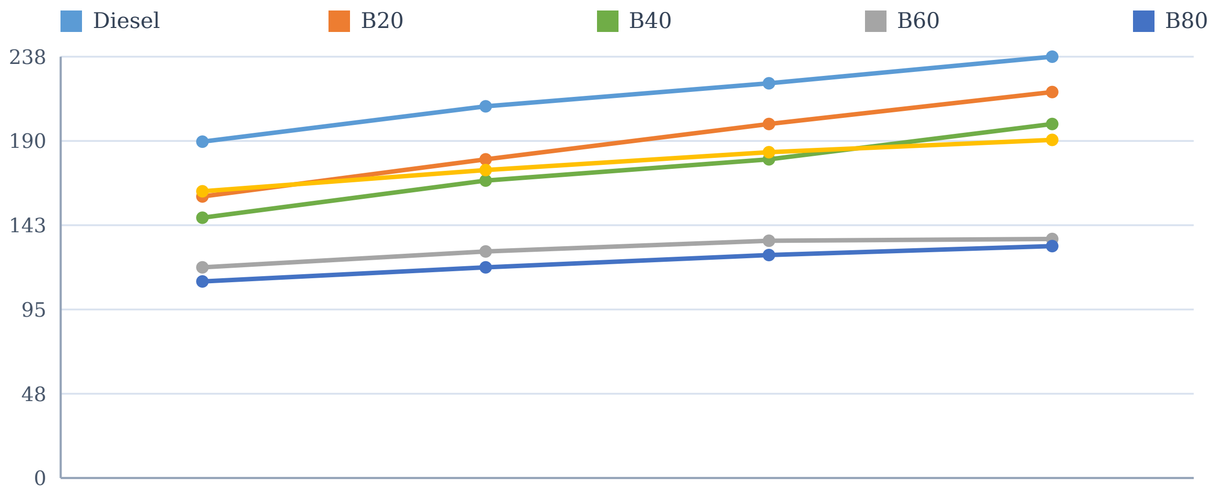


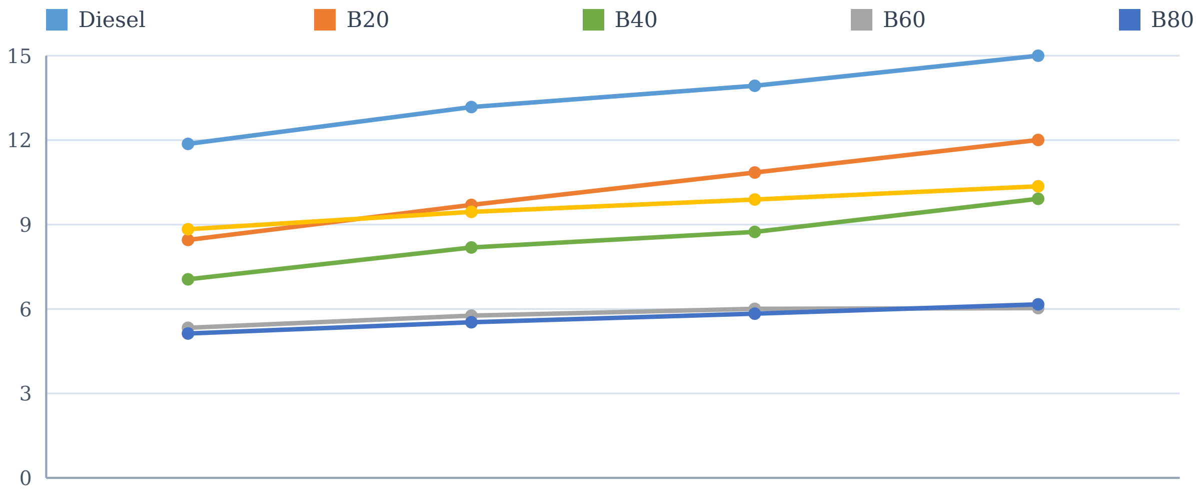
Figure 5: Variation of Exhaust Gas Temperature against Torque for Diesel and Tested Blends



5.5 Percentage Heat Loss to Exhaust

Percentage heat loss to the exhaust increased with engine load for both diesel and biodiesel blends. Diesel showed the highest percentage heat losses. Among the biodiesel blends, B60 and B80 recorded the lowest heat losses. At all load conditions, B100 lost more heat than B40, B60, and B80. Nonetheless, all jatropha blends exhibited significantly lower heat loss to the exhaust compared with diesel. This indicates that the jatropha blends retain more useful heat within the engine, contributing to relatively higher brake thermal efficiencies, a result that aligns with the findings of [13].

Figure 6: Variation of Percentage Heat Loss to Exhaust against Torque for Diesel and Tested Blends



5.6 Air–Fuel Ratio

The air–fuel ratio decreased with rising engine load for diesel and all Cape Verde biodiesel blends. Diesel maintained the highest air–fuel ratio across all loads. Among the Cape Verde biodiesel fuels, B20 had the highest and B40 the lowest air–fuel ratio. Reducing air–fuel ratios at higher blends could be associated with increased emissions and engine noise. Excessively high air–fuel ratios tend to cause high pumping losses and elevated peak cylinder pressures, whereas very low air–fuel ratios can result in poor combustion efficiency, excessive smoke, and high exhaust temperatures, which are undesirable for engine health. During the present study, no jerking, combustion instability, or problems such as burned valves or starting difficulties were observed.

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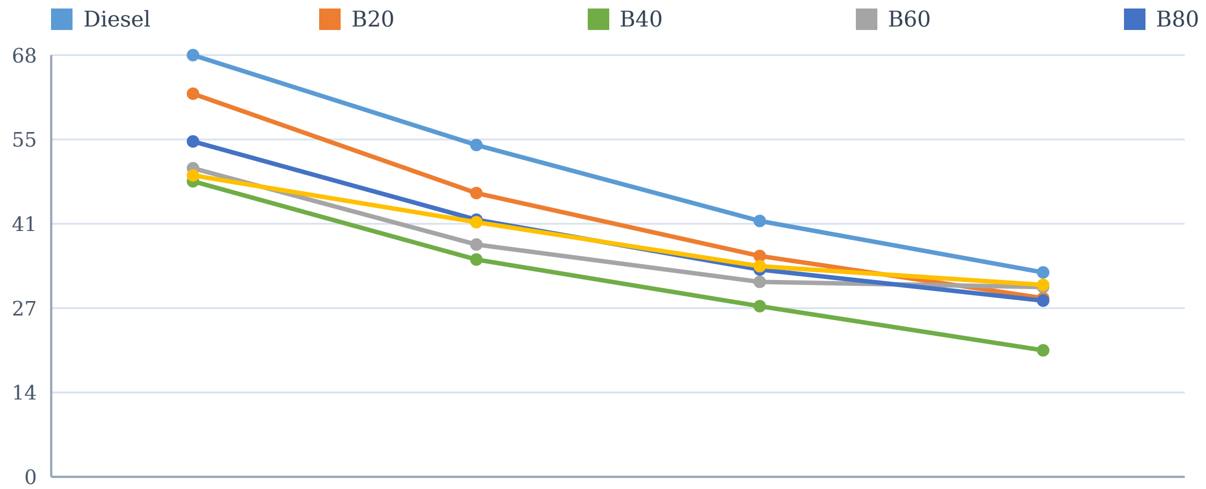
FEDERAL POLYTECHNIC, MUBI-NIGERIA

Figure 7: Variation of Air-Fuel ratio against Torque for Diesel and Tested Blends



5.7 Volumetric Efficiency

Figure 8 shows that volumetric efficiency decreased with increasing load for both diesel and all Cape Verde biodiesel blends. There was no significant difference between diesel and B20, while B40, B60, and B100 displayed slight variations. B100 achieved higher volumetric efficiency than B40 and B60 at all operating conditions. Volumetric efficiency represents the engine's ability to fill its cylinders with intake air. A higher volumetric efficiency implies greater air intake, which generally supports higher brake power and better torque.

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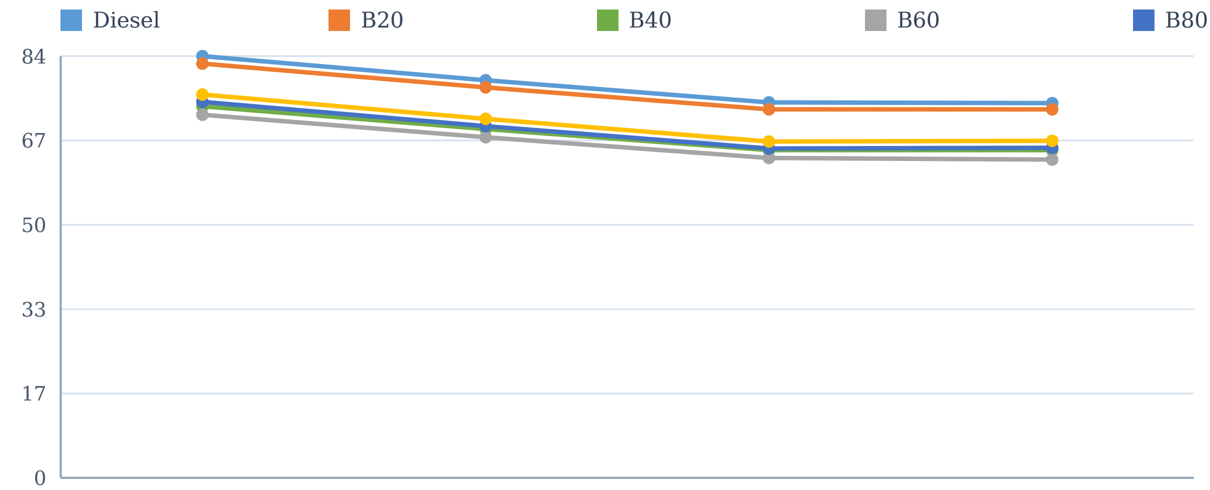
FEDERAL POLYTECHNIC, MUBI-NIGERIA

Figure 8: Variation of volumetric Efficiency against Torque for Diesel and Tested Blends



6.0 Recommendations

Several blends of Cape Verde biodiesel—80/20%, 60/40%, 40/60%, 20/80%, and 100%—were tested on a laboratory-scale, single-cylinder, direct-injection diesel engine under hybrid operation to assess short-term performance and determine key operational parameters at four load conditions. The following recommendations were made:

i. The Cape Verde biodiesel should be used as biodiesel fuel.

ii. The Cape Verde biodiesel B20 blend was found to be a promising replacement for conventional diesel fuel.

iii. The Cape Verde biodiesel blends demonstrate better performance with respect to engine and exhaust gas temperatures.

7.0 Conclusion

Operational parameters of a two-stroke, single-cylinder engine fueled with 80/20%, 60/40%, 40/60%, 20/80%, and 100% Cape Verde biodiesel under hybrid operation indicate that the diesel reference fuel delivers superior performance compared with Cape Verde biodiesel blends in terms of brake specific fuel consumption, brake thermal efficiency, and air–fuel ratio. However, the Cape Verde biodiesel blends demonstrate better performance with respect to engine and exhaust gas temperatures. There was essentially no difference between diesel and B20 in brake power and volumetric efficiency. B100 recorded the lowest engine temperatures among all blends and diesel fuel. For Cape Verde biodiesel blends, B20 can be regarded as a promising replacement for conventional diesel fuel, provided that long-term performance, combustion, and emission studies confirm the absence of adverse effects such as engine starting problems, excessive wear, material incompatibility, or catastrophic failure.

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ISSN: 2971-7760 | VOL 6, ISS 1 | 22 JULY 2026
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