Physical Properties of Agbabu and Yegbata Bitumen in Nigeria

Shadrach Olise Ogiriki*, Jennifer Oyindamola Adepoju, Adeyinka Sikiru Yusuff and Victor Anochie

Department of Chemical and Petroleum Enigeering, Afe Babalola Univetsity, Km 8.5, Afe Babalola Way, P.M.B. 5454 Ado-Ekiti, Nigeria

Abstract

This experimental work evaluates the physical properties of Abagbu and Yegbata bitumen from Nigeria with comparison with that of Canada being the world largest producer of crude oil from bitumen. This study employed the American Society for Testing and Materials (ASTM) methods in conducting laboratory experiments in order to determine the viscosity, specific gravity, API (American Petroleum Institute) gravity, pour point and flash point. A Gas Chromatograph (GC) was used to determine the hydrocarbon content of the bitumen samples. Test results showed that the specific gravity for the bitumen sampleswas 1.01 with a 0.9962 ^{O}API for Yegbata, while that of Agbabu bitumen sample was 8.599 specific gravity and 10.54 ^{O}API. Kinematic viscosity was 1.0×10^2 to 3.3×10^4 and 1.6×10^3 to 5.6×10^4, flash point of 288^oC and 282^oC and pour point of 44^oC and 47^oC. The gas chromatography analysis showed that the samples contained 46.35% and 7.59% saturates, 21.63% and 64.39% aromatics and 32.03% and 28.01% resins for Agbabu and Yegbata respectively. In comparison with Athabasca bitumen, the results were similar. The assessment and comparison of these properties with the properties of bitumen from Athabasca in Canada reveals that any surface or subsurface crude bitumen gotten from Agbabu and Yegbata in Ondo State, Nigeria can be exploited using similar technologies, if not the same as the technologies being used in Athabasca, Canada

Keywords: *Tar sand, Bitumen, Agbabu, Yegbata, Nigerian Bitumen, Nigeria, Physical properties,*

1. Introduction

Bitumen is a mixture of organic liquids that are highly viscous, black, sticky, entirely soluble in carbon disulphide, and composed primarily of highly condensed polycyclic aromatic hydrocarbons. Bitumen in its natural form is characterised by high viscosity, high density (low API gravity: which is the inverse of crude oil density relative to that of water. This is used to compare crude oil densities of crude oils), and high concentrations of nitrogen, oxygen, sulphur, and heavy metals [1]. Bitumen can also be described as a sticky, tar-like form of petroleum which is so thick and heavy that it must be heated or diluted before it will flow. Bitumen is found in tar sands, which are also a combination of clay, sand and water [2], it is extracted from these tar sands and then refined into oil. At room temperature, it has a consistency much like cold molasses (thick dark syrup produced by boiling down juice from sugar cane; especially during sugar refining). Refined bitumen is the residual (bottom) fraction obtained by fractional distillation of crude oil. It is the heaviest fraction and the one with the highest boiling point, at 525 °C (977 °F). It can also be refined to produce commercial products such

as gasoline, fuel oil and asphalt. Bitumen and extra-heavy oils are unconventional crude oils that generally require additional processing to extract, transport, and refine into petroleum products than conventional oils [3]. These additional steps typically incur additional costs - including investment costs as well as environmental and social costs [3]. As conventional oil reserves decline, oil and gas companies are increasingly turning their attention towards unconventional oils to meet rising global demand for petroleum products.

Nigeria has an estimated 38 billion barrels of extra-heavy oil and bitumen reserves [3]. While this amount is significant, and roughly equivalent to its present conventional oil reserves, this amount is much smaller than Canada's 2.4 trillion barrels and Venezuela's 2.1 trillion barrels [3]. Nigeria has the sixth largest bitumen deposit in the world with most of the reserve found in Ondo state [3]. The discovery of the Nigerian Bitumen dates back to the early 18th century. The history of bitumen in Nigeria goes as far back as 1903 [4]. The Nigerian bitumen reserves are found in Lagos, Ogun, Ondo and Edo States. Nigeria being one of the largest producers of crude oil however, the mid-stream sector of the oil and gas sector has made her heavily dependent on importing refined petroleum products and this includes bitumen. Currently, Nigeria's annual consumption of bitumen is a little over 500,000 metric tonnes and the market has been quite stable and increasing due to the epileptic performance of the Kaduna refinery which is the only refinery in the country that produces bitumen at the moment.

Three potential methods of bitumen extraction in Nigeria are:
1. Small-scale surface mining
2. Large-scale surface mining, and
3. Thermal extraction method.

The depth of bitumen below the surface determines which extraction type is possible. Both thermal extraction and large - scale surface mining operations are most likely to extract bitumen for upgrading into synthetic crude oil and/or other petroleum products. Bitumen from small-scale surface mining is likely to only be economical to use for paving roads. The three types of extraction methods stated above may have environmental impacts [3]. These impacts vary widely. While surface mining completely transforms the entire surface of the mining area, thermal sub-surface extraction renders changes to the underground. Most environmental impacts will directly affect land-based livelihoods throughout Nigeria's bitumen belt. For each type of extraction, impacts are ranked from 'HIGH', or large-scale, significant impact to 'LOW', or smaller- scale, moderate impact [3].

Thermal extraction involves the drilling of wells to extract the bitumen from the subsurface. (75-400m and further below the surface) [3]. Canadian projects currently use two types of thermal extraction methods:
1. Cyclic Steam Stimulation (CSS), and
2. Steam Assisted Gravity Drainage (SAGD).

The existence of bitumen in Nigeria dates back to its discovery in the early 18th century. However, due to the discovery of conventional crude oil in commercial quantities in the early 1960's among other factors, bitumen has since its discovery in Nigeria, remained untapped. Crude oil is a major source of energy in Nigeria and the world in general. For the past three decades, crude oil has been a major source of revenue and foreign exchange for the Nigerian economy. In the recent years, there has been a drastic drop in the price of a barrel of Brent crude to as low as $27.67 and $28.36 for US crude. This occurrence among others has shun more light to the bitumen industry in Nigeria. The techniques involved in extracting bitumen from the subsurface are now being evaluated and compared.

One major problem associated with extracting bitumen from subsurface formations is that it requires more advanced methods than those used to extract conventional oils. This is due to the high viscosity of bitumen. For this reason, coupled with other properties of the bitumen, selecting the most effective recovery method that would have little or no negative impact on the environment has been a major challenge in the bitumen industry.

This research evaluates the physical properties of Nigerian bitumen through laboratory tests (some of which include viscosity tests, specific gravity tests, pour point test, among others) and thus infer the best thermal recovery process for the bitumen deposits.

This study is limited to Nigerian bitumen deposits. Samples were collected from Ondo state in the south-western part of Nigeria. Experiments were conducted with this bitumen samples. The results and inferences made are limited to these samples.

2. Materials and Methods

2.1 Sample Preparation

The tar sand samples were obtained from two (2) different locations in Ondo State. Both samples were collected from locations within latitude 6°38′N and 6°39′N and longitude 4°55°E and 4°34°E of the Greenwich Meridian [5]. Sample A was obtained from Agbabu, situated in Odigbo, Ondo State, Nigeria lying on the coordinates 6°35′0″ North, 4°50′0″ East. Sample B was obtained from Yegbata, Ondo State, Nigeria.

The samples were collected from the surface of the ground from the vast tar sands outcrops and sealed in polythene bags to prevent the oxidation of the hydrocarbons before being taken to the laboratory.

The bitumen samples were extracted from the tar sands using the soxhlet extraction process. Experiments were carried out on the extracted bitumen samples to determine their physical properties. The physical properties determined in the laboratory include:

1. Density
2. Viscosity
3. Flash Point
4. Pour Point
5. Hydrocarbon Content

The Brookfield rheometer was used to determine the viscosity of the bitumen. This rheometers operate by rotating a spindle in the sample. Viscosity is determined by measuring resistance to this rotational force [7], while the flash point of the bitumen was determined with the 'open-cup' test method using the Cloveland open cup apparatus.

For the purpose of this study, the ASTM D97, Standard Test Method for Pour Point of Crude Oils also known as the Manual Method was used to determine the pour point of the bitumen sample as shown in Figure 3-5 below.

2.2 Bitumen Extraction

The obtained tar sand samples were in a solid compact form. As it was difficult to work with the tar sand samples in this form, the samples were crushed into powder and the bitumen was extracted from the tar sand using the soxhlet apparatus, as shown in Figure 1, with toluene as the extraction solvent.

The Soxhlet extractor, invented in 1879 by Franz von Soxhlet, was initially used to extract lipids from solid materials. The extractor only works when the solute being extracted has limited solubility in the solvent in which it is dissolved. This means that the Soxhlet extractor cannot be used to extract ionic salts from polar solvents such as water, because the solubility limit of such salts in water is extremely high. A Soxhlet Extractor has three main sections: A percolator (boiler and reflux) which circulates the solvent, a thimble (usually made of thick filter paper) which retains the solid to be laved, and a siphon mechanism, which periodically empties the thimble.

The soxhlet apparatus operates with the evaporation of gas formed from the heating of the solvent in the flat bottom flask into the condenser and the condensation of this gas back to liquid into the core in the long neck flask (reflux) where it cleans the oil from the pores of the core sample. The process is a continuous cycle that is repeated until the solvent going back into the flat bottom flask appears as a clear liquid.
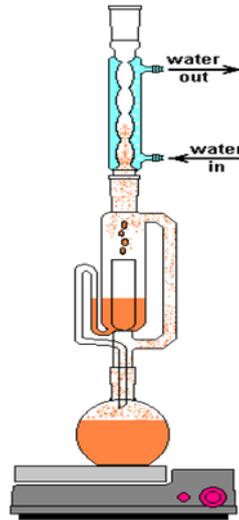
Figure 1. A soxhlet extraction mechanism.

2.3 Density

The density test was carried out using a pycnometer and a weighing balance. The value obtained for the density was then used to estimate the specific gravity and API gravity using standard equations.

Density determination by pycnometer is a very precise method. It uses a working liquid with well-known density, such as water to determine the unknown density of another fluid. For this experiment, distilled water was used as the reference liquid. Pycnometer, a precision piece of glassware consists of two portions: a bottle and a stopper. The bottom portion is a small bottle with a volume which may be accurately determined from the mass of water it holds at a particular temperature. The stopper is a capillary tube with a ground glass (frosted) bottom that fits snuggly into the ground glass (frosted) neck of the bottle [6]. The pycnometer is used in ISO standard: ISO 1183-1:2004, and ASTM standard: ASTM D854. Figure 2 shows the pycnometer being used to determine the density of the bitumen.

Figure 2. A pycnometer on a weighing balance.

2.3.1 Calculations.

The following equations were used to calculate various variables for this study.

Weight of water, m_{H_2O}:

$$m_{H_2O} = Weight\ of\ (Pycnometer - Water - Empty\ Pycnometer) \tag{1}$$

Weight of bitumen sample, m_{AB}:

$$m_{AB} = Weight\ of\ (Pycnometer - Bitumen\ Sample - Empty\ Pycnometer) \tag{2}$$

Volume of pycnometer, V_{pyc}:

$$V_{pyc} = \frac{m_{H_2O}}{\rho_{H_2O}} \tag{3}$$

Since the pynometr was used for both the bitumen sample and water, therefore the volume of bitumen, V_{pyc} is derived from equation (3);

$$V_{pyc} = \frac{m_{AB}}{\rho_{AB}} \tag{4}$$

:

Therefore, the density of bitumen sample, ρ_{AB}

$$\rho_{AB} = \frac{m_{AB}}{V_{pyc}} \tag{5}$$

Specific gravity of bitumen sample, γ_{AB}:

$$\gamma_{AB} = \frac{\rho_{AB}}{\rho_{H_2O}} \tag{6}$$

API gravity of bitumen sample, API;

$$API = \frac{141.5}{\gamma_{AB}} - 131.5$$

2.4 Hydrocarbon Content

The organic composition of the bitumen samples was evaluated by a gas chromatograph (GC).The American Heritage Dictionary defines GC as a physical method of separation in which the components to be separated are distributed between two phases, one being a stationary bed of large surface area, and the other a gas that percolates through the stationary bed. When the stationary phase is a solid, the separation process is more precisely called gas solid chromatography. This technique is generally used to separate gases in a gaseous solution. The more common technique (which was used in this experiment) is gas liquid chromatography (GLC) in which the stationary phase is a porous solid covered with an absorbing liquid. GLC is used to separate a wide variety of organic compounds.

The basic requirements for GLC are that the sample be volatile and that it not decompose in the vaporization process. Since the vaporization occurs in an inert atmosphere, decomposition of the sample is generally not a problem.

For the purpose of this research, a GC with a cool on–column injection port and GC oven cooling fan domiciled in the Department of Chemical and Petroleum Engineering Chemical Analysis Laboratory, Afe Babalola University was used to analize the samples. The GC is automated as the

results obtained were in graphics as shown in Figure 3 and Figure 4. The GC parameters are listed in Table 1.

Table 1. GC parameter setting

S/N	Parameter	Unit	Setting
**Column: Agilent 19091J - 413: 3516. 15684**			
1	Inlet Temperature	^{o}C	45°C
2	Max Temperature	^{o}C	300°C
3	Oven Temperature Program	^{o}C/min	45°C initial temperature hold for 2min then 0.5^{o}C/min to 58°C hold for 0min, then 1.5^{o}C/min to 160°C hold for 0min
4	Total Run Time	min	96mins
5	Carrier Gas Used		Helium (H$_e$)
6	Carrier Flow	mL/min	1.504mL/min
7	Solvent Used		Phenyl Methyl Siloxan
8	Injection Volume	μL	1.0μL
9	FID Temperature		OFF
10	Hold-up Time	Min	1.1215 min
11	Injection Mode		Split

3. Results

3.1 Density

For the experiments carried out to determine the density of the bitumen samples, the following results were obtained:

Table 2. Pycnometer readings for Agbabu bitumen sample

S/N	Description	Value
1	Reference Temperature(^{o}C)	25°C
2	Weight of Empty Pycnometer	26.02g
3	Weight of Pycnometer + Distilled Water	51.93g
4	Weight of Pycnometer + Bitumen Sample	52.23g

Table 3. Pycnometer readings for Yegbata bitumen sample

S/N	Description	Value
1	Reference Temperature (^{o}C)	25°C
2	Weight of Empty Pycnometer	25.70g
3	Weight of Pycnometer + Distilled Water	51.80g
4	Weight of Pycnometer + Bitumen Sample	51.70g

3.2 Viscosity

The viscosity for both bitumen samples were determined at temperatures of 100°C, 80°C, 60°C and 40°C. Table 4 shows the values of the viscosities obtained for each sample at the above stated temperatures.

Table 4. Viscosity values obtained for bitumen samples at various temperatures

S/N	Temperature (^{o}C)	Viscosity (cSt)	
		Agbabu	Yegbata
1	100°C	995.5	1679.4
2	80°C	1365.4	2587.5
3	60°C	3857.2	1.1×10^4
4	40°C	3.3×10^4	5.6×10^4

3.3 Flash Point

The temperatures representing the flash points obtained for both samples are recorded in Table 5.

Table 5. Flash point temperatures for the bitumen samples

S/N	Flash Point Temperature (^{o}C)	
1	Agbabu	Yegbata
	288°C	282°C

3.4 Pour Point

The temperatures representing the pour point obtained for both samples are recorded in Table 6. The actual pour point was estimated by adding $3^{o}C$ to the obtained pour point as stated in the procedures in appendix A.

Table 6. Pour point temperatures for the bitumen samples

S/N	Description	Agbabu	Yegabta
1	Obtained Pour Point (^{o}C)	41	45
2	Estimated Pour Point (^{o}C)	44	48

3.5 Gas Chromatography (GC) Analysis

The results obtained for the GC analysis of the bitumen samples are shown in Table 7 and 8 and the graphs shown in Figure 3 and 4.

Table 7. GC analysis result for Agbabu bitumen

Peak Number	Compound	Chemical Formula	Retention Time (min)	%Area	Hydrocarbon Group
1	p-Xylene	C_8H_{10}	5.362	15.38	Aromatics
	o-Xylene	C_8H_{10}			
2	o-Xylene	C_6H_6	6.244	3.68	Aromatics
	1,3-dimethybenzene	$C_6H_4(CH_3)_2$			
3	2-methylpropyl ether	$C_7H_{16}O$	9.927	1.08	Resins
	1,4-dihydro-(4-methylphenyl)methanol				
4	Benzene, 1,2,3-trimethyl-mesitylene-	$C_6H_3(CH_3)_3$	12.28	2.57	Aromatics
	Benzene, 1,2,4-trimethyl-mesitylene-	$C_6H_3(CH_3)_3$			
5	3-methyl-1-adamantaneaneactic acid pyridine		24.603	8.58	Resins
	Bis(1-methyl) ester				
6	1,2-dimethyl-5-nitroadamantane	$C_{12}H_{19}N_2O_3$	26.236	4.62	Resins
	N-Acetyl-L-tyrosinamide	$C_{11}H_{14}NO_2$			

7	1-methyl-3-ethyladamantane	$C_{13}H_{22}$	33.154	10.45	Saturates
	Pentamethyl pyride				Resins
8	1,3-dimethyl-adamantane	$C_{12}H_{20}$	33.836	4.5	Saturates
	1,4-dimethyl-adamantane	$C_{12}H_{20}$			
9	1,3-dimethyl-5-n-hexyladamantane	$C_{18}H_{32}$	34.831	5.01	Saturates
	1,3-dimethyl-5-n-propylladamantane				
10	1,3,6-trimethyladamantane	$C_{13}H_{22}$	37.871	10.45	Saturates
	1,3-dimethyl-5-n-propylladamantane				
11	1,3,5-trimethyladamantane	$C_{13}H_{22}$	38.421	10.36	Saturates
	1,3-dimethyl-5-n-hexyladamantane-2-propenal				
12	Isophthalic acid, Ethyl 2-methyloct-5-yn-4-yl ester	$C_{22}H_{30}O_4$	38.99	7.29	Resins
	N-dimethylbenzamide	C_9H_{11}			
13	1,3,5-Trimethyladamantane	$C_{13}H_{22}$	42.044	16.03	Saturates
	1,3,4-Trimethyladamantane	$C_{13}H_{22}$			
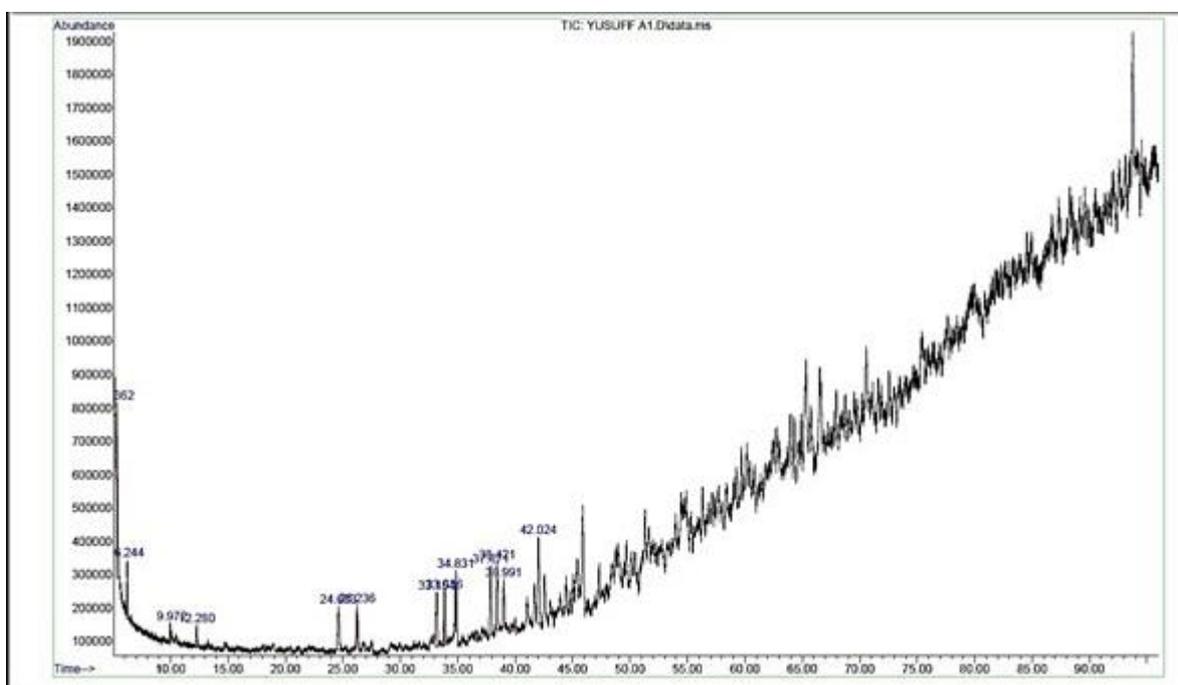
Figure 3. GC analysis graph for Agbabu bitumen.

Table 8. GC analysis result for Yegbata bitumen

Peak Number	Compound	Chemical Formula	Retention Time (min)	%Area	Hydrocarbon Group
1	1, 3-dimethylbenxane	$C_6H_4(CH_3)_2$	5.356	27.71	Aromatics
	p-Xylene	C_8H_{10}			
2	1, 3-dimethylbenxane	$C_6H_4(CH_3)_2$	6.238	6.65	Aromatics
	p-Xylene	C_8H_{10}			
3	Nonane	C_9H_{20}	6.607	1.37	Saturates
4	1-Decene	$C_{10}H_{20}$	9.328	0.99	Saturates
	1R,2c,3t,4t-Tetramethyl-cyclohexane	$C_{10}H_{20}$			
5	Benzaldehyde	C_7H_6	9.953	25.73	Resins
6	Benzene, 1,2,3-trymethyl-	C_9H_{12}	10.448	3.77	Aromatics
	Benzene, 1,2,3-trymethyl-	C_9H_{12}			
7	Benzene, 1-ethyl-3-methyl	C_9H_{12}	11.198	0.83	Aromatics
8	Mesitylene	C_9H_{12}	12.287	12.96	Aromatics
	Benzene, 1,2,4-trimethyl-	C_9H_{12}			
9	Decane	$C_{10}H_{22}$	13.25	3.95	Saturates
	Nonadecane, 1-chloro	$C_{19}H_{39}Cl$			
10	Benzene, 1,2,3-trymethyl-	C_9H_{12}	14.733	3.61	Aromatics
	Benzene, 1,2,4-trymethyl-	C_9H_{12}			
11	Benzene, 1-ethenyl-2-	$C_{13}H_{22}$	15.871	0.93	Aromatics
	Biclo[4.2.0]octa-1,3,5-triene, 7-	C_9H_{12}			
	methyl-	C_9H_{12}			
	Indane				
12	o-Cymene	$C_{10}H_{14}$	18.98	3.57	Aromatics
	Benzene, 1-methyl-3-(1-methylethyl)-	$C_{10}H_{14}$			
	p-Cymene	$C_{10}H_{14}$			
13	Benzene, 1-ethyl-3,5-dimethyl-	$C_{10}H_{14}$	22.089	1.05	Aromatic
	Benzene, -ethyl-1,4-dimethyl-	$C_{10}H_{14}$			
	Benzene, 4-ethyl-1,2-dimethyl-	$C_{10}H_{14}$			
14	Benzene, 4-ethyl-1,5-dimethyl	$C_{10}H_{14}$	26.223	1.99	Aromatics
	Benzene, 4-ethyl-1,5-dimethyl	$C_{10}H_{14}$			
15	Benzene, 1,2,3,4-tetramethyl-	$C_{10}H_{14}$	26.761	1.32	Aromatics
	Benzene, 1-ethyl-3,5-dimethyl-	$C_{10}H_{14}$			
	Benzene, 1-ethyl-2,3-dimethyl-	$C_{10}H_{14}$			

16	c-(3,5-Dimethyladamantan-1-yl) methylamine	$C_{10}H_{20}$	38.434	1.29	Saturates
	Ethanone, 1-(2,3-dihydro-1,4-Benzodioxine-6-yl)	$C_{10}H_{10}O_3$			Resins
	2-Propenal, 3-(2,6,6-trimethyl-1-Cyclohexene-1yl)-	$C_{10}H_{16}O$			Saturates
17	Trans-.beta.lonone	$C_{10}H_{20}O$	39.041	1.31	Resins
	1,3,5,6-Tetramethylladamantane	$C_{14}H_{24}$			Saturates
	2H-1-Benzopyran,3,5,6,8a-tetrahydro-2,5,5,8a-tetramethyl-,trans-	$C_{13}H_{20}O$			Resins
18	2-Propenol, 3-(2,6,6-trimethyl-1-Cyclohexen-1-yl)	$C_{13}H_{22}$	42.031	0.97	Aromatics
	1,3,4,-Trimethyladamantane				
	1(3H)-Isobenzofuranone, 3-[2(2,-Dihydro-1,4-benzodioxin-6-yl)-2-Oxoethyl]				
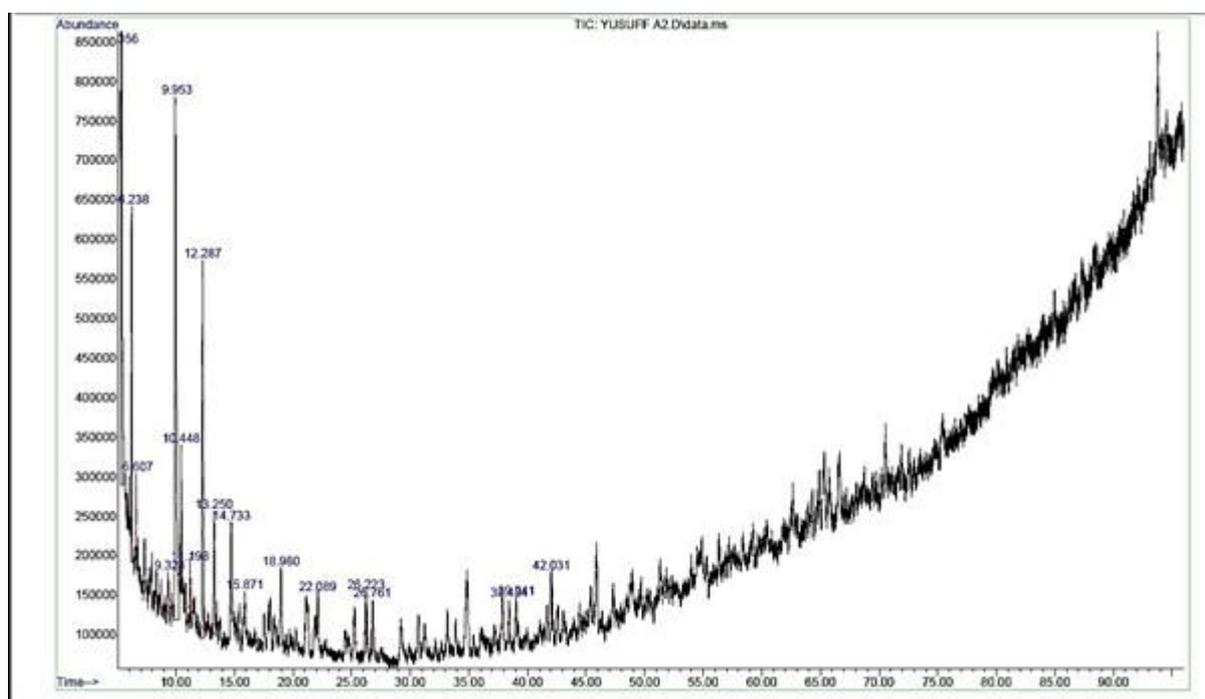
Figure 4. GC analysis graph for Yegabta bitumen

4. Discussion

In summary, the results for all the properties of the bitumen samples are highlighted in Table 9. This Table 9 highlights the properties of the bitumen samples from the two locations in Ondo state Nigeria. Applying equation (5), the values obtained for density for both locations are 1.0085g/cm³ and 0.9932g/cm³ for Agbabu and Yegbata respectively. The result shows that the Agbabu bitumen has a higher density than that of Yegbata,and is also denser than water with density of 0.99705 g/cm³ at the same temperature of 25°C. This indicates that the bitumen would sink while the water floats, if both

samples are mixed at 25°C. These values compare favourably with the density value of 2.24g/cm^3 obtained at Agbabu by Akande [8].

The density obtained for both samples were used to estimate the specific gravity of both samples applying equation (6). The values obtained for specific gravity are 1.01 and 0.9962 at 25°C/25°C for Agbabu and Yegbata respectively as shown in Table 9. The specific gravity values compare favourably with the value 0.92 and 0.95 obtained by Guma *et al.* [9] at two other different locations in Ondo state. It also compares favourably with that of asphalt having 1.013 specific gravity [9]. The specific gravity values were used to estimate, with equation (7), the API gravity values for both locations and values of 8.60^{o}API and 10.54^{o}API were obtained for Agbabu and Yegbata respectively. These values fall within the range of API gravity of bitumen defined by Subramanian *et al* [10] and Lancaster [11].

The temperature values recorded as the flash point for each sample were observed as shown on the Table 5 and Table 9 as 288°C and 282°C for Agbabu and Yegbata respectively. These flash point values lie within the value range of 245°C to 325°C as reported by Guma *et al.* [9] for most bitumen of good grade. The pour point observed for both locations are 44°C for Agbabu and 48°C for Yegbata respectively. These valeus compare favourably with the vales of 44.70^{o}C obtained by Adebiyi *et al.*[29].

Table 9. Comparison of the physical properties of Agbabu, Yebgata and Athabasca bitumen

S/N	Properties		Source of Bitumen		
			Agbabu	Yegbata	Athabasca Tar Sand Bitumen Laricina Energy[27]
1	Density g/cm^3 (25°C)		1.0085	0.9932	1.0077
2	Specific Gravity (25°C/25°C)		1.01	0.9962	1.0143
3	API Gravity ^{o}API		8.6	10.54	8
4	Pour Point (^{o}C)		44	48	
5	Flash Point (^{o}C)		288	282	
6	Viscosity (cSt)	100 ^{o}C	995.5	1679.4	
7		80 ^{o}C	1365.41	2587.5	
8		60 ^{o}C	3857.2	1.1×10^4	
9		40 ^{o}C	3.3×10^4	5.6×10^4	
10	SARA Composition (wt %)				
	Saturates		46.35	7.59	14.5
	Aromatics		21.63	64.39	34.8
	Resins		32.02	28.01	38
	Asphaltenes				12.7

The viscosity of both bitumen samples were observed at various temperatures of 100°C, 60°C and 40°C as shown in Table 4. The kinematic viscosity of Agbabu bitumen ranges from 1.0×10^2 cSt-3.3×10^4 cSt as the temperature decreased from 100°C-40°C. That of Yegbata ranged from 1.6×10^3 cSt-5.6×10^4 cSt as the temperature decreased from 100°C-40°C.

The gas chromatography analysis carried out on the samples showed that the samples contained 46.35% and 7.59% saturates, 21.63% and 64.39% aromatics and 32.03% and 28.01% resins for Agbabu and Yegbata respectively.

4.1 Density

From Table 9, it can be seen that the density of the bitumen samples of both location (Agbabu and Yegbata), obtained was 1.0085g/cm^3 and 0.9932g/cm^3 at 25°C respectively, which has a close range. This similarity also falls within a close range with the value of 2.24g/cm^3 reported by Akande [8]. Comparing this values obtained, with the value of 1.0077g/cm^3 estimated by Strausz [12], it can be seen that there exist minute differences in the density of the bitumen samples and that of the Athabasca bitumen. Yaser *et al.* [13] estimated a value of 1.0129g/cm^3 for the Athabasca bitumen which is also similar to the values obtained for the bitumen for both locations. The Alberta Department of Energy [14] reported values of 1.0136g/cm^3 and 0.9945g/cm^3 for the bitumen density at 15°c and although at lower temperature the values are close.

4.2 Specific gravity and API gravity

The specific gravity obtained for both locations as shown in Table 9 are 1.01 and 0.9962 for Agbabu and Yegbata respectively. The specific gravity of bitumen gives an estimated measure of the amount of lighter hydrocarbons present [15]. Lower specific gravity which corresponds to higher API gravity yields more light fractions during fractional distillation. The values obtained for the samples fall within a close range to each other. These values are also within the range of asphalt standard of 0.9 - 1.013 [15] obtained from the same geological location. This low specific gravity value indicate that the bitumen is of high quality. The specific gravity values compare favourably with the values reported by Guma *et al.* [9].

Generally, API gravity determines the grade of bitumen and its value increases with decrease in specific gravity. Low API gravity as in the case of the bitumen samples used for the study is associated with either bio-degraded oil or with immature sulphur-rich oils.

From Table 9, the API gravity obtained for both location is 8.60 and 10.54. These values show a close range of API gravity values with the range of 8.88 − 10.78^{o}API which falls within the specifications of Nigerian Association of State Highway and Transportation Officials Standard for Road Materials and also compare favourably with the values (1.011, 0995, 1.001) ^{o}API obtained by Onajake and Ndubuka [15]for other samples within the same geographic location and 10.060^{o}API reported by Adebiyi *et al.* [16], for Nigerian bitumen. The range of API when compared with those obtained from Athabasca Canada and Cold Lake bitumen samples with API gravity of 8.1 and 10.8^{o}API respectively, reported by the Alberta Department of Energy [14], compares favourably.

4.3. Viscosity

Viscosity is a measure of internal friction of a liquid to the reluctance of a fluid to flow freely. It therefore indicates the ability of a fluid to flow from the point to another. Kinematic viscosity represents the dynamic viscosity of a fluid per unit density expressed in cSt (Centistoke). Viscosity affects the performance of injection systems [15]. Low viscosity can result in excessive wear in some injection pumps and power loss due to pump and injector leakage. High viscosity fluids on the other hand cause excessive pump resistance or filter damage and higher line pressures [15]. From Table 4, it can be seen that the viscosity for Agbabu bitumen ranges from 995.5 to 3.3×10^4 cSt as the temperature decreased from 100^{0}C to 40^{0}C. For Yegbata bitumen, the kinematic viscosity values range from 1.6×10^3 to 5.6×10^4 cSt as the temperature decreased from 100^{0}C to 40°C. These values agree with the

value range of 4.3×10^3 to 5.6×10^3 cSt reported by Onajake and Ndubuka [15]. These ranges are higher than the value range of 1.8×10^4 to 1.0×10^6 cSt reported by Laricina Energy [17].

The values reported by the Alberta Department of Energy [14] are also lower than the value ranges of the Nigerian bitumen, this agrees with Onajake and Ndubuka [15] report that the Nigeria bituminous sands are higher in viscosity than its Athabasca Counterpart. The high viscosities of the bitumen samples are also attributed to its asphaltene content. This high viscosity is advantageous in that the bitumen in its deposits will not flow into the environment to cause pollution in the event of spillage like the conventional oil will do.

4.4 Flash Point

Flash point measures only the response of the bitumen sample to heat and flame in or controlled laboratory conditions. The values obtained for the flashpoint of the bitumen samples as shown in Table 5 are 288^oC and 282^oC for Agbabu and Yegbata respectively. These values are higher than the 260^oC and 269^oC obtained by Guma *et al.* [9] from samples obtained within the same geographical locations. The values can be seen to fall within the flash point range of 245 to 352^oC reported by Guma *et al.* [9] in assessing the overall flammability hazard of samples, the flash point must be considered.

4.5 Pour Point

Pour point when used in conjunction with the reservoir temperature gives a better indication of the condition of the oil, in the reservoir than does its viscosity, thus it presents a more accurate assessment of the condition of the oil in the reservoir, being an indicator of the mobility of the oil in the reservoir.

For the sampled bitumen, following the pour point determination procedures stated in Appendix A, the temperature values of 44^OC and 48^OC were obtained for Agbabu and Yegbata respectively, with the Agbabu bitumen precise, while the Yegbata bitumen is close to the value of 44.70^OC obtained by Adebiyi *et al*. [16], indicating the very low mobility on the bitumen fluids at reservoir conditions. It also compares favourably with the pour point temperature range of 50 to 100^oC identified by Speint. In summary, the pour point is an important consideration because, for efficient production, additional energy must be supplied to the reservoir by a thermal process to increase the reservoir temperature beyond the pour point.

4.6. GC Analysis

The results obtained from the gas chromatography are shown in Table 7 and Table 8 for Agbabu and Yegbata respectively. The results provide the hydrocarbons present in the bitumen samples from both locations. It gives the chemical formula of the samples, their retention time, mole% area and the group of hydrocarbons to which each belongs. From the tables, it can be seen that there exist no long chain asphaltenes compounds in the bitumen samples from both locations, but there exists saturates, aromatics and resins in both samples. The compositions of these hydrocarbons were used for the SARA composition as shown on Table 9. Form Table 9, it can be seen that the bitumen from Agbabu contains 46.35% saturates, 21.63% aromatics and 32.03% resins and that of Yegbata contains 7.59% saturates, 64.39% aromatics and 28,01% resins.

5. Conclusions

It can be concluded that the samples of bitumen from Agbabu and Yegbata in Ondo State of Nigeria has similar physical properties with Canadian Bitumen. The physical properties of the samples bitumen from Agbabu and Yegbata in Nigeria makes it feasible for exploitation. The bitumen is also can be exploited or developed using the techniques employed in the development of Canadian Bitumen.

Acknowledgments

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