

Production and performance evaluation of Biodiesel from Atili (*Canariul Schwrinfurthii*) seed

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Abstract:

The process of producing biodiesel from Atili's non-edible oil involved transesterification, a method that combined crude oil with methanol and NaOH as catalyst. The resulting biodiesel exhibited vital fuel properties: a specific gravity of 0.860, a relative density of 860 kg/m³, a viscosity of 5.14, a flash point of 128 at 60°C, a calorific value of 3700 kg/kg and an impressive cetane number of 49. Furthermore, emission quality measurements of the produced biodiesel indicated specific percentages: 0.20% for O₂, 0.015% for CO, 4.03 for NO_x, 2.3 for SO_x, and CO₂. Upon comparing these characteristics with conventional petrol diesel fuel properties and emission quality standard limits, it was evident that the biodiesel derived from Atili seed oil closely aligned with the benchmarks of standard Conventional diesel. This alignment suggests the potential of Atili biodiesel as a viable alternative fuel for conventional diesel engines, affirming its compatibility within the existing framework of diesel engine operations.

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1. Introduction

Biodiesel serves as a beacon of hope in the pursuit of sustainable energy solutions. It represents a paradigm shift towards renewable, eco-friendly fuel derived from an array of sources including vegetable oil, animal fat, tallow, and waste cooking oil. This transformational process, known as transesterification (TE), taps into oilseeds like rapeseed, Atili, palm, or soybean as primary sources. The environmental virtues of biodiesel are manifold. Its 'carbon-neutral' nature, producing minimal carbon dioxide (CO₂) compared to fossil diesel, marks a pivotal advantage. This biofuel's non-toxicity and higher flash point further set it apart from conventional diesel. In Nigeria, a rich tapestry of oilseed cultivation spans both edible and non-edible varieties. To circumvent competition with food crops, there's a resounding recommendation to prioritize non-edible oilseeds for fuel production, a step poised to amplify the sustainable impact of biodiesel production [1].

The global energy landscape stands at a critical juncture. Non-conventional energy sources are emerging as pivotal players, set to significantly bolster national economies [2]. The narrative of depleting non-renewable fuels intertwines with escalating energy demands, under the shadows of pressing factors like Middle East crises and stock market fluctuations, which have relentlessly driven oil prices to staggering heights, hovering around 39.55 dollars per barrel. This economic strain raises concerns about potential stagnation in the global economic machinery [3].

The narrative of dwindling world petroleum reserves converges with burgeoning environmental apprehensions, steering humanity's gaze towards alternatives to petroleum-based fuels. Scientific revelations portraying a concerning rise in Earth's surface temperature, predominantly attributed to human activities, accentuate the urgency of pivoting towards alternative energy sources [4]. Chemical compounds like carbon dioxide (CO₂) and black carbon hold substantial culpability in exacerbating global warming. The remedy lies in the concerted development and implementation of innovative technologies harnessing renewable energy resources, paving the way for a more sustainable and environmentally benign energy matrix [5].

The concerted efforts to safeguard dwindling reserves of crude oil and fossil fuels manifest in ongoing endeavors to foster alternative energy sources [6]. The global surge in population and urbanization patterns directly influences energy demands, predominantly met by crude oil and fossil fuels across nations. However, the limitations inherent in these sources, from their finite supply to their detrimental environmental footprint, underscore the indispensable need for a proactive shift towards renewable fuel sources [7].

The integration of Atili seed oil in biodiesel production can create employment avenues for the youth. The process involves various stages, from cultivation to extraction and processing, presenting opportunities for skill development and employment for young individuals within the agricultural and biodiesel production sectors. By leveraging Atili seed oil for biodiesel production, this initiative not only contributes to the renewable energy sector but also addresses waste

management, supports local economies, and offers avenues for youth employment, fostering a more sustainable and inclusive socio-economic environment. The future trajectory of biodiesel rests upon the sustainable production of feedstocks to ensure continued cost competitiveness without encroaching on land crucial for food production or damaging natural ecosystems. With its clean emissions profile, user-friendly nature, and multifaceted advantages, biodiesel stands as one of the most rapidly growing alternative fuels globally. Its economic competitiveness with petroleum diesel, even with minimal subsidy, has attracted millions of users who have experienced and enjoyed its tangible benefits. This renewable, cost-effective fuel is poised to play a pivotal role in addressing the escalating shortages of petroleum while delivering substantial economic and environmental dividends well into the 21st century [3].

2. Materials and methods

2.1 Materials for Atili biodiesel production

Experimental Arrangement: The assessment of the Atili biodiesel's performance was conducted using a four-stroke single-cylinder engine connected to an electric dynamometer. This engine setup was meticulously assembled, including a coupling to mount it on a rigid frame. Instruments such as a tachometer for RPM readings, U-tube manometer, an air filter, a fuel measuring tube and a gas analyzer were integrated into the arrangement for precise measurements and analysis during the experiments.

2.2 Gas Analyzer

The Gas Analyzer with specification No. IMR 1400 model is specifically designed to sample emission by-products directly from the combustion chamber. It provides precise measurements for various parameters, including:

- Flue gas temperature
- Excess air
- Carbon dioxide (CO₂)

- Carbon monoxide (CO) calibrated to (Corrected to 0% O₂)
- Nitrous oxide (NO_x) calibrated to (Corrected to 0% O₂)
- Sulfur oxide (SO_x) calibrated to (Corrected to 0% O₂)
- Combustion efficiency

The methodology employed in this study encompassed the following steps for the traditional extraction of Atili oil:

2.3 Methods

2.3.1 Preparation and Washing

The harvested fruits were carefully sorted to eliminate any impurities or foreign materials. Subsequently, they were thoroughly washed with cold water to remove surface dirt. Following this, the fruits were gathered in a clean container [7].

2.3.2 Softening the Fruits

Hot water, maintained at 65°C, was poured over the fruits in the container and left undisturbed for 5 minutes. This process aimed to soften the fruit tissues for easier extraction.

2.3.3 Extraction Process

Using a mortar and pestle (as depicted in Figure 2), the softened fruit pulp was manually beaten for approximately 10 minutes. The resultant pulp was then sun-dried for a duration of 2 days to eliminate residual moisture.

2.3.4 Mixing and Oil Extraction

The dried pulp was mixed with a small quantity of cooled water within a clay pot and allowed to rest for a day. Afterward, hot water at 100°C was poured into the mixture and stirred for 10 to 15 minutes. This action facilitated the release of oil, which surfaced due to gravity differences. The oil was then carefully scooped out using a spoon for subsequent refinement processes. The flow diagram of activities involved in the process are shown in Figure 1.

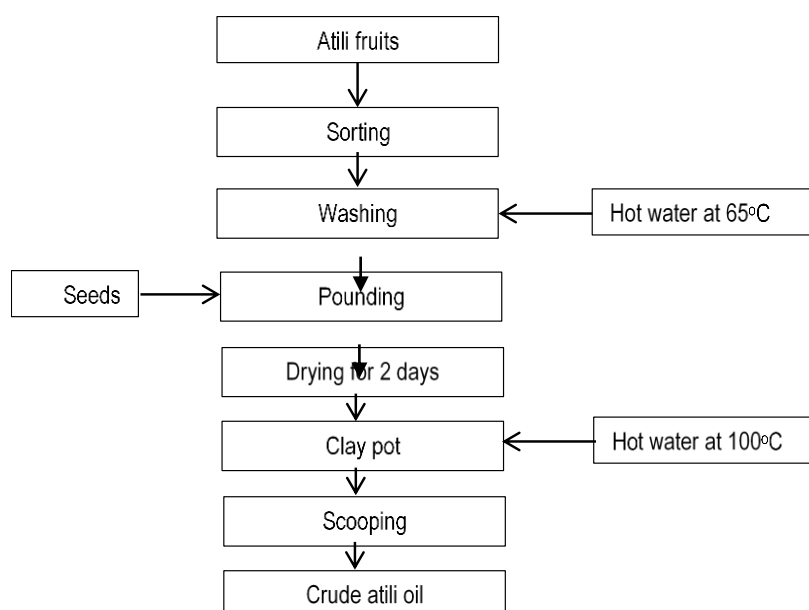


Figure 1 showing the flow chart of traditional method of Atili oil extraction

2.4 Characterization

The Atili oil underwent a thorough analysis at the NAFDAC laboratory in Maiduguri to gauge its properties, following precise methodologies outlined by [6 and 8]. Transforming the Atili seed oil into biodiesel involved a two-step procedure. Initially, an acid-catalyzed esterification reaction was followed by a base-catalyzed transesterification process. Analysis revealed a higher level of free fatty acids in the oil, a common characteristic in some oils. However, oils with free fatty acid values exceeding 1.5% of their mass need esterification prior to transesterification to prevent excessive catalyst usage [9, 12].

To commence, a specific quantity of anhydrous NaOH was combined with methanol and stirred until completely dissolved. Subsequently, 50g of the oil (triglyceride) was placed in a 250 cm³ conical flask and heated to 40°C to reach an equilibrium temperature. The methanolic NaOH solution was then introduced to the oil, and the resulting blend was stirred using a magnetic stirrer on a hotplate at 50°C for 60 minutes. This mixture was then transferred to a separating funnel mounted on a stand, allowing gravity to naturally separate the contents overnight. This separation resulted in a dark green liquid containing glycerol and impurities, distinct from the lighter yellowish, lower-density biodiesel that drained from the funnel. Additional methanolic NaOH solution was added to the fatty acid methyl ester mixture in the separating funnel and stirred for another 30 minutes. The mixture was left to stand overnight, facilitating a gradual separation process



Figure 2. Characterization of Atili oil biodiesel

In the characterization process of Atili oil biodiesel (Figure 2), sodium hydroxide was introduced to methyl alcohol to create sodium methoxide. Simultaneously, the oil was heated in a separate vessel within the

transesterification reactor while being stirred. Once the oil temperature hit 60°C, it was blended with the sodium methoxide and stirred for ninety minutes.

After the reaction concluded, the resulting mixture was transferred to a separating funnel for glycerol and methyl ester settling over 8-10 hours. Post-settling, manual separation removed raw glycerol from the methyl esters. These esters underwent a thorough hot water wash to eliminate any lingering traces of sodium hydroxide. Neutralization of the biodiesel was achieved by adding phosphoric acid. The washed product was distilled to eliminate moisture, yielding a premium-quality biodiesel. This final product was subjected to rigorous chemical analysis to determine its physico-chemical properties, a comprehensive procedure carried out at NAFDAC Maiduguri.

3. Result and discussions

3.1 Atili Oil extraction result

The oil extraction process employs traditional methods. In this experiment, 49 kilograms of Atili seed were used, resulting in the extraction of 15 liters of oil, yielding approximately 30.6%. The extracted oil appears dark green with an unpleasant odor. The characteristics and chemical composition of the Atili oil are as detailed in Table 1 and 2

Table 1: Characteristics of Atili Oil

Test performed	Results
Physical Test:	
Yield:	28.01%
Appearance:	Dark green oil
Net volume (ml):	-
Taste:	Sugary
Odor:	Un-objectionable
Colour:	Dark green
Physio-Chemical test:	
Volatile matter at 105°C (%)	1.7728
Saponification value (mgKOH/g)	193.4000
Iodine value (mg iodine/100g)	19.9000
Peroxide value (meq/Kg)	6.0000
Acid value (%)	0.6097
PH (ambient)	4.4940
R.I @27°C	1.4690
Specific gravity at 25°C	0.9150
Protein (%)	2.6250
Soap content (%)	0.0002

3.2 Atili oil Biodiesel Result

The Atili oil underwent transesterification to produce Atili oil biodiesel, followed by a distillation process to eliminate moisture. This process yielded approximately 86.48%, resulting in a high-quality biodiesel product that underwent subsequent chemical analysis. The comparative physico-chemical properties of Atili methyl ester and diesel are presented in Table 3.

Table 3 highlights the suitability of Atili oil biodiesel as an alternative to fossil fuels, focusing on its properties such as moisture content, density, viscosity, flash point, fire point, calorific value, and cetane number. These properties align with the standard specifications outlined in ASTM [10 and 13], indicating that Atili oil biodiesel meets the requisite benchmarks for efficient utilization as a fuel alternative.

Table 2: The GCMS chemical composition of Atili oil (biodiesel).

Peak	Component Name	Component Formula	% Composition
1	2-Ethyl-2-Hexanal	C ₈ H ₁₄ O	0.26
2	Methyl Octanoate	C ₉ H ₁₈ O ₂	0.49
4	Methyl tridecanoate	C ₁₄ H ₂₈ O ₂	0.34
5	Methyl myristate	C ₁₅ H ₃₀ O ₂	0.89
6	Methyl tridecanoate	C ₁₄ H ₂₈ O ₂	0.38
7	Methyl hexadecanoate	C ₁₇ H ₃₄ O ₂	6.53
8	Methyl 14-methylpentadecanoate	C ₁₇ H ₃₄ O ₂	13.50
9	Methyl isoheptadecanoate	C ₁₈ H ₃₆ O ₂	0.49
10	Methyl linolelaidate	C ₁₉ H ₃₄ O ₂	6.49
11	Methyl linolelaidate	C ₁₉ H ₃₄ O ₂	34.06
12	Methyl octadecenoate	C ₁₉ H ₃₈ O ₂	9.51
13	linoleic acid	C ₁₈ H ₃₂ O ₂	3.69
14	Methyl linolenate	C ₁₉ H ₃₂ O ₂	2.45
15	10-Undecinal	C ₁₁ H ₂₀ O	3.43
16	Methyl ricinolate	C ₁₉ H ₃₆ O ₃	4.28
17	Methyl eicosanoate	C ₂₁ H ₄₂ O ₂	3.57
18	2,6,6-Trimethyl Pinanol	C ₁₀ H ₁₈ O	2.66
19	Methyl 11,14,17-icosatrienoate	C ₂₁ H ₃₆ O ₂	1.36
20	Methyl-5,8- octadecadienoate	C ₁₉ H ₃₄ O ₂	1.00
21	Methyl behenate	C ₂₃ H ₄₆ O ₂	1.29
22	Methyl heneicosanoate	C ₂₂ H ₄₄ O ₂	0.23
23	6,9-pentadecadien-1-ol	C ₁₅ H ₂₈ O	1.17
24	Methyl heneicosanoate	C ₂₂ H ₄₄ O ₂	0.23
25	Supraene	C ₁₅ H ₃₀	0.78

Table 3: The physio- chemical properties of Atili methyl Ester compare with diesel

Fuel Property	Diesel (B0)	Atili (B100)
Specific Gravity	0.84	0.860
Density (Kg/m ³)	840	860
API Gravity	40.24	29.3
Ash Content (%)	0.060	0.094
Water Content (%)	0.070	NA
Carbon residue (%)	0.080	0.530
Flash Point (°C)	66	128
Pour Point (°C)	15	7
Fire Point (°C)	72	134
Calorific Value (KJ/Kg)	44000	37700
Viscosity (cSt)	4.2	5.14
Cetane Number	48	49
Stoichiometric AFR	14.45	12.7

3.3 Engine performance Test

3.3.1 Brake Power

At the engine's lowest speed of 1000 rpm, the brake power showed nearly uniform levels across different blends. However, with an increase in blend percentage, there was a discernible uptick in brake power concerning engine speed, as demonstrated in Figure 3. B0% exhibited minimal variance in brake power at varying speeds. Conversely, B10%, B20%, B30%, B40%, and B50% showed slightly amplified variations in brake power relative to engine speed, indicating a proportional increase in brake power as engine speed climbed. Diesel, in comparison, registered the lowest brake power, likely due to insufficient oxygen in the intake charge pre-combustion, resulting in reduced output and performance. The presence of oxygen within biodiesel's composition notably elevates the combustion process within the engine, a trend that corroborates with the findings of [11].

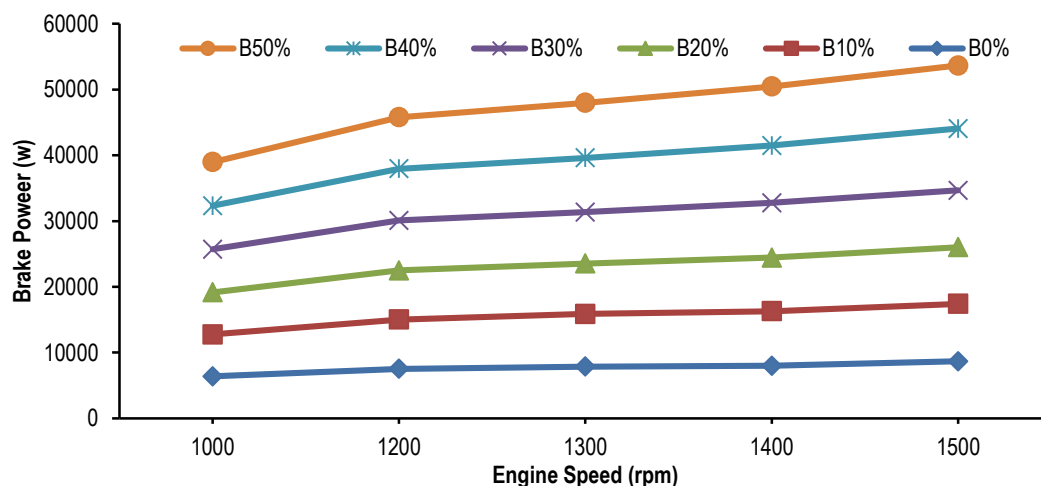


Figure 3. The brake power (W) with the corresponding engine speed (rpm)

3.3.2 Torque

At lower engine speeds of approximately 1000rpm, the torque remains fairly consistent across the various blend percentages. However, as the engine speed increases, accompanied by a rise in the blend percentage of B10%,

B20%, B30%, B40%, and B50%, there is a distinct decrease in torque observed between the lowest and highest speeds of 1000rpm and 1500rpm, respectively as depicted in figure 4. Conversely, B0% displays minimal torque fluctuation concerning engine speed, this may be attributed to the absence of Atili oil biodiesel in this particular blend.

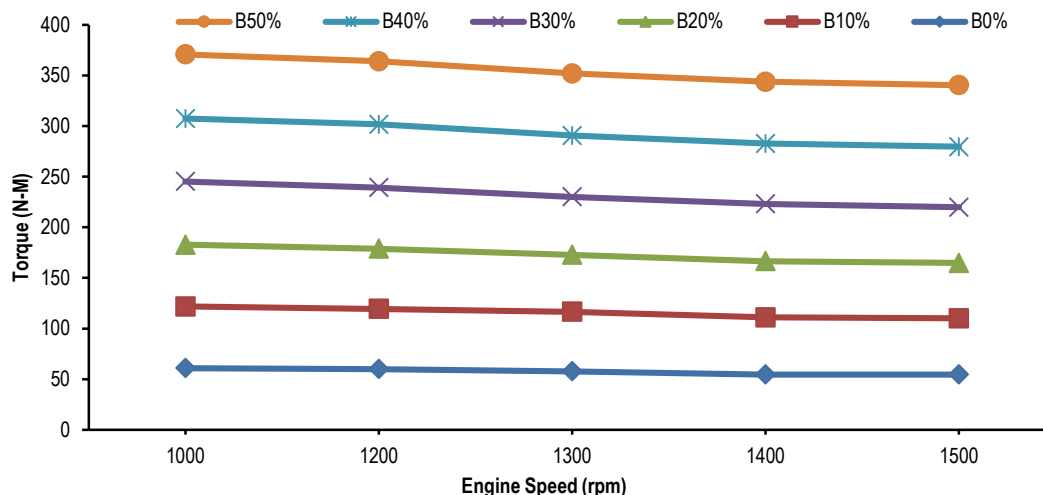


Figure 4: Torque (N/M) with the corresponding engine speed (rpm)

3.3.3 Brake mean effective pressure

Torque and Brake Mean Effective Pressure (BMEP) have a direct correlation with engine size. The incorporation of biodiesel into fossil diesel introduces oxygen, fostering a more favorable combustion of fuel, as noted in the study by

[13]. This improved combustion, attributed to the presence of biodiesel, influences torque and BMEP, which are significant factors influenced by the characteristics and composition of the fuel used in an engine as shown in figure 5.

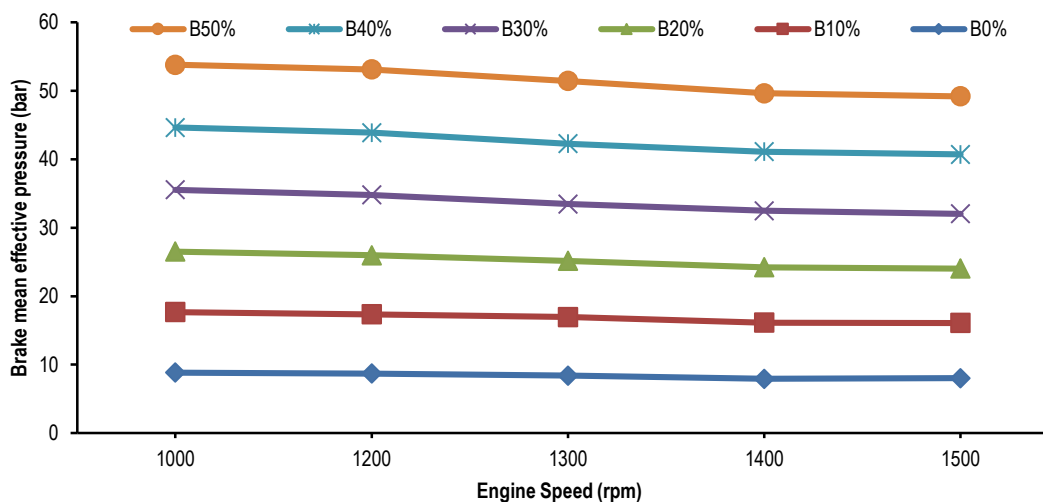


Figure 5: The brake mean effective pressure (bar) with the corresponding engine speed (rpm)

3.3.4 Volumetric efficiency

Figure 6 illustrates that the volumetric efficiency experiences a mild impact with the rise in blends of fossil diesel and biodiesel. The highest peak of 95 in volumetric efficiency was observed in the Atili oil blend B50% at an engine speed of 1500 rpm, while the lowest volumetric efficiency of 10.09% was recorded for fossil diesel (B0%). This observation aligns with findings in [13 and 15], indicating an inverse relationship between volumetric efficiency and engine speed.

3.3.5 Consumption rate

Observing Figure 7 it's evident that as speed increases, fuel consumption decreases. Interestingly, Atili biodiesel in the B50 blend exhibits notably lower consumption compared to diesel fuel. This reduced consumption in Atili biodiesel blends might be attributed to the presence of oxygen within the fuel mixture. At lower speeds, the higher viscosity of Atili biodiesel could result in incomplete combustion, necessitating an additional fuel-air mixture to achieve a comparable power output to diesel fuel.

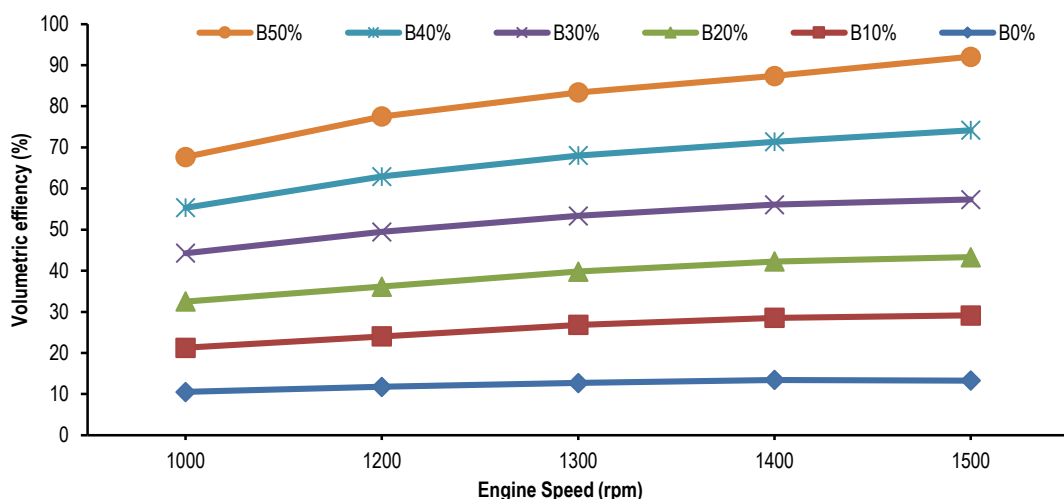


Figure 6: The volumetric efficiency with the corresponding engine speed (rpm)

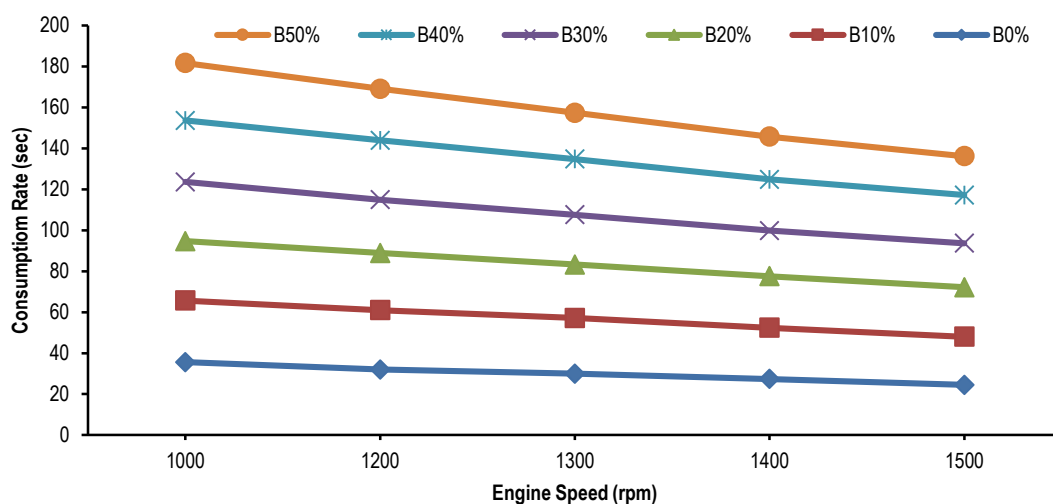


Figure 7: showing the consumption rate (L/sec) with the corresponding engine speed (rpm)

3.4 Exhaust gas analysis results

3.4.1 Exhaust gas temperature (EGT)

The exhaust gas temperature in an engine serves as an indicator of the conversion of heat into work. Figure 8

illustrates the fluctuations in exhaust gas temperature concerning the load for different fuel blends. It's noteworthy that the exhaust gas temperature for B0 and all other blends remained constant throughout the analysis.

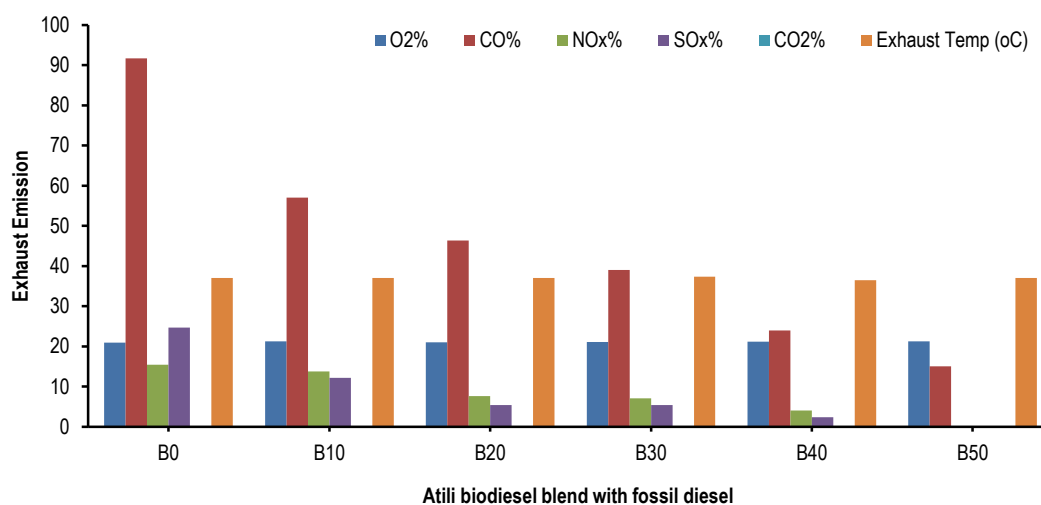


Figure 8: Exhaust Emission Test

3.4.2 CO Emission

The concentration of CO in the exhaust demonstrates a consistent increase as the excess fuel blend decreases. Figure 8 illustrates the CO exhaust emissions of both diesel and pure Atili oil biodiesel. Notably, B50% exhibits lower CO emissions at 15%, in contrast to B0%, which records higher CO emissions at 80%. This variance is attributed to B50% having a higher blend percentage, providing additional oxygen that facilitates more complete fuel combustion. Similar findings by other researchers also highlight that biodiesel fuel tends to yield lower CO emissions compared to diesel, particularly under full load conditions [14, 15].

3.4.3 NO_x Emission

NO_x emissions are a significant concern, especially in diesel engines, as they contribute to respiratory issues like asthma and persistent coughing. Higher combustion temperatures, increased oxygen content, and faster reaction rates—conditions conducive to NO_x formation—are achieved more rapidly in biodiesel combustion compared to conventional diesel. Consequently, NO_x formations from biodiesel blends are typically lower than those from neat diesel. Figure 7 indicates that NO_x values appear to be higher from B0 to B30 blends but significantly decrease in B40 and B50 blends.

4. Conclusion

The traditional method of Atili oil extraction proved laborious, time-consuming, and yielded approximately 15 liters from 49kg of crude, highlighting its inefficiency.

Atili oil was successfully transesterified into biodiesel using NaOH and methanol, achieving an 86.48% conversion at 60°C. This biodiesel offers several advantages: it's more lubricating, biodegradable, non-toxic, and boasts a high flash point for safe transportation and storage. Additionally, it burns cleanly, improving injection and atomization due to its low viscosity, with a higher cetane number and reduced emissions. It serves as a renewable, domestic energy source, potentially reducing reliance on crude oil imports and creating employment opportunities in agriculture.

Performance evaluation and exhaust emission analysis yielded key observations:

- Brake thermal efficiency is significantly influenced by heating value and viscosity.
- Biodiesel blends exhibited higher exhaust gas temperatures compared to diesel.
- CO emissions were lower in biodiesel blends than in diesel.
- NO_x emissions increased with lower chamber temperatures, yet biodiesel showed lower NO_x emissions overall.

These findings suggest that the Atili biodiesel blend, specifically B50, displays promising performance and emission characteristics when compared to conventional diesel. Therefore, it stands as a viable alternative for use in diesel engines without requiring modifications, potentially reducing environmental impact and reliance on conventional diesel fuel.

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