



## Comparative analysis of the quality of automotive gas oil (AGO) produced from Nigerian and foreign refineries

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### Abstract

The physicochemical properties of Automotive Gas Oil (AGO) are of utmost importance in determining its quality. The properties of various AGO samples were investigated with the purpose of establishing their suitability for local and by extension, global consumption. Nigerian (KRPC) and foreign AGO samples were collected from Kaduna Refinery and Petrochemical Company (KRPC) and major oil marketer respectively and they were blended in various ratios. The combustion quality of the AGO samples was measured in terms of cetane rating while the volatility measured in terms of distillation, specific gravity and pour point using the analytical techniques of American Society for Testing and Materials (ASTM) methods. This study showed that both Nigerian (KRPC) AGO (A), foreign AGO (B) and their blends (AB1, AB2, AB3 and AB4) have almost the same physicochemical properties except for flash point and Sulphur content. The flash points of Nigerian (KRPC) and foreign AGO are 189 and 227 respectively. The Sulphur content of the foreign AGO (0.147) was found to be higher than that of the Nigerian (KRPC) AGO. The results showed that all the properties of the blended AGO samples are within the ASTM specifications and falls within the range of the Nigerian (KRPC) and foreign AGO values for each property. In comparison of these parameters with ASTM specifications for AGO, the Nigerian (KRPC) AGO is more suitable for use in industrial/domestic energy provision and transportation operations.

**Keywords:** AGO, cetane number, pour point, sulphur content

### Introduction

Diesel oil, also known as automotive gas oil (AGO) is a product derived from crude oil and its composition vary with the source of crude (Dryer and Kerho 1987) <sup>[9]</sup> and is composed entirely or substantially of higher hydrocarbons (Klimisch, *et al.*, 1997) <sup>[18]</sup>. The atmospheric distillation temperature is at about 300 – 350 °C and appear after all the other lighter products have been removed from refining streams (Luis, 1998) <sup>[22]</sup>. Distillation differs considerably in sulphur, heavy metal levels and specification requirements (Speight, 1999) <sup>[28]</sup>.

Crude Oil is the naturally complex liquid mixture in the earth crust consisting predominantly of hydrocarbons and varying qualities of sulfur, nitrogen, oxygen, derivatives of hydrocarbons and extraneous substances such as water, inorganic matter and gas as well as trace amount of nickel, vanadium, and elements present as organometallic compounds (Henrich and Kasztelaan, 2001) <sup>[13]</sup>.

Crude oil varies widely in appearance and viscosity from field to field, thereby differing in colour, odor and chemical properties. They are classified in terms of their predominant chemical nature such as paraffin, naphthenic and aromatic or by their specific gravity at light, medium, or heavy crude oil. It can also be classified as a sweet crude where the sulfur content is less than 0.5% or sour crude where the sulphur content above 0.5 %. Nigerian crude oil is characterized by having low sulfur content below 0.5 % and low wax content. That gave it the name sweet crude oil (Henrich and Kasztelaan, 2001; Speight, 2008) <sup>[13, 29]</sup>.

Crude oil with a high percentage of aromatic or naphthenic hydrocarbons have been found to be superior to the typical

paraffinic type. Petroleum derived diesels is composed of about 75 % saturated hydrocarbon (primarily paraffin's including, ISO and cycloparaffins) and 25 % aromatic hydrocarbons (including naphthalenes and alkyl benzenes). The average chemical formula for common diesel fuel is C<sub>12</sub>H<sub>23</sub> ranging from approximately C<sub>10</sub>H<sub>20</sub> to C<sub>15</sub>H<sub>28</sub> (Chikwe *et al.*, 2012) <sup>[7]</sup>.

The three primary fuels for stationary reciprocating IC engines are gasoline, diesel oil (AGO) and natural gas.

Gasoline is used primarily for mobile and portable engines, thus gasoline is an essential fuel for small and medium size stationary engines. AGO (Diesel) is easily transported and therefore is used in small and medium size engines. Also generally higher efficiencies exhibited by diesel engines make diesel oil an ideal fuel for large engines where operating cost must be minimized. Thus, AGO is the most versatile fuel for stationary reciprocating engines (Khalid and Ali, 2010) <sup>[17]</sup>.

When examining the world wide trends in Automotive Gas Oil (AGO) over the past years, the outcome has being ambiguous. The quality of fuels produced in some countries have improved while some have deteriorated.

Moreover, quality trends differ between geographical areas although, no dramatic changes are evident for AGO quality. There has been reported cases of fuel explosion during domestic and industrial usage due to adulteration and poor qualities of fuels. Thus, there is substantial need to provide information about constituents in complex mixture of various fuel importation and adulterations, with attendant health and environmental

concerns, and the risk of engine failure in terms of inferior quality fuel.

This research is aimed at comparing the qualities of automotive gas oil (AGO) produced in Nigeria and abroad through their macroscopic characteristics and physiochemical properties.

## Materials and Methods

### 1. Sample Collection

The foreign AGO (diesel) used for this research was produced in Niger Republic and imported by a major oil marketer while the Nigerian AGO was produced by Kaduna Refining and Petrochemical Company (KRPC). The sampling lines were flushed prior to sample collection. The AGO samples were collected from the top, middle, and bottom of the AGO storage tanks from KRPC, and also from the top, middle, and bottom of the storage tanks from one of the major oil marketer (foreign AGO) in Kaduna.

Composite sample was then formed for each samples (KRPC and foreign AGO) by transferring equal volumes of the top, middle and bottom samples into a 1000 cm<sup>3</sup> sample bottle. The mixture was thoroughly blended to develop a homogenous sample and labelled immediately for identification. The Nigerian (KRPC) AGO was labelled "A" while foreign AGO was labelled "B". From the composite sample of each AGO sample (i.e. Nigerian (KRPC) and foreign AGO), blends of Nigerian (KRPC) AGO and foreign AGO were formed in the following percentage composition ratios; 10 % A: 90 % B (AB1), 20 % A: 80 % B (AB2), 40 % A: 60 % B (AB3) and 50 % A: 50 % B (AB4) respectively.

### 2. Methodology

The methods used were based on American Standard for Testing and Materials (ASTM) procedures. Those includes: specific Gravity (ASTM D1298), colour (ASTM D1500), flash Point (ASTM D93), Pour Point (ASTM D97), Kinetic viscosity (ASTM D455), Bottom Sediment and Water/Total Recovery (ASTM D96), while cetane number was calculated from the specific gravity.

#### 2.1 Determination of Specific Gravity

The specific gravity of the AGO sample was determined by using hydrometer with a range of 0.800 – 0.900. The sample was brought to specified temperature and a test portion was transferred into hydrometer cylinder that has been brought to approximately the same temperature. The hydrometer was lowered into the test portion and allowed to settle after the temperature equilibrium is attained, the hydrometer scale read, and the temperature of the test portion was taken. The "observed hydrometer reading with the corresponding temperature" was then corrected to the actual value by means of petroleum s.g. conversion table (ASTM, 2002).

#### 2.2 Distillation or Recovery at 357 oC

The vacuum distillation of the AGO samples at 357 oC was determined using the reduced pressure Advanced Distillation Curve (ADC) apparatus and the ASTM D1160 method.

#### 2.3 Determination of Bottom Water and Sediment (BS&W) OR Total Recovery

This determination is by "centrifuge method". Equal volumes of AGO sample and saturated toluene (50 mL + 50 mL) was placed in each of the cone shaped centrifuge tubes. They were then placed in a centrifuge equipment and centrifuge at a controlled speed and at temperature above ambient temperature for 15 min, the volume of water and sediment at the bottom layer was calculated (ASTM, 2002).

#### 2.4 Determination of Flash Point

The AGO sample was placed in the cup of the tester and with the lid closed, heated at a slow rate. An ignition source was directed into the cup at regular intervals. The flash point was taken at the lowest temperature at which the ignition source causes the vapours above the sample to flash are then recorded. (ASTM, 2002).

#### 2.5 Determination of Pour Point

The AGO sample are poured into a pour point test glass tubes to the level of the mark and closed with a cork carrying a thermometer, the sample was cooled inside the pour point cooling bath equipment at a specified rate of cooling and examined at intervals of 3 oC for flow characteristics. The lowest temperature at which the sample ceased to flow, when held horizontally for 5 sec. The reading is the recorded, and three degrees centigrade (3 oC) was added to the result as a correction factor to give the pour point of the sample. (ASTM, 1990).

#### 2.6 Determination of Kinematic Viscosity

The viscosities of the samples were determined by using the viscometer at the temperature of 82.2 oC. The sample was sucked into the viscometer, and left in the viscometer glycerin bath for at least 30 min to allow for temperature equalization to 82.2 oC. A stop watch was started when the sample reached the first timing mark and stopped when it reached the second timing mark on the viscometer. The various timing was recorded and average time was taken. The kinematic viscosity principle is by gravity flow of samples and the kinematic viscosity is calculated from the equation;

$$V = Ct \quad [1]$$

Where; V= Kinematic viscosity, C = Constant, t = Average time of the flow.

#### 2.7 Determination of Total Sulphur

X-ray florescence analyzer (SLFA – 2100/2800) with a detection limit of about 5 mg/L and a measuring range of 0 – 0.999 % was used in the determination of total sulphur. The sample cells were approximately half filled with AGO sample, while ensuring that the thin film windows are not damaged when placing them in the X-ray analyzer (Horiba, 1992). The resultant characteristic was measured, and the sulphur value recorded.

#### 2.8 Determination of Cetane Number

The cetane number (CN) of the AGO samples was calculated using the Equation 2 (Willard, 1997):

$$CN = -420.34 + \left[ \frac{0.016G}{T_{50}} \right]^2 + 0.192(\log T_{50}) + 65.01(\log T_{50})^2 - \left[ \frac{0.0001809T}{T_{50}} \right] \quad [2]$$

where G is the API (American Petroleum Institute) specific gravity and T50 is the distillation temperature as 50 vol. % fuel sample distilled and condensed in °F.

## Results and Discussion

The specification covers grades of diesel fuel, suitable for various types of diesel engine, Nigeria, foreign and their blends. Table 1 presents the physiochemical characteristics of Nigerian (KRPC) AGO, foreign AGO and the blends of both at various percentage composition ratio. It was observed from Table 1, that the specific gravity values for all the AGO samples are within the ASTM specification. However, the foreign AGO exhibited a higher specific gravity value of 0.8714 compared to the Nigeria (KRPC) AGO and the blended AGO samples. The measurement of specific gravity of an oil gives an indirect indication of the fuel composition, giving rise to classification of fuel (Ancillotti and Fattore, 1998). Thus, the high specific gravity value of the foreign AGO could suggest high percentage of heavy ends used in the blending of the foreign AGO with light naphtha (LN). Table 1 also showed that the specific gravity values of the blended AGO samples, increases with increase in the percentage composition of the foreign AGO in the blended samples. Typical values of specific gravity for AGO are around 0.82 (Williams, 1979; Wilks, 2005) [32, 30].

In the ASTM specification, colour has been stipulated at 3.5 maximum (ASTM, 2002). The colour shows the degree of refining and the pattern of blending. A straight run distillate or hydro-treated fuel shall be finer and lighter in colour whereas the fuels blended with cracked products and containing more "higher fractions" would be darker in colour (Moore and Dunning, 1996) [24]. This research reveals that all the AGO samples meet the requirement stipulated in the ASTM specifications. It was observed from the result that the foreign AGO sample is much darker (Table 1) as it has the highest colour value. The colour of the blended samples become darker with increase in the percentage composition of foreign AGO in the blended samples.

ASTM specifications of 90 % recovery is stipulated as 357 °C temperature. This study showed that over 90 % of each of the AGO samples were recovered. However, 97 % and 96 % of Nigeria AGO and AB4 blended AGO sample were respectively recovered at 357 °C. The amount of water present in each of the AGO samples was determined by distillation at 100 °C (i.e. total recovery). The result in Table 1 showed that the Nigeria (KRPC) AGO contains the least amount of water (0.02 %) which as a result 98 % of it was recovered. The blended samples contain higher amount of water which are between 0.04 % and 0.03 % since their amount that was recovered range between 96 – 97 %. The water content of all the AGO samples were within the ASTM specifications.

It was observed that the flash point values of all the AGO samples studies range between 189 – 227 °F which is within the ASTM specifications of 150 °F minimum value. Thus, the high flash point values of the AGO samples as shown in Table 1, is an indication that these fuels (i.e. AGO samples) can be handled and stored without serious fire hazards (Odularo, 2007) [26]. This could also suggest the absence or negligible presence of highly volatile or flammable fractions in the relatively non – volatile or flammable fuels (i.e. the

AGO samples), as reported by Juopori (2004) [16]. The results (Table 1) also showed that the foreign AGO (B) had the highest flash point value (227) among the AGO samples studied and thus, suggesting that the amount of volatiles/flamable contaminants in the foreign AGO (B) is low compared to the Nigeria AGO (B) and the blended AGO samples. The flash point values of the blended AGO samples increased with increase in the percentage composition of the foreign AGO in the blended samples.

The pour point of a liquid is the temperature below which the liquid loses its flow characteristics (Luyben, 2006) [23]. Hence, pour point is the temperature at which oil ceases to flow and becomes semi-solid as the test vessel is held in a horizontal position for 5 seconds (Cormark, 1999). Table 1 showed that the pour points of all the AGO samples studied are within the ASTM specification. However, the foreign AGO has the highest pour point of 40 which according to ASTM specification, is the maximum pour point for any AGO sample. This suggests high paraffinic content in the foreign AGO sample compared to the Nigeria AGO and the blended samples (Buxton, 2008). It is critical to control the wax content of diesel to prevent operational problems (Luyben, 2006) [23]. Viscosity is a measure of the internal fluid friction or resistance of oil to flow, which tends to oppose any dynamic change in the fluid motion (Sivaramakrishnan and Ravikumar, 2012) [27]. Viscosity is one of an oil's most important physical properties. It is often one of the first parameters measured by most oil analysis labs because of its importance to oil condition and lubrication (Amorim *et al.*, 2007) [2]. The viscosity values of the AGO samples are between 4.3 and 4.5 cSt (Table 1) which is within the limits reported by ASTM (2002) and Garki and Akpan (2007) [11]. It was observed that the blended AGO sample, AB1, has the highest viscosity value while the Nigeria (KRPC) AGO and blended AGO sample, AB4, had the lowest viscosity values. Thus, AB1 is more viscous than all other AGO samples studied.

High sulphur content in fuel oil causes formation of harmful sulphur compounds, increase corrosion and pollution effect, increases the formation of sulphate deposits in boilers, contamination of products in direct contact with furnace gases such as glass and steel, and accelerate the formation of gum and sediments during storage (Nelson, 2005) [25]. The total sulphur content for all the AGO samples were found to be within ASTM specification as shown in Table 1. The sulphur content value of Nigerian AGO was found to be quite low compared to that of the foreign AGO samples. The sulphur in foreign AGO doubled the sulphur content value in the Nigerian AGO. Hence, it forms secondary particulate matter, which can cause serious respiratory adverse health effects, acid rain, risk of erosion, equipment failure and fouling (Kurnets and Shmidt, 2003) [19]. This also suggest that the Nigeria (KRPC) AGO is suitable for transportation and industrial or domestic energy provision purposes. However, it was observed that the sulphur contents of the blended AGO samples decreases with increase in the proportion of foreign AGO in the blended AGO samples. The blends, AB3 and AB4 has lower sulphur contents than the Nigeria AGO. Thus, in terms of sulphur content, the blends AB3 and AB4 are better AGO fuels than the Nigeria AGO while the Nigeria AGO is better than the foreign AGO. This is because it has been reported that the

lower the sulphur content value, the better the quality of the AGO (Glasby, 2006) [12]. The sulphur content of an oil depends on the type of crude processed in the refinery. Sulphur is chemically bonded to crude oil components, during refining; it concentrates in bottom fraction, AGO, fuel etc. (Gangali, 2010) [10].

The cetane number is a measure of the ignition quality of diesel fuel and is based upon the compound cetane or hexadecane which is assigned a cetane number of 100 (Atoshi and Thomas, 2004) [4]. Cetane number is the principal yardstick for measuring the quality of compression ignition engine fuels. It measures the ignition delay time, it affects ease of starting, duration of white smoke after start up, drivability before warm up and intensity of diesel knock at idle (Laza and Berezky, 2010) [20]. The results showed

that although the cetane number of the Nigeria (KRPC) AGO is higher than that of the foreign AGO, the cetane number of all the AGO samples are within the ASTM specification. This indicates that the Nigeria (KRPC) AGO has shorter ignition delay, duration of combustion, less occurrence of knocking, and lower formation of nitrogen oxides (NOx); than the foreign AGO (Lin and Lin, 2007; Hong *et al.*, 2002; Barabas *et al.*, 2010) [21, 14, 5]. However, the Nigeria (KRPC) AGO has the same cetane number with AB3 and AB4 of the blended AGO samples.

The result of the AGO samples indicates that pumping these fuels from the tanks to combustion chambers in internal combustion engine will result in proper combustion, correct atomization with little pressure drop.

**Table 1:** Physicochemical Characteristics of AGO Samples

Test	Unit	A	B	AB1	AB2	AB3	AB4	Specification
Specific Gravity at 15/4 0C		0.8565	0.8714	0.8575	0.8589	0.8619	0.8635	0.820 min
Colour		1.0	2.0	1.0	> 1.0	>1.0	1.1	3.0 max
Recovery at 357 0C	% Vol.	97±0.021	93±0.07	94±0.01	94.2±0.08	93.6±0.03	96±0.01	90 min
Total Recovery	% Vol.	98±0.05	96±0.14	96±0.09	96.5±0.12	97±0.02	97±0.04	96 min (0.05 max)
Flash Point	0F	189±1.00	227±0.73	189.0±0.01	189.3±0.24	189.5±0.05	189.5±0.007	150 min
Pour Point	0F	36±0.11	40±0.03	34±0.007	34±0.001	35.8±0.37	36±0.003	40 max
Kinematic Viscosity at 82.2 0C	cSt	4.3±0.001	4.4±0.002	4.5±0.001	4.4±0.003	4.4±0.001	4.3±0.001	1.6-5.5
Total Sulphur	% wt	0.090	0.147	0.0937	0.0909	0.0894	0.0891	0.5 max
Cetane Number		45±0.001	43±0.005	44±0.002	44±0.009	45±0.001	45±0.004	40 – 46

Key: A = Nigeria AGO (KRPC); B = Foreign AGO; AB = Blend of Nigerian AGO (A) and foreign AGO (B)  
 AB1 = 10 % A: 90 % B; AB2 = 20 % A: 80 % B; AB3 = 40 % A: 60 % B; AB4 = 50 % A: 50 % B

## Conclusion

The comparison of the quality of AGO from Nigeria, foreign and the blends of both, has been studied. The result showed that the physio – chemical properties of all the AGO samples are almost within the ASTM specification and there is no significant difference in their studied physicochemical properties except for their sulphur content and flash point. It was observed that flash point and sulphur content values of the foreign AGO were higher than that of Nigeria AGO. It can also be established from the results, that the Nigeria (KRPC) AGO and foreign AGO samples can be blended together to improve on or achieve a desired physicochemical property of the AGO sample. The Nigeria (KRPC) AGO, and blends AB3 and AB4, are very suitable for transportation and industrial energy provision purposes because of their very low sulphur content and high cetane number.

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