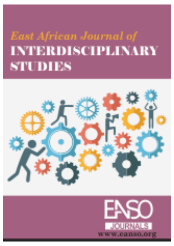

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Original Article

Experimental Investigation of the Physicochemical Quality of Gasoline Refined by Indigenous Technology in Nigeria

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ABSTRACT

Fuel produced by artisanal refiners using indigenous technology continues to find its way into the Nigerian oil market despite the proscription of such refining activities in the Niger Delta, owing largely to the illegal means by which the artisans procure crude oil and also related to doubt about the quality of products coming from their covertly operated facilities. Therefore, in this study, gasoline samples were collected across 30 artisanal refiner camps, and their properties were examined to ascertain their conformity with the minimum requirements of the Standard Organisation of Nigeria (SON) and the American Society for Testing and Materials (ASTM) on fuel quality. Standard test protocols on fuel characterisation published by ASTM were utilised for the analysis. The specific gravity of the samples determined at 15°C ranged from 0.796 – 0.807 g/cm3. The Antiknock Index ranged between 78.75% and 82.45% for the fuel, and the initial and final boiling points of the samples were about 32 – 39.1°C and 226.3 – 238.7°C, respectively. The distillation profiles of most of the fuel samples were satisfactory. Experimental data gathered from this study indicate that notwithstanding the artisanal refiners' shortcomings, they are still able to produce fuels that meet some minimum local and international requirements.

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INTRODUCTION

Artisanal crude oil refining has become an unending nightmare in Nigeria despite the tough measures the government is taking against illegal refiners. Amangabara and Obenade (2014), Goodnews and Wordu (2019) and Ogele and Egobueze (2020) have examined the factors contributing to the prevalence of artisanal refining activities in Nigeria and the resultant socioeconomic impacts. A major factor identified as a contributor to this situation is the lack of political will of successive governments to get existing refineries in the country up and running or establish new ones. The bulk of the gasoline consumed in Nigeria is imported and sold to consumers at high prices, and the generality of the masses experiences intermittent scarcity of the product. The importation of gasoline as the major means of assessing the commodity makes it insufficient to meet consumers’ demand, and this provided an avenue for illegal refiners to supply their products into the market, especially in the southern and eastern zones of the country. Information has it that some licensed oil marketers also mix partially refined products or condensate from illegal refiners with imported PMS, aiming solely to increase their turnover.

The intent of the government to proscribe artisanal refining is mainly informed by the economic backlash, social consequences, and environmental pollution arising from their activities (Asimiea & Omokhua, 2013; Naanen & Tolani, 2014; Obenade & Amangabara, 2014; Yabrade & Tanee, 2016; Nwankwoala *et al.*, 2017; Maclean & Steve, 2019); consideration is not given to the quality of fuel produced by these indigenous plants and little has been reported on the physicochemical properties of the artisanal products (Udo *et al.*, 2020). However, there has been a call for the government to legalise the application of indigenous technology to petroleum refining as employed by artisanal refineries in order to embrace the possibilities and benefits their operations offer in ameliorating problems associated with the availability and pricing of finished oil products in the market instead of continuously shining the torch on the negative dimension of their practices. In this regard, Umukoro (2018) referred to artisanal refined fuel as a homegrown solution to recurring shortages of petroleum products in Nigeria, owing majorly to the lack of refining capabilities in Nigeria.

Gasoline is a complex mixture of hydrocarbons containing between 4 to 11 carbon atoms in addition to other components and additives present in trace quantity such as oxygenates, pure alcohol, sulphur, and nitrogen, and also having boiling point ranging around 25 – 210℃ (Fernández-Feal *et al.*, 2017). Harper and Liccione (1995) reported that the composition and quality of gasoline varies depending on the crude oil used, the refinery processes available, and the additives and blending agents employed. Furthermore, RFF (2009) stated that the composition of gasoline influences the energy content of the fuel, which in turn determines the fuel economy, a reason why Refiners often make compositional changes to gasoline in order to improve fuel quality. The introduction of unleaded gasoline in the 1970s was the first move in this direction, and the reduction in volatility and oxygenation of fuel achieved in 1992 was another milestone (Renewable Fuel Foundation, 2009).

American Society for Testing and Material (ASTM D4814, 2020) list the properties defining fuel quality to include specific gravity, viscosity, specific heat, calorific value, sulphur and ash content, free water, final boiling point, copper strip corrosion, residue, existent gum, and octane rating. These variables are classified into three namely: operational-related properties, which determine the composition and chemical stability of fuel; handling and storage safety-related properties; and environmental-related properties (Matijošius & Sokolovskij, 2009). While all parameters that determine fuel quality play key roles in the operational performance of the engine in which the fuel is used, the distillation profile, i.e., fuel volatility and octane rating, are critical because both influence engine performance and extent of pollutant emission (Fernández-Feal et al., 2017; Álvarez & Callejón, 2005; Hsu & Robinson, 2006; Lluch, 2008; Chikwe et al., 2016; Vempatapu & Kanaujia, 2017; Worldwide Fuel Charter, 2019). These qualities must not be compromised irrespective of the method employed in refining the fuel.

Studies conducted on the characterisation of fuel quality in Nigeria (Matijošius & Sokolovskij, 2009; Onojake *et al.*, 2012; Igbani & Lucky, 2015) have focused primarily on fuel samples generally assumed to be imported or produced from government-owned refineries. Onojake *et al.* (2012) compared its experimental data with a reference sample supplied by the NNPC laboratory and reported that some gasoline sold in the fuel stations is adulterated, an indication of multiple routes through which refined petroleum products find their way into the Nigerian market. However, the current classification of artisanal refineries scattered across the Niger-delta region using local technology for the production of refined petroleum products in the country as illegal makes it difficult to understand what the components of their products are and how safe they are for human consumption. Udo *et al.* (2020) made an effort to bridge this gap, but the study was limited to five artisanal refined gasoline samples collected within Akwa-Ibom State, a fragment of the Niger-delta.

In order to examine the usability and relevance of indigenous technology employed by the illegal refiners, this study aims to characterise the quality of gasoline samples obtained from 30 artisanal refineries across the entire Niger Delta region of Nigeria using experimental research design. Furthermore, the study compares experimental results with local and international standards on gasoline quality, specifically the Nigerian Industrial Standard NIS 116 (Standard Organisation of Nigeria, 2017) and the ASTM D4814 (2020).

MATERIALS AND METHOD

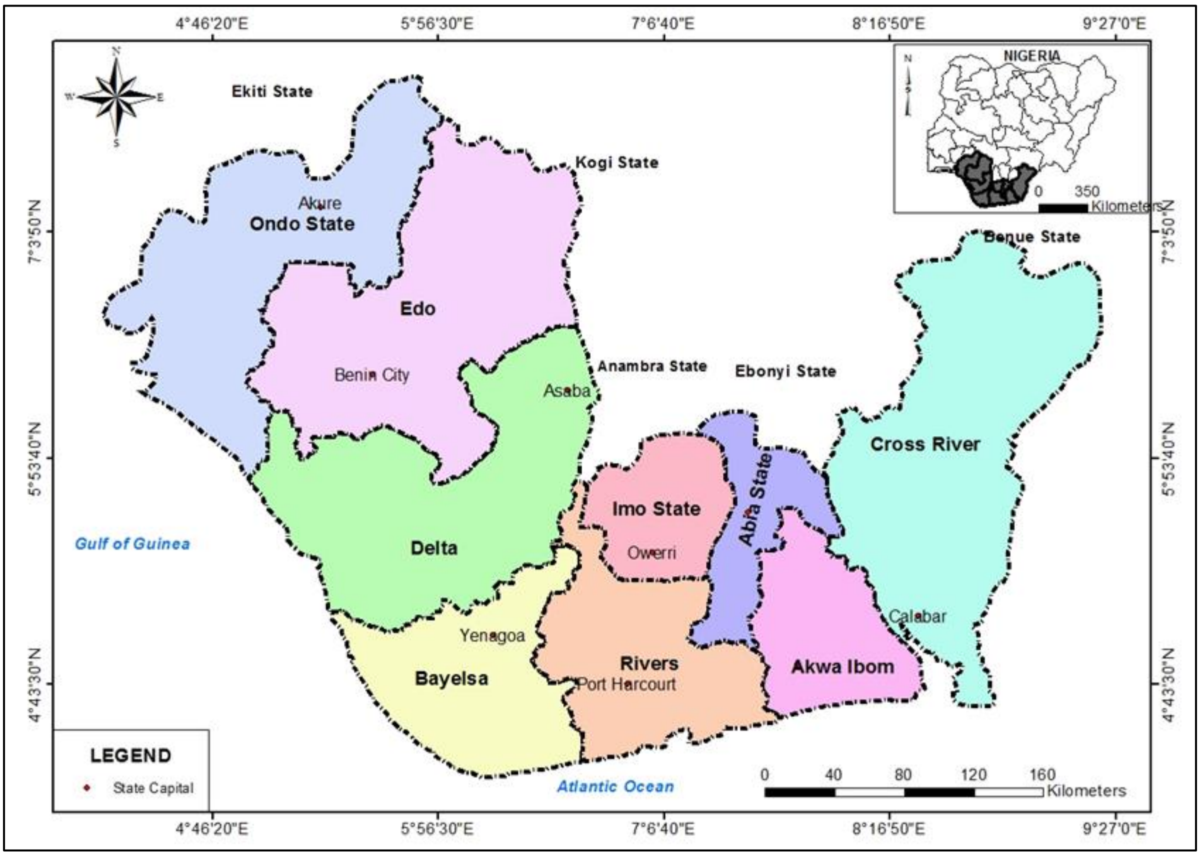
Sample collection

This study accessed some of the illegal refinery sites located in the oil-producing region of Nigeria, comprising nine states, which are Rivers, Bayelsa, Akwa-Ibom, Delta, Cross River, Ondo, Imo, Abia and Edo States, as shown in *Figure 1*. Petrol samples from the local refiners were collected in high-density polyethene (HDPE) bottles in order to ensure that the quality of the gasoline is preserved and returned to the Petroleum Engineering and Environmental Engineering Laboratories of the Chemical Engineering Department, Obafemi Awolowo University, Ile-Ife, Nigeria for physical and chemical characterisation.

Experimental procedure

Eleven major parameters influencing fuel quality were determined for each of the gasoline samples obtained from 30 artisanal refiner’s camps, including appearance, presence of suspended matter and free water, specific gravity, copper strip corrosion, residue, existent gum, sulphur content, motor octane number, research octane number, and final boiling point. Standard test protocols for petroleum products’ characterisation recommended by ASTM were employed in this study, and the guidelines utilised for measuring each parameter are summarised in *Table 1*.

Figure 1: Oil Producing States constituting the Niger Delta Region



Source: Shaibu and Weli, 2017

Table 1: ASTM guidelines for gasoline characterisation

Parameter	ASTM Guidance
Appearance, free water, and suspended water	D4196 (2017)
Specific gravity	D1298 (2017)
Sulphur content	D129 (2020)
Initial and Final boiling point; Residue	D86 (2020)
Copper strip corrosion	D130 (2019)
Existent gum	D381 (2019)
Research Octane Number (RON)	D2699 (2019)
Motor Octane Number (MON)	D2700 (2019)

Data analysis

Following the experimental data obtained for the research octane number (RON) and motor octane number (MON) of the samples, the Antiknock index (AKI) of each of the fuel samples was estimated using Equations 1 (ASTM D2700, 2019).

$$\text{AKI (\%)} = \frac{\text{RON+MON}}{2} \qquad (1)$$

The data obtained from the experiments conducted on the samples were analysed using descriptive statistical methods.

RESULTS AND DISCUSSION

Laboratory analysis of the appearance of the samples revealed that the petrol samples collected across the 30 camps were clear and bright and did not contain free water. Suspended matter is also not detectable in the test samples. Hence, the artisanal refined petrol conformed to the standard requirement by SON in this regard. The observation is attributable to the high quality of crude oil the artisanal refiners steal from oil pipelines. The results of other properties determined by the experimental procedure are presented in *Table 2*, and the data are the average of three experimental trials for each parameter.

The specific gravity of the samples determined at 15℃ ranged from 0.796 – 0.807 g/cm^{3,} and the mean value across the camps is 0.802 g/cm^3 with a standard deviation of 0.01. The petrol samples are heavier than the standard specified by SON but satisfy ASTM recommendations. The measured specific gravity indicates that the gasoline contains other fractions which are associated with heavy components of crude oil and surely will impair the effectiveness of the fuels.

Copper strip corrosion (CSC) factors of the samples fell in class 2, exceeding the maximum allowable level by both SON and ASTM. This result implies the fuel can cause engine corrosion and also impair the emissions control systems of motor vehicles. The high CSC factor is attributable to the high sulphur content of the samples, which analysis indicated in a range of 0.019 – 0.024 %wt., with an average value that is 40% higher than the permissible limit. The crude technology of the refiners hinders them from adopting separation operations that remove impurities from the products impurities, such as sulphur-containing compounds known for their corrosive effect, majorly hydrogen sulphide, usually found in crude oil. Aside from the effects on engine performance, the presence of sulphur in fuel causes poisonous air emissions when such fuel is combusted.

For another important fuel quality parameter- the octane rating, samples from two of the thirty camps met the SON requirement while all failed the ASTM standards for MON. The experimental data ranged between 76.7% and 81.3%, averaging 79.2% and a standard deviation of 1.52. Only one of the samples satisfies both SON and ASTM specifications for the RON with 91.5%. The RON for the remaining 29 samples ranged from 76.5 – 87%. In terms of the Antiknock Index (AKI), which depends on vehicular fuel economy and engine performance, the fuel was short of specification. Across the 30 samples, values ranging between 78.75% and 82.45% were estimated, while the requirement is a minimum of 87%. The AKI data indicate poor octane rating and the likelihood of knocking in engines as a result of using artisanal fuel, especially if the fuel is not improved using appropriate additives.

Results of fuel volatility across the entire boiling range of gasoline determined by distillation test are presented in *Table 3*; the initial boiling point (IBP) and final boiling point (FBP) of the samples were about 32 – 39.1℃ and 226.3 – 238.7℃, respectively. While the IBP of the fuel conforms to gasoline volatility specified by ASTM, the FBP of the samples are far above SON and ASTM requirements, an indication that some less volatile components are present. The distillation residue of the petrol samples supports this claim as experimental data ranged at 3.43 – 4.03 %vol. With a mean value which is twice the published specification, a situation caused by the presence of heavy composites such as polyunsaturated hydrocarbon in the fuel is usually retained after proper distillation because of their higher boiling point.

Table 2: Experimental data measured for fuel qualities across 30 artisanal refiner's camps

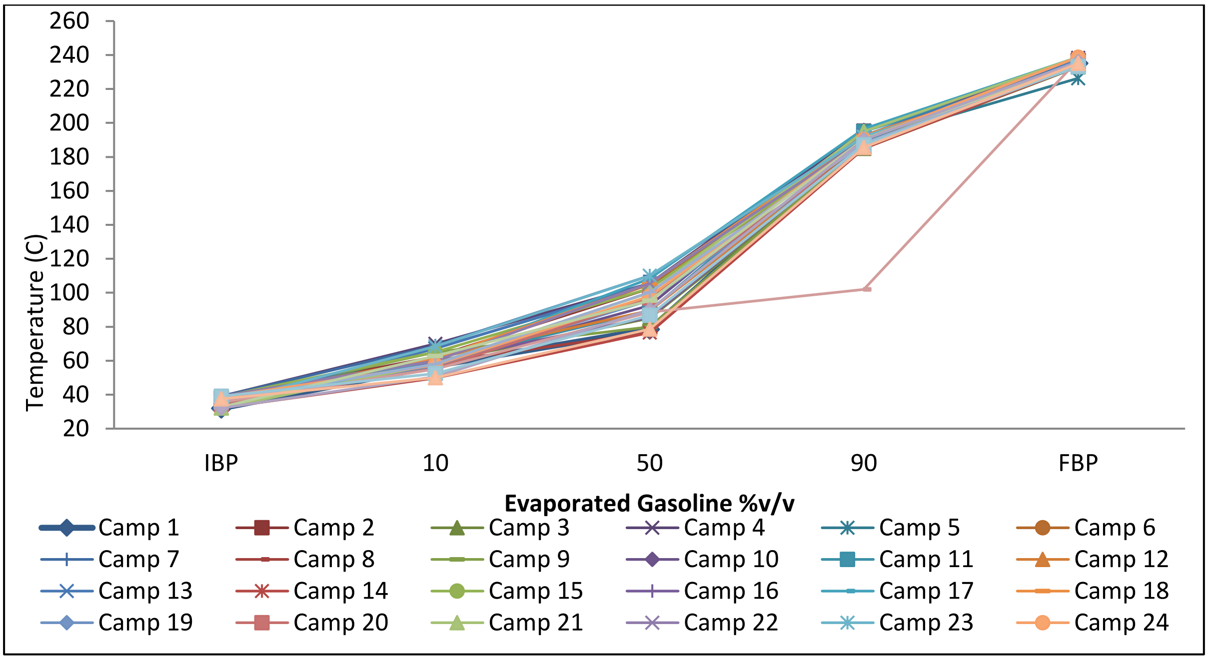
	Gasoline Properties							
Camp	**Specific Gravity at 15°C, (g/cm^3)**	**Copper Strip Corrosion**	**Residue (%Vol.)**	**Existent Gum (mg/100ml)**	**Sulphur Content (%wt.)**	**Motor Octane Number (%)**	**Research Octane Number (%)**	**AKI (%)**
1	0.796	2c	3.53	4.3	0.023	80.3	83.7	82
2	0.796	2c	3.37	5.7	0.02	77	81	79
3	0.796	2b	3.47	5.3	0.02	77	76.5	76.75
4	0.807	2b	3.6	4.7	0.021	80.7	86.5	83.6
5	0.796	2c	3.8	4	0.021	81.3	91.5	86.4
6	0.796	2b	3.33	4.3	0.02	79	78.5	78.75
7	0.807	2c	3.6	5.3	0.022	80.7	82	81.35
8	0.796	2b	3.57	3.7	0.021	78.3	80	79.15
9	0.796	2b	3.87	4.7	0.02	76.7	79.5	78.1
10	0.807	2b	3.97	4.7	0.02	78.3	81	79.65
11	0.807	2c	3.73	4	0.019	80	80.5	80.25
12	0.796	2c	3.87	3.7	0.019	78.7	79	78.85
13	0.807	2b	3.97	5	0.023	79.7	83	81.35
14	0.796	2b	3.9	4.3	0.02	77.7	80.3	79
15	0.807	2b	3.6	4.3	0.019	80	80.7	80.35
16	0.807	2b	3.67	4.7	0.022	81	80.2	80.6
17	0.796	2b	3.83	4	0.022	78.7	86.5	82.6
18	0.807	2c	4.07	5.7	0.024	80	81.7	80.85
19	0.807	2c	3.73	5	0.019	78	85	81.5
20	0.796	2b	3.8	4.7	0.023	80	82	81
21	0.807	2c	3.83	4.7	0.021	81	81.3	81.15
22	0.796	2c	4.03	4.3	0.023	79	82	80.5
23	0.807	2b	3.8	4.7	0.019	78	78.2	78.1
24	0.796	2b	3.83	4.3	0.024	80.7	84.2	82.45
25	0.807	2c	3.8	4.7	0.022	79	84	81.5
26	0.807	2b	3.57	5.3	0.019	80	86	83
27	0.807	2c	3.6	4.7	0.023	77.3	77	77.15
28	0.807	2b	3.6	5	0.023	79.3	80.5	79.9
29	0.796	2b	3.43	4.3	0.023	78.7	87	82.85
30	0.796	2b	3.67	4.3	0.02	79	83.1	81.05
SON	0.72-.78	max. 1b	max. 2 %v/v	max. 4mg/100ml	0.015 wt%	min. 81	min. 90	min.87
ASTM	0.75–0.85	max. 1b	max. 2 %v/v	max. 5	0.01–0.05%wt	min. 83	min. 91	min.87

Table 3: Initial and final boiling points of the gasoline samples

	Evaporated Gasoline %v/v					
	Camp	**IBP**	**10**	**50**	**90**	**FBP**
Temperature (C)	1	32	57	78.5	190	235
	2	38	62.5	102.5	195.2	236.7
	3	34.5	59	85	185	233
	4	39.1	70	105.5	195.6	238.3
	5	32.3	67.3	105	189.5	226.3
	6	36	60.5	105	186	237.3
	7	39	68.9	110	190.5	238.3
	8	34.4	59	76.6	185	236.3
	9	37	65	80	187.5	237.7
	10	35	57.6	92.5	195.6	237.3
	11	38.2	59.2	89.5	195	234
	12	37.5	61.5	89.5	187	236
	13	35.3	67.2	105.6	192.6	237
	14	32.2	49.8	76.5	185	233.3
	15	38.7	65	102.5	190	235.7
	16	39	59.5	85.6	187.5	234.3
	17	32.5	60.3	108.3	196.5	238.7
	18	36	61.5	105.4	192.5	233.7
	19	33.7	56.8	95.6	185.6	236.7
	20	34.2	55.5	96.8	185.5	234.7
	21	32.1	58.2	100	195	238.7
	22	39	60	105.5	190	235.7
	23	35	68.5	110	192	232.7
	24	38.5	57.5	98	190.2	238.7
	25	36.4	58	100.2	188	234.3
	26	35.5	55	88.5	102	237
	27	32.7	62.7	95.4	190.5	234.3
	28	32.1	50.6	90	190	236
	29	39.1	52.5	86.7	187.1	233.3
	30	37.5	50	78.6	185.5	235
SON						Max. 210
ASTM		35-39	60	77 -100	130 – 175	195-204

The distillation curve (*Figure 2*) comparing the volatility across the 30 fuel samples shows that the temperature (49.8 – 70℃) at which 10% of the fuel evaporates is sufficiently low to ensure cold starting of the engine and the temperature (76.5 – 110℃) at 50% fuel evaporation is also sufficient to maintain engine's appropriate warm-up performance. The distillation profiles of the fuel samples are satisfactory and would not pose engine performance problems, and likewise limit the extent of pollution resulting from the fuel.

Figure 2: Distillation curve of the Gasoline samples across the 30 camps



The presence of heavy crude oil components is also responsible for the existent gum content of most of the gasoline samples, failing both local and internationally published recommendations. Existent gum contents of samples from 27 camps were above 4.3 mg/100ml, and some had content as high as 5.7 mg/100ml, while SON and ASTM maximum specification is 4.0 mg/100ml. Contamination of gasoline with oils and particles having very high boiling points constitutes its outrageous gum content, and this situation could arise from either or both improper production processes and poor storage of refined fuel storage. The effect of the high residue and existent gum in fuel is that the fuel leaves deposits in the engine system resulting in poor intake of fuel and recurring damage to the fuel pump.

The result of the experimental analysis of fuel samples of the artisanal refiners has indicated that while they made an attempt to provide fuel suitable for use, they lack sufficient refining knowledge, and the use of crude facilities impedes their progress. A challenge with their methods has to do with training, instrumentation, and precision. Achieving proper distillation of fractions hinges on locating the appropriate boiling point range for each fraction, and it is a function of adequate instrumentation and precision. Product purification methods also need to be incorporated into the refining technology in order to improve fuel quality; an important technology is fuel desulphurisation, which limits the sulphur content of fuel to the barest minimum. As practised in conventional petroleum refineries, the inclusion of additives to improve fuel quality and ensuring proper storage of refined fuel are some of the major skills lacking in the artisanal refiner's camps.

CONCLUSION

The experimental data gathered from this study indicated that despite their shortcomings, artisanal refiners are still able to produce fuels that meet some minimum local and international requirements. Fuel quality parameters satisfied include appearance, specific gravity, and volatility. For parameters failed by the samples, experimental data were close to standard.

This study concluded that the indigenous technology employed by the artisanal refiners is not completely obsolete. While the artisanal refiners, otherwise classified as illegal, are doing their business for economic gain, they do not completely compromise the quality of the products they bring to the market. An upgrade in their methods and equipment to ensure adequate separation, coupled with the introduction of appropriate additives to the fuel as practised in conventional petroleum refineries, will significantly reduce impurities, and improve the fuel octane rating.

Therefore, the Nigerian government is encouraged to extend the olive branch to the artisanal refiners and assist them in collaborating with experts in the refining industry with the aim of achieving economic prosperity for the nation at large.

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