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Technical Assessment of Diesel Obtained from Modular Refinery for Use in Industries and Transportation

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ABSTRACT
The growing use of modular refinery systems in Nigeria calls for a comprehensive analysis of the quality and performance properties of the petroleum products generated in such refineries. In this research, the technical analysis of diesel fuel produced from one of the modular refineries in Nigeria was done in order to determine its applicability in industries and transport vehicles. The collected diesel samples were tested by the standard ASTM test methods. The following physicochemical properties were determined: water content (ASTM D95); density (ASTM D1298); flash point (ASTM D93); kinematic viscosity (ASTM D445); sulfur content (ASTM D1266); and atmospheric distillation characteristics (ASTM D86). The analyses were carried out under controlled laboratory conditions and the measurements were repeated in duplicate for increased accuracy and consistency. The test results were then compared against the Nigerian regulatory standards and a number of international diesel fuel standards. It was found that the diesel sample exhibited desirable quality features, with no water content, density of 0.869 g/cm³, flash point of 73°C, kinematic viscosity of 5.05 mm²/s, and sulfur content of 0.1661 wt%. The atmospheric distillation analysis showed an initial boiling point of 180°C and a final boiling point of 380°C, which is below the Nigerian maximum limit of 385°C. Most of the properties under consideration complied with the Nigerian fuel quality standards, thus indicating good combustion, storage safety, lubricating performance, and environmental acceptability.

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INTRODUCTION

It is evident that diesel fuel is one of the most essential energy commodities globally because of its wide utilization in transportation, industrial processes, agriculture, mining, construction, marine industry, and electricity generation. Even though global investment in renewable energies and de-carbonization measures is growing rapidly, diesel-powered systems have continued to maintain dominance in heavy transport and industrial areas because of their high efficiency, excellent energy density, reliability, and economical operation (Bacha *et al*., 2007). For this reason, the quality of diesel fuel has become an essential component in providing efficient engine operation, safety, environmental sustainability, and longevity of machines. The performance qualities of diesel fuel are determined by its physicochemical properties, which include density, viscosity, flash point, sulfur, water content, cetane quality (40-55), and distillation range. Such factors affect atomization, combustion, and ignition delays, lubricity of fuel injection system components, emission of pollutants, storage stability, and engine performance as a whole(Bebeteidoh *et al*., 2020; ASTM International, 2024). Deviations from standard properties of diesel fuel may cause injector deposits, incomplete combustion, higher fuel consumption, higher engine wear, and increased emissions of particulates and SOx emissions. It means that international organizations like ASTM and EN 590, as well as national authorities responsible for regulation of petroleum products, establish very strict requirements to the quality of diesel fuel (Bacha *et al*., 2007).

Modular refineries have been found to be among the most effective solutions to the problems of insufficient refining capacities in most oil-exporting developing countries in the recent past. Modular refineries are relatively small, scalable, and low-capital processing plants that are built for the purpose of converting crude oil into usable petroleum products in close proximity to where the oil is being produced. They are increasingly being considered as a good alternative to large refining plants because of their shorter construction period, flexibility, less capital costs, and easy scalability. These kinds of plants are especially useful in areas where the growing demand for energy and logistical difficulties, among others, continue to cause inadequacy of domestic petroleum products (Chukwu *et al*., 2025).

Nigeria is one of the unusual countries within the global oil sector. The country is among those nations endowed with enormous amounts of crude oil deposits in Africa despite relying heavily on imported products due to inadequate local processing capabilities. This situation has been a major contributor to fuel shortages, economic inefficiencies, supply chain weaknesses, foreign exchange pressures, and economic loss (Bello, 2018). In order to alleviate these problems, the government of Nigeria has promoted the development of modular refineries as a strategy geared towards developing domestic refining capability in efforts of achieving energy independence (Chukwu *et al*., 2025). Recently published information from various sources within the industry has revealed that the contribution of modular refineries towards providing diesel fuel in Nigeria has been growing recently, although limited by a number of factors, including feedstock and operational problems. Of all the products produced in modular refineries, the most important is automotive gas oil (AGO) known as diesel, since it plays a significant role in powering different operations in Nigeria. Diesel fuel is the main source of power for different activities such as agriculture, construction, transport, industry, telecommunication, and backup power systems. Being such an important product, it must meet set specifications in terms of performance and safety of usage (Bello, 2018).

Properties of diesel fuel are related to the process of refining and crude oil characteristics. The density is the factor that determines the energy content and calibration of the injection systems. The viscosity parameter defines the atomization level and lubricity of the injection system. The flash point is considered as a criterion of safety during storage and transport. The sulfur content of the product is one of the factors that play an important role in terms of the environmental impact since sulfur compounds lead to acid rain production, catalyst poisoning, emissions of particulates, and corrosion issues. Also, distillation properties are used for assessing the volatility, combustibility, low temperature, and deposit formation of diesel fuel (Bacha *et al*., 2007). The increasing importance of clean fuels and environmental legislation has increased the demand for thorough quality assessment of diesel products before their commercial release. Despite the availability of many studies concerning the physicochemical properties of imported diesel fuel, conventionally refined diesel, and locally refined petroleum products in Nigeria, there is not enough scientific data regarding the technical quality of diesel obtained at the new modular refineries. The majority of the existing research concerns economic feasibility, regulatory framework, supply chain issues, and sustainability of the modular refineries, but there are only a few studies on laboratory investigation of the technical quality of modular refinery diesel according to the national and international standards (Bebeteidoh *et al*., 2020; Chukwu *et al*., 2025).

In addition, the increased focus on localized refining and fuel self-reliance in Nigeria has emphasized the importance of quality control in the entire oil chain. The recent trends in the Nigerian refining industry show that there have been increased attempts towards reduction in reliance on fuel imports and enhanced local fuel manufacturing. This calls for continual assessment and testing of petroleum products to ascertain compliance with regulatory standards and international best practices (Chukwu *et al*., 2025). For this reason, the study carries out a detailed technical analysis of the diesel fuel from a Nigerian modular refinery for both industrial and transport purposes. This study examines the determination of physicochemical parameters including moisture content, density, flash point, kinematic viscosity, sulfur content, and atmospheric distillation properties through the use of standard ASTM methods. The determined values are compared against Nigerian and international standards of diesel fuel to establish the compliance level, evaluate the quality of the fuel and its fitness for commercial purposes. The results will be useful additions to the body of knowledge on modular refining processes (Bebeteidoh *et al*., 2020; Chukwu *et al*., 2025).

MATERIALS AND METHODS

On 1 August 2026, a sample of petroleum product was taken from a currently operating modular refinery in Nigeria. The sampling point had been operated for a suitable length of time, prior to sampling, to assure that the sample collected was representative of the product being sampled from the process stream. The sample was collected directly from the product outlet into a clean and dry, chemically compatible 1,000 cm^3 glass sample bottle. The bottle was filled to about 85% full to ensure good headspace and to prevent excessive pressure from building up during subsequent handling and analysis. The container was immediately covered, labeled and sent to the laboratory with minimal exposure to excessive heat, sunlight, and contamination, and containing all necessary product information and sample identification with date of collection. The sample was stored in a cool, well-ventilated area until analysis (Soukayna *et al*., 2018).

The flash point of the sample was determined in accordance with ASTM D93 (Pensky–Martens closed-cup method). The sample was carefully homogenized before being transferred into the test cup of the calibrated flash-point apparatus to the filling mark. The test cup was then covered with the lid and thermometer, and the sample was heated at the appropriate controlled rate. The test flame was applied to the vapour space above the liquid at the specified temperature intervals, following the ASTM D93 procedure. The flash point of the sample was taken as the temperature at which a test flame caused a noticeable flash, which means the vapour above the liquid surface is ignited. The analysis was carried out in a controlled lab environment and the outcome was expressed in degrees Celsius (°C) (Abdulsalam *et al.*, 2015).

Test Procedure for Measurement of gravity and API (hydrometer) - ASTM D1298

The sample was poured into a measuring cylinder of 500cm3, to the marked. The temperature of the sample was adjusted to 15.5°C. The oil sample was allowed to come to thermal equilibrium of 15.5°C at a constant temperature bath (Faruq *et al*., 2012). A hydrometer was inserted and allowed to float free from the walls of the cylinder to the bottom and the specific gravity value was read direct from the calibration of the hydrometer. The API was calculated using the following formula API = $\left(\frac{141.5}{SG}\right)$ –131.5. (Al-Dahhan & Mahmood, 2019).

Viscosity Analysis (Kinematic ASTM D445)

An appropriate volume of the sample was poured into the reservoir of the viscometer. Sample was placed in a constant temperature bath to allow it to reach the thermal equilibrium. Suction was done with the help of a rubber tube to the upper part of the viscometer by aspirator. The sample was aspirated up into the tube with two bulbs to a level above the second bulb. The timing needed for the level of the sample under test to the signal markings was achieved. The time in seconds was multiplied by the calibration constant of the viscometer to give the kinematics viscosity in mm^2/sec (Abdulfatai, 2004).

Distillation Analysis ASTM D86

The sample of diesel was measured in 100cm3, transferred to the distillation flask and three boiling chips were added to prevent it from splashing. The set-up for distillation was prepared in the distillation apparatus, having the sample in the distillation flask connected to the receiving cylinder (Faruq *et al*., 2012). The heating source was set on and temperature increased was gradual. The temperature of first drop of the distillate in the receiving cylinder was recorded as the LBP (lowest boiling point or initial boiling point). The process continue as the temperature of the corresponding volume were recorded, 5cm^3, 10cm^3 15cm^3 up to 90 cm^3 or more which was observed until it started dropping down and the temperature was record as the EBP (end boiling point). The setup was left to cool and all the volume recovered was measured. The volume of the residue in the bottom of the distillation flask was measured. (ASTM D86) standard test method for distillation of petroleum products was used at atmospheric pressure (Bebeteidoh *et al*., 2020; Chukwu *et al*., 2025).

RESULTS AND DISCUSSION

Result

Tabel 1 and 2 shows different parameters tested and how much is present in the sample tested.

Table 1

No	Parameters	Unit	Method	Limit		Test Results
				Min	Max	B40
1.	Density at 15ºC	g/cm^3	ASTM D1298	0.820	0.870	0.869
2.	Kinematic Viscosity at 40 ºC	mm^2/s	ASTM D445	2.000	5.500	5.050
3.	Water content	% vol	ASTM D95	—	0.050	ND
4.	Flash point	℃	ASTM D93	66	96	73
5.	Sulphur content	%wt	ASTM D1266	—	0.300	0.166

*ND = Not detected

Table 2

	Unit	Method	Measured	Result
Distillation	°C	ASTM D86	LPB	180
			10%	228
			50%	302
			90%	367
			95%	—
			EBP	380

Discussion

Flash Point

The flash point (77°C) in Table 1 is within the minimum requirement of the Nigerian standard of 66°C. The result is consistent with Bello (2018) report in analysis of detection of the performance characteristics of diesel fuel. The result showed that samples comply with the requirement on this parameter that plays an important role in safe use of water (Bebeteidoh *et al*., 2020). In the treatment and storage of fuel oil, the outcome is also above minimum requirement for flash in global diesel specifications for 1-D, 2-D and 4-D (Bacha *et al.*, 2007).

Viscosity: Sample was tested for viscosity per the ASTM D-445 method. The results obtained 5.05 mm ^{2}/s is within the acceptable viscosity range for diesel as recommended by the Nigerian Industrial Standard (NIS) of 1.6-5.5 mm ^{2}/s. These findings are also in consistent with those reported by (Bebeteidoh *et al*., 2020). This is an important parameter that determined the performance of the fuel injection system (Bello, 2018). The result is also in line with the ASTM D 975 requirements for diesel fuel oils number 4-D, which give the ranges between 5.5 and 24 mm²/sec(Bacha *et al*., 2007).

Density: Table 1 shows the values of the specific gravity of the sample studied in this work. The result reveals that the value of the specific gravity of the sample is within the standard base on existing criteria. The acceptable range of density for diesel fuel in Nigeria is 0.820 – 0.870 (Bello, 2018). However the result is higher than the EN 590 requirements for diesel fuel 0.820 - 0.845g/cm³ (Bacha *et al*., 2007). The density of the fuel introduced into the engine at a specific injector setting influences the energy content of the fuel (Bacha *et al*., 2007).

Distillation: Table 1 shows the results of the atmospheric distillation profile. Diesel fuel boiling point range, as stipulated by Nigerian Midstream and Downstream Petroleum Regulatory Authority (NMDPRA) and the standard organisation of Nigeria (SON) specifies that the final boiling point (FBP) of diesel fuel should not exceed 385°C while the recovery at 357°C should not be less than 90% (v/v). It can also be seen from the table that the sample is within the standard specification (Bello, 2018). However, the outcome is not up to ASTM D 975 requirements for diesel fuel oils, where the requirement is to recover a maximum of 90% volume recovered at 338°C(Bacha *et al.*, 2007)..

CONCLUSION

Using known ASTM test procedures, this study assessed the technical quality of diesel fuel from an operational modular refinery in Nigeria, with a focus on the fuel's suitability for transportation and industrial uses. The findings show that the diesel sample under investigation has physicochemical properties that are typically acceptable. The sample's density was 0.869 g/cm³, its kinematic viscosity was 5.05 mm²/s, its flash point was 73 °C, its water content was undetectable, and its sulfur content was 0.166 weight percent. Its ultimate boiling point was below the Nigerian standard of 385 °C, and its atmospheric distillation profile varied from an initial boiling point of 180 °C to an end boiling temperature of 380 °C.

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