
INVESTIGATION OF THE PHYSICOCHEMICAL PROPERTIES, ENGINE PERFORMANCE AND EMISSION CHARACTERISTICS OF GLYCINE MAX BIODIESEL–DIESEL BLENDS IN A COMPRESSION IGNITION ENGINE

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ABSTRACT

This study investigated the performance and emission characteristics of biodiesel blends produced from Glycine max oil in a compression ignition engine. Biodiesel was produced through transesterification using methanol and potassium hydroxide. The produced biodiesel was blended with conventional diesel at 5% (B5), 10% (B10) and 20% (B20), and burnt in a single-cylinder Kirloskar TV1 diesel engine at speeds of 1200rpm and 1400rpm. Physicochemical properties including density, kinematic viscosity, pour point and flash point were determined. Engine performance parameters such as brake power (BP), brake thermal efficiency (BTE), brake mean effective pressure (BMEP), brake torque (BT) and brake specific fuel consumption (BSFC) were also evaluated. The experimental results showed that increasing Glycine-Max content from 0 – 20% increased the flash point from 71 – 79°C and decreased the kinematic viscosity from 3.327 – 3.269 (mm²/s). While Brake Power (BP) increased with engine speed increase regardless of the blends; the Brake Thermal Efficiency (BTE) decreased with increasing proportion of Glycine-max from 5 – 20% irrespective of the blend. There was decreasing trend for exhaust emissions with increasing biodiesel blend proportions from 5% to 10% and 20% for HC, CO and CO₂. Nitrogen oxide (NO_x) emissions increased slightly with increasing biodiesel content. The findings indicate that Glycine-max biodiesel have potential as renewable substitutes for petroleum diesel in compression ignition engines.

Keywords: Glycine max; Diesel; Biodiesel; Compression Ignition Engine; Engine Performance

1. INTRODUCTION

The increasing global demand for energy, coupled with growing environmental concerns associated with the continued use of fossil fuels, has intensified the search for cleaner, renewable, and sustainable energy alternatives. To address these challenges, many researchers have explored various renewable energy sources, including solar, wind, and biomass, to support future economic development. Although solar and wind energy have shown considerable potential, their dependence on weather and environmental conditions limits their ability to completely replace conventional petro-fuels in the short term. In contrast, biodiesel produced from vegetable and animal oils through transesterification exhibits combustion characteristics comparable to those of petroleum diesel while offering additional advantages such as renewability, biodegradability, and environmental sustainability, making it a promising alternative fuel source (Chuah et al., 2021).

Despite serving as the primary energy source for industrialized societies, fossil fuels have been identified as major contributors to environmental degradation and climate change. The combustion of fossil fuels releases significant quantities of greenhouse gases, including carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), which contribute substantially to global warming. Furthermore, the finite nature of fossil fuel reserves underscores the need for energy diversification, particularly within the transportation and industrial sectors (Pasha et al., 2021).

Extensive experimental and modelling studies have been conducted to investigate the combustion and emission characteristics of diesel engines fuelled with various biodiesel feedstocks. These studies have shown that biodiesel can improve combustion efficiency due to its oxygen content, which enhances oxidation processes in fuel-rich zones and consequently reduces emissions of

particulate matter (PM), carbon monoxide (CO), and unburned hydrocarbons (HC) (Zhang et al. 2022). In addition, biodiesel can be blended with conventional diesel fuel in varying proportions without requiring significant engine modifications. However, biodiesel possesses certain limitations, including higher viscosity, lower calorific value, reduced volatility, and poor cold-flow properties. Moreover, several studies have reported increased nitrogen oxide (NO_x) emissions associated with biodiesel combustion. Consequently, considerable research attention has been directed towards biodiesel–diesel blends as a means of improving fuel properties while maintaining environmental benefits (Dandajeh et al., 2020).

Biodiesel blends are typically designated as BXX, where XX denotes the percentage volume of biodiesel present in the blend. Common examples include B5 (5% biodiesel and 95% petroleum diesel) and B20 (20% biodiesel and 80% petroleum diesel). Previous studies, including that of Kaisan and Pam (2013) and Dandajeh et al, 2020, have demonstrated that biodiesel–diesel blends can achieve reduced carbon dioxide emissions while maintaining satisfactory engine performance in compression-ignition (CI) engines without requiring substantial modifications to existing engine systems.

Since biodiesel is predominantly utilized in compression-ignition engines, understanding the operational characteristics of these engines is essential for evaluating fuel performance. The compression-ignition engine, commonly known as the diesel engine, was invented by Rudolf Diesel in the late nineteenth century. Its operation is based on the principle of auto-ignition, whereby fuel combustion is initiated by the high temperatures generated during air compression within the engine cylinder. Due to their high thermal efficiency and superior torque characteristics, diesel engines are widely employed in transportation, agriculture, construction, and other heavy-duty applications (Heywood, 1988).

Although palm and rapeseed oils have received considerable attention in biodiesel research, the application of glycine max biodiesel blends in compression-ignition engines remains relatively underexplored within the Nigerian context. This gap is aimed at reducing the environmental impacts associated with conventional fossil fuels. The paper presents an experimental investigation of the Physicochemical Properties, Engine Performance Characteristics and emissions of Glycine max Biodiesel–Diesel Blends in a Compression Ignition Engine.

2. METHODOLOGY

The materials used in this study included Glycine max (soybean) oil, petroleum diesel, methanol, potassium hydroxide (KOH), phenolphthalein indicator, distilled water, and ethanol. The chemicals were obtained from the National Institute for Leather Science and Technology (NILEST), Zaria, while diesel fuel was purchased from a commercial filling station in Zaria. The equipment used for biodiesel production and characterization included an electronic weighing balance, burette, glass reactor, heating mantle with magnetic stirrer, water bath, separatory funnel, drying oven, digital viscometer, bomb calorimeter, gas analyzer, thermometer, and measuring cylinders. Engine performance and emission tests were conducted using a single-cylinder compression ignition (CI) engine coupled to an eddy-current dynamometer. The engine specifications are presented in Table 1.

Table 1: Specifications of the Test Engine

Parameter	Specification
Model	Kirloskar TV1
Engine Type	Four-stroke, single-cylinder, water-cooled, direct-injection diesel engine
Bore × Stroke	87.5 mm × 110 mm
Compression Ratio	17.5:1
Rated Power	5.2 kW at 1500 rpm
Displacement Volume	661 cc
Fuel Type	Diesel/Biodiesel
Cooling System	Water-cooled
Starting System	Manual
Loading Device	Eddy-current dynamometer

The free fatty acid (FFA) content of the soybean oil was determined using the standard titration method. Approximately 5.04 g of oil was dissolved in ethanol and titrated against 0.1 N KOH using phenolphthalein as indicator. The average FFA value obtained was 0.25%, indicating that the oil was suitable for direct base-catalyzed transesterification without esterification pretreatment. Biodiesel was produced through alkali-catalyzed transesterification. Methanol and potassium hydroxide were mixed to form methoxide solution and reacted with filtered soybean oil in a three-neck reaction flask.

The reaction was carried out at a temperature of 60–65°C under continuous stirring (600–800 rpm) for approximately 3 hours. After completion of the reaction, the mixture was transferred into a separating funnel and allowed to settle for 48 hours to facilitate separation of biodiesel from glycerol. The biodiesel layer was subsequently washed with warm distilled water until neutral and dried in an oven at 60°C for 24 h. The produced biodiesel was blended volumetrically with conventional diesel to prepare B5, B10, and B20 blends, corresponding to 5%, 10%, and 20% biodiesel concentrations, respectively.

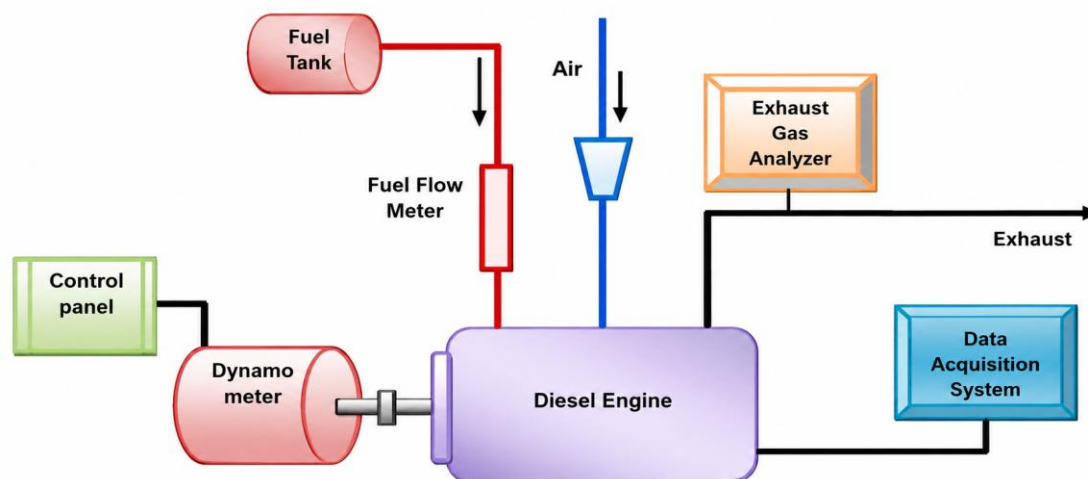


Figure 1: Schematic diagram of the experimental set-up

The physicochemical properties evaluated included density, kinematic viscosity, pour point, flash point, and calorific value. Density was measured using a digital density meter, while viscosity was determined at 40°C using a digital viscometer. Pour point, flash point, and calorific value were determined using standard laboratory procedures.

Engine performance and emission tests were carried out using the Kirloskar TV1 diesel engine coupled with an eddy-current dynamometer. The fuels tested were diesel, B5, B10, and B20. Performance tests were conducted at engine speeds of 1200rpm and 1400 rpm. The performance

parameters evaluated included brake power (BP), and brake thermal efficiency (BTE). Exhaust emissions including carbon monoxide (CO), carbon dioxide (CO₂), nitrogen oxides (NO_x), and unburned hydrocarbons (HC) were measured using a gas analyzer connected to the engine exhaust system.

3. RESULTS AND DISCUSSION

3.1 Physicochemical Properties of Glycine max Biodiesel Blends

The physicochemical properties of Glycine max biodiesel blends, shown in Table 2, were evaluated to determine their suitability for compression ignition engine applications. Table shows that density increased slightly with increasing biodiesel concentration from 1.522 g/cm³ for B5 to 1.532 g/cm³ for B20. This increase is attributed to the higher density of fatty acid methyl esters (FAME) present in biodiesel compared to conventional diesel. Similarly, flash point increased with increasing proportion of biodiesel, indicating improved safety during storage and transportation. For example; The flash point for B5 is 67.5°C, 69.5°C for B10 and 79°C for B20. However, pour point decreased from 28°C for B5, to 24°C for B10 and to 12°C for B20. However, no clear trend was seen for kinematic viscosity. This could be due to the combined effects of biodiesel composition, blending interactions, and experimental variability.

Table 2: Physicochemical Properties of Glycine max Biodiesel Blends

Blend	Density (g/cm ³)	Kinematic Viscosity	Pour Point (°C)	Flash Point (°C)
Diesel	1.142	3.327	10	71
B5	1.522	2.628	28	67.5
B10	1.525	3.279	24	69.5
B20	1.530	3.269	12	79

The kinematic viscosity values of all blends were within the acceptable operating range for diesel engines, suggesting satisfactory fuel atomization and lubrication characteristics. Pour point results showed that pure biodiesel exhibited better cold-flow properties than some of the lower biodiesel blends, indicating the influence of feedstock composition on low-temperature fuel behavior. Overall, the measured fuel properties confirmed that Glycine max biodiesel blends possess characteristics suitable for utilization in compression ignition engines without requiring engine modifications.

3.2 Engine Performance Characteristics

The performance characteristics of the engine fueled with Glycine max biodiesel blends were evaluated in terms of brake power (BP) and brake thermal efficiency (BTE)

Figures 2a) and b) show that brake power increased with increasing engine speed, respectively, from 1200 rpm to 1400 rpm for all fuel blends. For B5 instance, the brake power increased by a factor of 2.25 for increased speed from 1200 -1400rpm. Interestingly Brake Power for diesel and B10 increased by 100% for engine speed increase from 1200 -1400rpm. At lower engine speed of 1200rpm, B10, B20 and diesel exhibited roughly similar brake power due to improved combustion arising from the oxygenated nature of biodiesel.

Fig 3a) and b) show the brake thermal efficiency (BTE) at speeds of 1200rpm and 1400rpm respectively. The results showed that BTE decreased with increasing biodiesel proportion from 5 to 20% regardless of the increased speeds from 1200 - 1400rpm. For example, the BTE of B5 was 39.4%, and it decreased by 18.5% for B20.

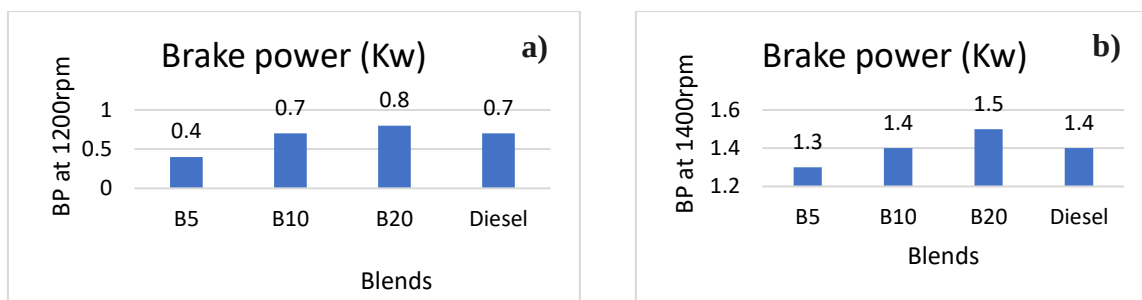


Figure 2: Brake Power (kW) at: a)1200rpm b)1400rpm

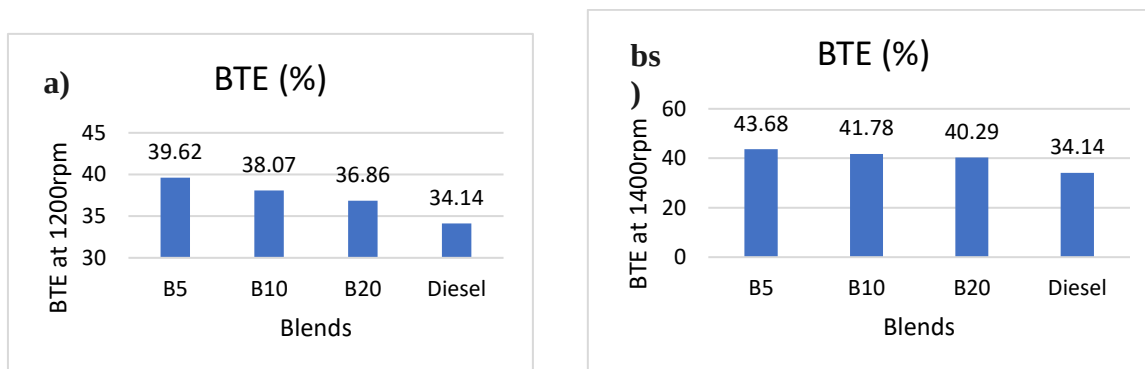


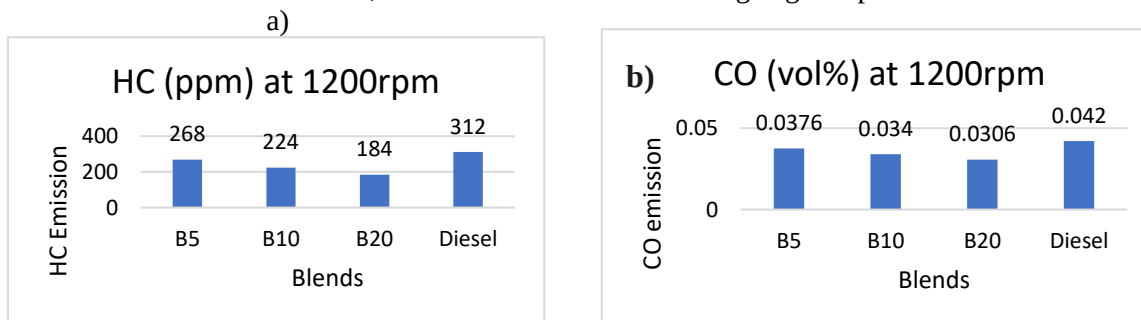
Figure 3: Brake Thermal Efficiency at: a) 1000rpm b) 1200rpm c) 1400rpm

Considering engine speed variations, BTE increased for B10 for example, from 33.6% at 1000rpm to 38.7% at 1200rpm and to 41.78% at 1400rpm. This indicates better conversion of fuel energy into useful work.

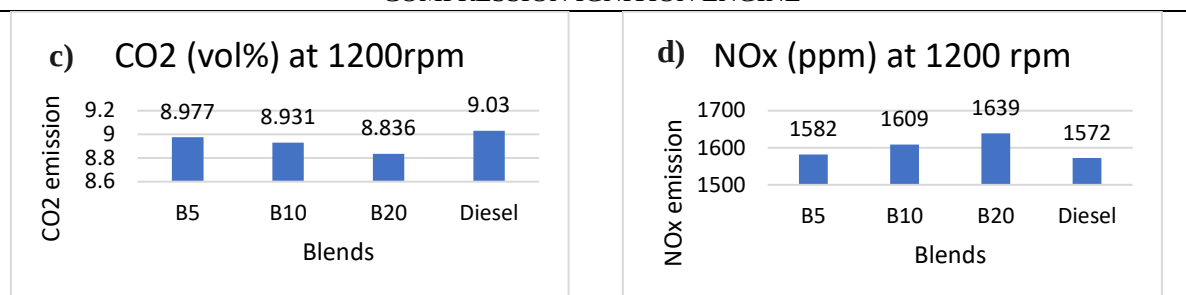
3.3 Emission Characteristics

Figure 4a), b) c) and d) respectively show the results of emission values of Glycine max biodiesel blends of hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO₂), and nitrogen oxides (NO_x) at constant speed of 1200rpm. The results showed decreasing exhaust emissions with increasing biodiesel blend proportions from 5% to 10% and 20% for HC, CO and CO₂. This reduction is attributed to the oxygen content present in biodiesel, which promotes more complete oxidation of fuel during combustion. Figure 4d) shows that only NO_x was seen increasing from 1582ppm for B5, to 1609ppm for B10 and to 1639ppm for B20. This is consistent with previous studies (Dandajeh et al. 2020; Bawa et al. 2023).

Overall, the emission results indicate that Glycine max biodiesel blends can significantly reduce harmful exhaust emissions of HC, CO and CO₂ while maintaining engine operation.



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Figures 4: Exhaust Emissions at 1200rpm a) HC (ppm) b) CO (vol%) c) Nox d) CO₂ (vol%)

Conversely, NO_x emissions exhibited a slight increase with increasing biodiesel concentration. This behavior is commonly associated with higher in-cylinder temperatures and improved oxygen availability during combustion. The enhanced combustion process responsible for lower HC and CO emissions simultaneously promotes thermal NO_x formation.

4. CONCLUSION

1. The Glycine max biodiesel blends exhibited acceptable physicochemical properties: density, viscosity, flash point, and pour point; indicating their suitability for smooth compression ignition engine operation without requiring engine modifications.
2. Brake power increased respectively with increasing engine speed from 1200rpm to 1400rpm for all the fuel blends. Brake power for B5 increased by a factor of 2.25 for increased speed from 1200 -1400rpm
3. Brake Thermal Efficiency decreased with increasing biodiesel proportion from 5 to 20% regardless of the increased speeds from 1200 - 1400rpm.
4. There was decreasing trend for exhaust emissions with increasing biodiesel blend proportions from 5% to 10% and 20% for HC, CO and CO₂. Nitrogen oxide (NO_x) emissions increased slightly with increasing biodiesel content

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