EMISSION CHARACTERISTICS OF DESERT DATE (*BALANITES AEGYPTIACA)* BIODIESEL–KEROSENE BLENDS IN A DOMESTIC KEROSENE STOVE

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ABSTRACT

Growing concerns over the adverse health effects of kerosene emissions, the rising cost of fossil fuels, and the need for sustainable household energy alternatives motivated this research. This study investigates the emission characteristics of Desert Date (Balanites aegyptiaca) biodiesel–kerosene blends used in a domestic kerosene stove. Biodiesel was produced via transesterification and blended with kerosene at varying proportions. Emissions of carbon monoxide (CO), carbon dioxide (CO_2), and unburned hydrocarbons (HC), were measured under steady operating conditions. Results indicate that increasing biodiesel content significantly reduced CO and HC emissions due to improved oxygen availability in the fuel, while CO_2 emissions showed a marginal increase, indicating more complete combustion. Increasing balanites aegyptiaca biodiesel content in kerosene significantly reduced CO and HC emissions, while CO_2 decreased slightly across all blends. ANOVA results confirmed that these differences were statistically significant. Although BB100 produced the lowest emissions, BBK5 is recommended as the most suitable blend, offering cleaner combustion with performance characteristics closest to kerosene. The findings suggest that balanites aegyptiaca biodiesel–kerosene blends can serve as a cleaner alternative fuel for domestic cooking applications.

Keywords: Balanites aegyptiaca biodiesel, biodiesel blends, kerosene stove, emissions, CO, HC, CO_2

1 INTRODUCTION

Kerosene remains a widely used household fuel in developing countries, particularly for cooking applications in regions with limited access to modern energy infrastructure [1]. In Nigeria, its use is prevalent across rural and peri-urban households where cleaner energy alternatives are often unavailable or unaffordable [2]. However, the combustion of kerosene in domestic wick stoves is associated with the emission of harmful pollutants, raising significant environmental and health concerns. Kerosene combustion typically produces pollutants such as carbon monoxide (CO), particulate matter, and unburned hydrocarbons (HC), especially under incomplete combustion conditions [3, 4]. These emissions are particularly dangerous in poorly ventilated indoor environments and have been linked to respiratory illnesses including asthma and bronchitis [5]. The relatively low combustion efficiency of wick stoves further exacerbates pollutant formation, highlighting the need for cleaner fuel alternatives suitable for domestic use [6]. Biodiesel has emerged as a viable alternative due to its renewable nature, low sulfur content, and inherent oxygen composition, which promotes more complete combustion [7, 8]. It is produced through transesterification of triglycerides with alcohol in the presence of a catalyst, yielding fatty acid methyl esters and glycerol [9, 10]. The oxygenated structure of biodiesel contributes to reduced emissions of CO and HC compared to conventional kerosene [11. Among the various biodiesel feedstocks, Balanites aegyptiaca (Desert Date) has attracted attention due to its adaptability to arid environments and its non-edible nature [11]. The seeds contain substantial oil content, typically ranging between 46.7% and 56.7%, making them suitable for biodiesel production [12]. Additionally, the oil exhibits favorable properties that support efficient combustion and compliance with biodiesel standards [13]. Blending Balanites aegyptiaca biodiesel with kerosene offers a practical approach to improving emission characteristics in existing wick stoves. The presence of oxygen in biodiesel enhances fuel oxidation, thereby reducing incomplete combustion products such as CO and HC. However, differences in fuel properties may influence combustion behavior and emission profiles, making it necessary to experimentally evaluate these blends. This study therefore assesses the emission characteristics of Balanites aegyptiaca biodiesel–kerosene blends in a domestic kerosene stove. The study focuses on quantifying carbon monoxide (CO), carbon dioxide (CO_2), and unburned hydrocarbons (HC), and compares the emissions of the blends with pure kerosene as the reference fuel.

2 MATERIALS AND METHODS

2.1 Feedstock collection and oil extraction

The desert date fruits were purchased at Sabon-Gari market located in Zaria, Kaduna State, Nigeria. These seeds, in turn, functioned as the primary raw material for extracting the oil essential for the production of biodiesel. Following collection, the seeds were moved to the processing center within the National Research Institute for Chemical Technology (NARICT), Zaria, Kaduna State, Nigeria. There, they were screened and removed the defective ones and then soaked in a large bowl of water overnight to eliminate the glycoside pulp from the seed coat. The purified seeds were kept at atmospheric temperature for three days, softening the mesocarp and facilitating the easy removal of the kernels. The kernels obtained from the fruits were then grounded into pastes using a pestle and mortar.

2.2 Oil extraction (solvent)

American Society for Testing and Materials (ASTM) ASTM E 2881 was followed. The extraction process was executed using a direct extraction method, wherein both the sample (seed pastes) and the solvent (n-hexane) were combined in a round bottom flask. A quantity of 500g of the sample and 150 ml of the solvent was measured. The extraction utilized a Soxhlet apparatus, with the extractor connected to a glass tube in the middle, then to a condenser above it, and finally placed on a heating mantle, which was set at 50℃. At the conclusion of each one-hour interval, the middle glass tube was disconnected. Subsequently, the round bottom flask containing the solvent, oil, and sample was removed and allowed to cool at room temperature. The sample was then filtered to separate the residue. The filtrate, solvent, and oil were combined in a beaker, allowing the solvent to evaporate by exposure to the atmosphere. The entire process was repeated for another constant mass of 500g until complete extraction was achieved. The pure oil was then extracted and dried on a hot plate set at 100°C for 15 minutes to eliminate any residual solvent present in the oil.

2.3 Biodiesel Production via Transesterification

American Society for Testing and Materials (ASTM) ASTM D 6751 was followed for the production of biodiesel through transesterification process. The *Balanites aegyptiaca* oil was subjected to base transesterification. The calculated amount of NaOH catalyst (NaOH of 1% w/w) and methanol (at 6:1 molar ratio of methanol to oil) were added to the reaction mixture, which was set at a temperature of 65°C and allowed to stand for a reaction time of 60 minutes. The base transesterification was carried out using a 500 ml volume reflux condenser fitted with a thermo-regulator heater and stirrer. One hundred milliliters (100 ml) of *Balanites aegyptiaca* oil was measured into the flask and heated to the specified temperature.

All reactions were carried out at atmospheric pressure with 1wt% sodium hydroxide as a catalyst at a speed of 140 rpm. After the base transesterification process, the reaction mixture was allowed to settle for 24 hours inside a separating funnel to allow clear separation of biodiesel from glycerin by gravity. The layer on the top was the biodiesel, while the bottom layer was the glycerol. Thereafter, the two layers were separated by settling using a separating funnel. The biodiesel separation was carried out by decanting as the glycerol was drained off, while the biodiesel remained. Warm distilled water at 40°C was added to the separated biodiesel, and the mixture was shaken vigorously. The water was allowed to drain through the bottom of the separating funnel. This process was carried out five times until clear biodiesel was obtained. Anhydrous CaC_{12} (at a 1:5 CaC_{12} to biodiesel weight ratio) was added to the biodiesel and kept in an oven at 50˚C for 30 minutes. The anhydrous CaC_{12} was then separated from the biodiesel by filtration to obtain clear, dry biodiesel. The weight of the biodiesel obtained from the sample was determined, and the percentage yield of biodiesel was calculated using equation (1). Physicochemical properties such as density, viscosity, flash point, specific gravity, calorific value and color were determined according to ASTM D6751 standards.

$$\text{Biodiesel Yield (\%)} = \frac{WBS}{WBS} \times 100 \qquad 1$$

Where WBS = weight of biodiesel after separation. WBO = weight of *Balanites Aegyptiaca* oil used for the transesterification [11].

2.4 Preparation of Biodiesel–Kerosene Blends

The biodiesel was blended with conventional kerosene in varying proportions by volume to create the following blends (plate 1}. BBK0: This contained 100% kerosene by volume. BBK5: This blend contained 5% *Balanites* biodiesel and 95% kerosene by volume. BBK10: This blend contained 10% *Balanites* biodiesel and 90% kerosene by volume. BBK15: This blend contained 15% *Balanites* biodiesel and 85% kerosene by volume. BBK20: This blend contained 20% *Balanites* biodiesel and 80% kerosene by volume. BB100: This contained 100% biodiesel by volume. Blending was carried out at ambient temperature, and the mixtures were stirred thoroughly to ensure homogeneity.

Plate 1. Pure biodiesel, pure kerosene and their blends

2.5 Stove Design and Test Setup

The procedure employed for this estimation was succinctly outlined as follows: A 2kg, 1-liter capacity kerosene stove (NR33 Model) equipped with 10 wicks was used. The blend, BBK5 (5% Biodiesel and 95% Kerosene), was filled to approximately 25% of the fuel tank's capacity. All ten wicks were ignited, and the time required to achieve a steady flame was recorded. Special attention was given to the ignition behavior of 100% biodiesel (BB100) to determine whether it could sustain combustion. An aluminum vessel was chosen for the experiment. A thermometer (Ranged from 0 to 300 degrees) was employed to monitor the water temperature throughout the experiment. To ensure the even distribution of heat, an aluminum stirrer was crafted and used in agitating the water. Weight measurements of both water and the stove were conducted using an electronic weighing balance with a minimum measurement increment of 1 gram. The procedure was conducted according to [3].

2.6 Emissions characteristics of the blends

American Society for Testing and Materials (ASTM) ASTM D 7036-16 was followed. Portable gas analyzer had been calibrated and set up according to the manufacturer's instructions. It was correctly zeroed and measured the concentrations of carbon monoxide (CO), carbon dioxide (CO_2), and hydrocarbons (HC) emissions. The kerosene stove was prepared in a laboratory with six different set of wicks, and BBK5 blend (5% *Balanites aegyptiaca* biodiesel and 95% kerosene) was initially used and the gas analyzer was positioned near the stove at a safe distance (Plate 2). The sampling probe or inlet was placed to capture emissions directly from the stove through the exhaust output which was incorporated at the top of the hood tied to the laboratory clamp. The kerosene stove was lit and allowed to reach a stable operating condition. It operated under typical usage conditions during the test, and the gas concentrations were recorded in parts per million (ppm) and percentage (%) respectively, as specified by the gas analyzer's guidelines. Accurate records of the emissions concentration readings for each measured gas were carefully maintained. This process was repeated three times each for all the samples of the fuel blends.

Plate 2. Experimental Set-up

3 RESULTS AND DISCUSSION

3.1 Emissions Characteristics

The emission characteristics of Balanites biodiesel–kerosene blends revealed important environmental implications for their suitability as domestic fuels in kerosene stoves. Figures 1 to 3 show how progressive blending of Balanites biodiesel with kerosene influenced the emission levels of carbon monoxide (CO), unburned hydrocarbons (HC), and carbon dioxide (CO_2), with BBK0 (pure kerosene) serving as the reference fuel.

3.2 Carbon Monoxide (CO) Emissions

A consistent reduction in CO emissions was observed with increasing biodiesel concentration (Figure 1). Compared to BBK0 (0.10%), CO emissions declined steadily across the blends, reaching 0.02% for BB100 (pure biodiesel). This reduction reflects the oxygenated molecular structure of biodiesel, which enhances oxidation of carbon and promotes more complete combustion. Similar findings were reported by [14].

3.3 ANOVA Interpretation (Table 1)

The analysis of variance ($F = 2.49 \times 10^{31} >> F_{crit} = 3.11$, $p \approx 0.00$) shows highly significant differences ($p < 0.05$) in CO emissions among the blends. This indicates that biodiesel addition substantially influences CO formation. Although BB100 yielded the lowest CO, BBK5 displayed a CO value (0.09%) closest to BBK0, signifying combustion characteristics most similar to kerosene. Therefore, BBK5 can be considered a practical and cleaner substitute for kerosene, maintaining stable combustion while lowering CO output which is in consonance with [4].

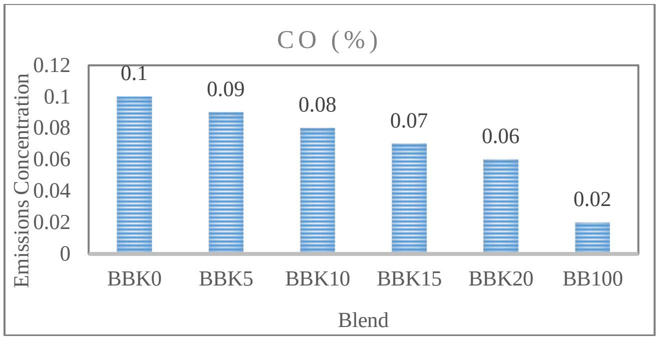

Figure 1. CO Emissions of Pure biodiesel, pure kerosene and their blends

Table 1. ANOVA for CO Emissions

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.012	5	0.0024	2.49E+31	1.2E-185	3.105875
Within Groups	1.16E-33	12	9.63E-35			
Total	0.012	17				

3.4 Unburned Hydrocarbon (HC) Emissions

Unburned hydrocarbon emissions also decreased consistently with increasing biodiesel fraction (Figure 2). HC levels dropped from 23.7 ppm (BBK0) to 9.7 ppm (BB100). This trend reflects more complete combustion due to the inherent oxygen content of biodiesel. Comparable reductions in HC emissions have been reported for biodiesel blends from jatropha and coconut oil. [15, 16].

3.5 ANOVA Interpretation (Table 2)

The ANOVA test revealed a statistically significant difference among blends ($F = 222 \gg Fcrit = 3.11$, $p = 2.16 \times 10^{-11}$). This strong significance confirms that increasing biodiesel concentration has a major effect on HC reduction. While BB100 achieved the cleanest combustion, BBK5 again performed favorably, reducing HC by nearly 9% relative to BBK0 while preserving stable burning. Its moderate biodiesel content ensured improved oxidation without adversely affecting combustion stability, positioning BBK5 as a cleaner and efficient compromise fuel.

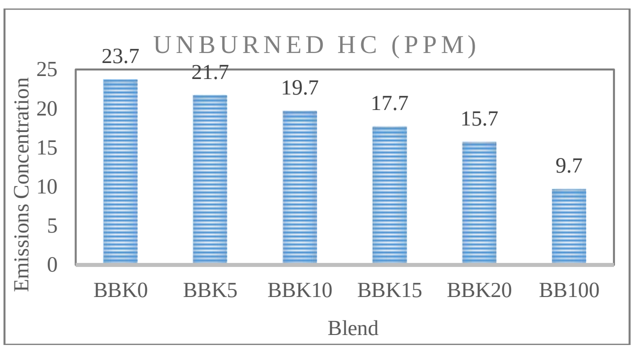

Figure 2. Unburned HC Emissions of Pure biodiesel, pure kerosene and their blends

Table 2. ANOVA for unburned HC emissions

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	370	5	74	222	2.16E-11	3.105875
Within Groups	4	12	0.333333			
Total	374	17				

3.6 Carbon Dioxide (CO_2) Emissions

CO_2 emissions decreased progressively with increasing biodiesel content (Figure 3). Values declined from 4.32% for BBK0 to 4.10% for BB100, indicating a lower carbon intensity of Balanites biodiesel. These findings agreed with [17, 18].

3.7 ANOVA Interpretation (Table 3)

The results show F = 583.37 >> Fcrit = 3.11 ($p = 6.9 \times 10^{-14}$), confirming a highly significant difference ($p < 0.001$) among blends. This validates that biodiesel proportion strongly influences CO_2 emissions. Although CO_2 decreased progressively across blends, BBK5 again maintained emission characteristics closely aligned with BBK0, implying similar combustion completeness but lower carbon output—an ideal balance between performance and environmental impact.

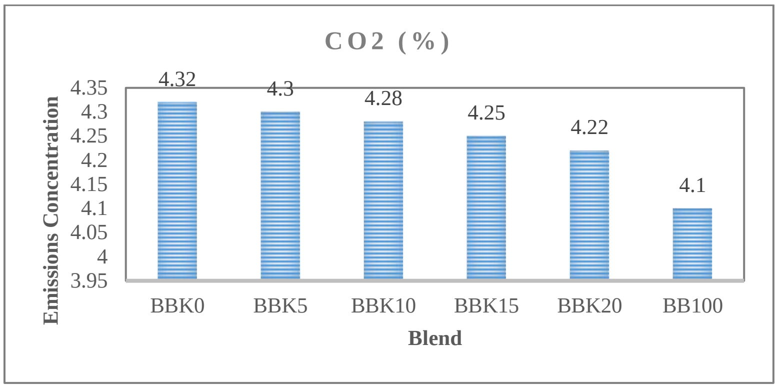

Figure 3. CO_2 Emissions of Pure biodiesel, pure kerosene and their blends

Table 3. ANOVA for CO_2 emissions

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.097228	5	0.019446	583.3667	6.9E-14	3.105875
Within Groups	0.0004	12	3.33E-05			
Total	0.097628	17				

4 CONCLUSIONS

Increasing Balanites aegyptiaca biodiesel content in kerosene significantly reduced CO and HC emissions, while CO_2 decreased slightly across all blends. ANOVA results confirmed that these differences were statistically significant. Although BB100 produced the lowest emissions, BBK5 is recommended as the most suitable blend, offering cleaner combustion with performance characteristics closest to kerosene.

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