

Original Article

Analysis and Classification of Nigerian Crude Oil Types for Modular Refinery Operations

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Abstract - This study proposed the revampment of the four major refineries and the operation of conventional modular refineries in the localities for efficient and adequate availability of petroleum products. Hence, the research focused on the suitability and operations of the conventional modular refinery process by considering twenty (20) different types of Nigerian crude oil for crude oil assay analysis and classification using Aspen Hysys. The crude oil assay analysis results categorized the twenty Nigerian crude oil types as Sweet crude (sulphur content below 0.5wt%), Light crude oil (API value above 38), and Medium crude oil type (API value between 22 and 28). Also, the Nigerian crude oil types were grouped based on their percentage recovery volume at a true boiling point of 370°C as Group A (crude oil with recovery volume above 80% and residual percentage less than 20%), which is suitable for modular refinery operations in Nigeria. In comparison, Group B (crude oil with recovery volume between 70% and 79% and residual percent of over 20%) and Group C (crude oil with recovery volume below 70% and residual percentage value above 30%) are proposed for modified modular refinery process due to its high residual percent (above 20%) or are transported via pipelines or tankers to the major conventional refinery for the further operational process.

Keywords - Crude Assay, API Value, Watson Factor, Sulphur Content, Recovery Volume, Aspen Hysys.

1. Introduction

Crude oil refining involves subjecting the feedstock to a series of physical and chemical processes resulting in different products being generated. Petroleum refining processes are chemical engineering processes and other facilities used in crude oil refineries (also referred to as oil refineries) to transform crude oil into useful products such as liquefied petroleum gas, gasoline, kerosene, jet fuel, diesel oil, and fuel oils [1]. Crude oil refineries are large industrial complexes with many processing units and auxiliary facilities such as utility units and storage tanks. Each refinery has its unique arrangement, and the combination of refining processes is largely determined by the refinery location, desired products, and economic considerations [2]. In many ways, oil refineries technology is similar to a chemical plant, and crude oil feedstock is processed in an oil production plant before refining. There is usually an oil depot (tank farm) at or near an oil refinery to store incoming crude oil feedstock and bulk liquid products. An oil refinery is considered an essential part of the downstream sector of the petroleum industry [3]. Raw or unprocessed crude oil is not generally useful in industrial applications, although light, sweet crude oil (low viscosity, low sulphur) has been used directly as a burner fuel to produce steam for propulsion seagoing vessels [4]. The lighter elements, however, form explosive vapours in the fuel tanks and are therefore hazardous, especially in warships. Thus, the different hydrocarbon molecules in crude oil are separated in a refinery operation into components that can be used as fuels, lubricants, and as

feedstocks in petrochemical processes that manufacture products such as plastics, detergents, solvents, elastomers, and fibers (nylon and polyesters) [5].

Oil refineries are large-scale plants, processing about a hundred thousand to several hundred thousand barrels of crude oil daily. Due to this high capacity, many units operate continuously instead of processing in batches, at a steady state or nearly steady state for months to years. The high capacity also makes process optimization and advanced process control desirable [6]. Once crude oil is extracted from the ground, it is transported and refined into petroleum products with different values. These products are then transported to end-use consumers or retailers. The overall well-to-consumer supply chain for petroleum products is often segmented into three components [7].

1.1. Upstream Activities

This involves exploring crude oil deposits and the production of crude oil. Examples of firms that would belong in the upstream segment of the industry include companies that own rights to drill for oil, such as ExxonMobil and companies that provide support services to the drilling segment of the industry, such as Halliburton [7]

1.2. Midstream Activities

This involves the distribution of crude oil to refiners, refining crude oil into saleable products, and distributing products to wholesalers and retailers. Examples of firms



that would belong in the midstream segment of the industry include companies that transport oil by pipeline, truck, or barge, such as Oando Plc, and companies that refine crude oil, such as the Nigerian National Petroleum Corporation [7]

1.3. Downstream Activities

This involves the retail sale of petroleum products. Gasoline stations, commonly referred to as filling or petrol stations in Nigeria, are perhaps the most visible downstream companies, but companies that deliver heating oil or propane would also fall into this category [7]

Crude oil combines many different hydrocarbons, varying compositions, and complexities. To separate the crude oil into different components that make up the raw natural resource, crude oil must be refined (refinery process) so that components can be removed according to their temperature difference (Boiling points) [8]. Thus, the Nigeria government owns and operates four major refineries through the Nigerian National Petroleum Corporation (NNPC), namely, the old and new Port-Harcourt Refining Company (OPHRC and NPHRC), Kaduna Refining and Petrochemical Company Limited (KRPC), and Warri Refining and Petrochemical Company Limited (WRPC). Despite these refineries, 80% of petroleum products consumed in Nigeria are based on the importation, as the refineries operate at less than 20% to 25% of their original capacities [9, 10]. Therefore, the dependency on importing petroleum products in Africa's largest crude oil producer, Nigeria, has led to a continuous and continual scarcity of petroleum products. In addition, illegal refineries that feed on stolen crude oil abound in Nigeria with associated operational and production hazards such as environmental pollution, theft, fire safety risk, poor quality petroleum products, etc. [11]. To curb the ongoing and continual scarcity of petroleum products and environmental hazards associated with illegal (local) refineries and reduce the importation of petroleum products, the existing refineries must be revamped and operated at full capacity.

In contrast, new refineries are built by partnering with the private sector, thereby leading to deregulation [12]. Since the construction of major refineries is capital intensive and time-consuming, modular refineries have been licensed as a panacea to the scarcity of petroleum products to meet local demands in Nigeria, thereby enhancing the availability of good quality products by eliminating illegal refineries and their associated environmental hazards. Therefore, this research study focused on analyzing and classifying Nigerian crude oil types as effective feedstocks for conventional modular refinery operations by performing crude oil assay analysis on available Nigerian crude oil types using Aspen Hysys to determine their properties, compositions, and recovery volume. Crude oil characterization and product cut fraction evaluation at process recovery temperature.

2. Materials and Method

The materials applied in this research study include twenty (20) different types of Nigerian crude oil, API values, Watson characterization factor, sulphur content, Aspen Hysys Version 10, etc. Thus, the following procedures are applied in carrying out this research study.

2.1. Crude Oil Assay

This research study involved crude oil assay analysis on twenty (20) different types of Nigerian crude oil from different oil fields using Aspen Hysys Version 10 to determine their compositions, properties, and product cuts and ascertain their suitability as feedstock for modular refinery (topping plant). Thus, crude oil assay consists of a compilation of data on the properties and composition of crude oils. The assay provides critical information on the suitability of crude oil for a particular refinery and estimates the desired product yields and quality. It also indicates how extensively a given crude oil should be treated in a refinery to produce fuels that comply with environmental regulations. A crude oil assay includes the following major specifications: API gravity, total sulfur (% wt), pour point ($^{\circ}\text{C}$), viscosity @ 20°C (cSt), viscosity @ 40°C (cSt), nickel (ppm), vanadium (ppm), total nitrogen (ppm), total acid number (mgKOH/g), distillation data, Watson characterization factor. Thus, these parameters are evaluated and used in determining the nature or grade of the crude oil type (light, medium, heavy, sweet and sour crude). In addition, the crude oil assay analysis results showed general information about the crude weight percentage of pure crude components, crude properties, and true boiling point distillation.

2.2. Crude Oil Classification

Besides, the twenty (20) Nigeria crude oil types were characterized after crude oil assay analysis to determine products recovery temperature range and product cut fractions.

3. Results and Discussion

The results of the crude oil assay analysis carried out on twenty (20) Nigerian crude oil types using Aspen Hysys comprise the crude oil general information (crude name, oil field, location, assay ID, etc.), pure components weight percent (methane, ethane, propane, isobutene, normal butane, isopentane, normal pentane, benzene, cyclopentane, C_6 -naphthene, C_6 -paraffins, C_7 -paraffins, C_7 -naphthenes, and toluene), crude oil properties (API, sulphur content, kinematic viscosity at 50°C , 100°C , 150°C , nitrogen, vanadium, nickel, asphaltenes, Watson characterization factor, wax content, total acid number and pour point) and true boiling point distillation. Therefore, based on the crude oil assay results, the twenty (20) Nigeria crude oil types are classified as light crude (API value above 38) and medium crude (API value between 22 and 38) but no heavy crude (API value below 22). Also, these crude oil types are sweet crude since their sulphur contents are generally less than

0.5wt% (Sour crude oil sulphur content is above 0.5wt%), and the Watson characterization factor of the twenty (20) crude oil types is slightly above 11. Thus they are neither highly paraffinic nor highly naphthenic crude. The classification of the Nigerian crude oil types is shown in Table 1, with their recovery volume and sulphur weight contents percentage depicted in Figures 1 and 2, respectively. Also, based on the recovery volume of each type of crude oil at an operating temperature of 370°C from the assay result in analysis results, the Nigeria crude oil types are grouped into three based on recovery volume and residual percentages, as shown thus. Therefore, Group A Nigerian crude oil types yielded a high recovery volume of over eighty percent (80%) and above and relatively low residual value, as shown in Figures 3 and 4, respectively, thereby making them useful as precursors or feedstocks for conventional modular refinery operation. In addition, Group B and Group C, with recovery volumes between 70% and 79% and below 70%, respectively, are unsuitable for conventional modular refinery operation in Nigeria due to their high residual values (above 20%).

Table 1. Classification of Nigeria Crude Oil Types

S/N	Crude Oil Type	Classification
1	Agbami 2012	Light Sweet Crude
2	Akpo Blend 2011	Light Sweet Crude
3	Akpo 2014	Light Sweet Crude
4	Amenam Blend 2011	Light Sweet Crude
5	Nigeria Brass 2012	Light Sweet Crude
6	Oso Condensate 2016	Light Sweet Crude
7	Bonny Light 2011	Medium Sweet Crude
8	Brass River 2011	Medium Sweet Crude
9	Erha 2012	Medium Sweet Crude
10	Forcados Blend 2014	Medium Sweet Crude
11	Nigeria Brass 2015	Medium Sweet Crude
12	Okwori 2011	Medium Sweet Crude
13	Okwuibome 2014	Medium Sweet Crude
14	Qua Iboe 2012	Medium Sweet Crude
15	Bonga 2012	Medium Sweet Crude
16	Okoro 2012	Medium Sweet Crude
17	Nigeria Forcados 2012	Medium Sweet Crude
18	Bonga 2014	Medium Sweet Crude
19	Usan 2013	Medium Sweet Crude
20	Usan 2015	Medium Sweet Crude

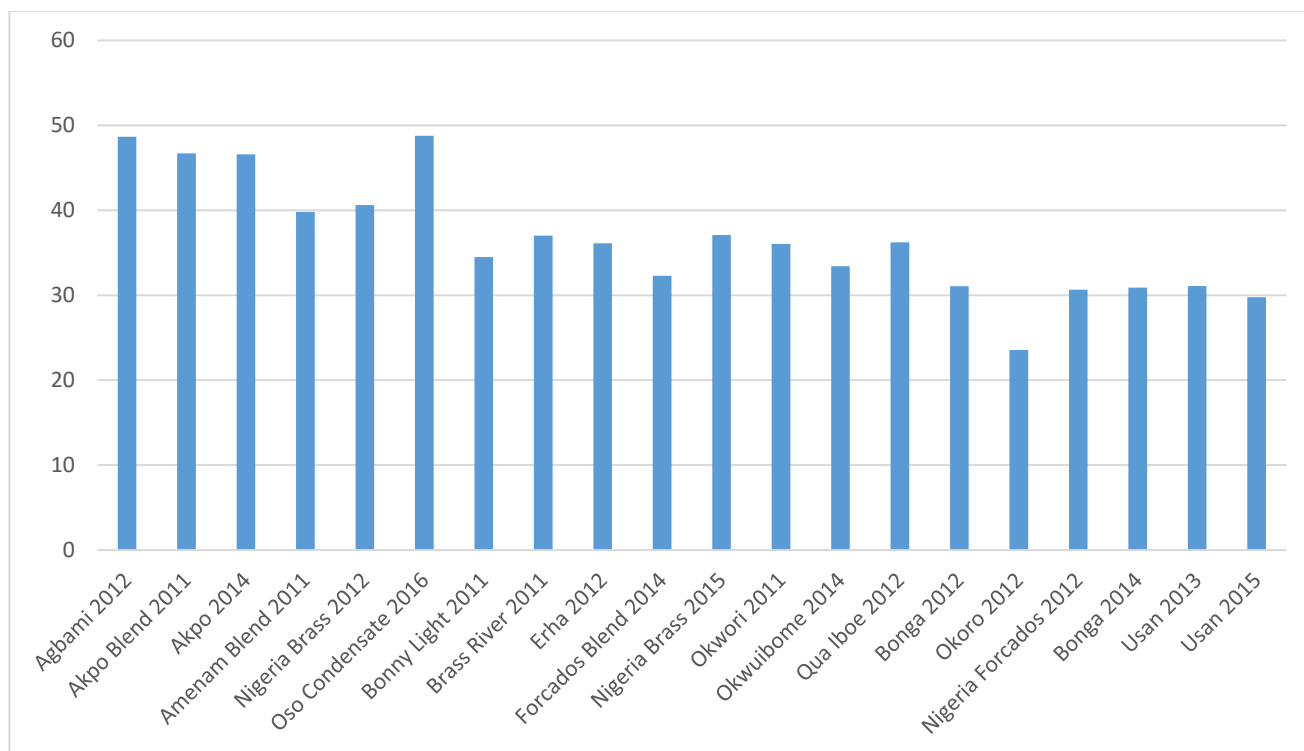


Fig. 1 API Values of Nigerian Crude Oil Types

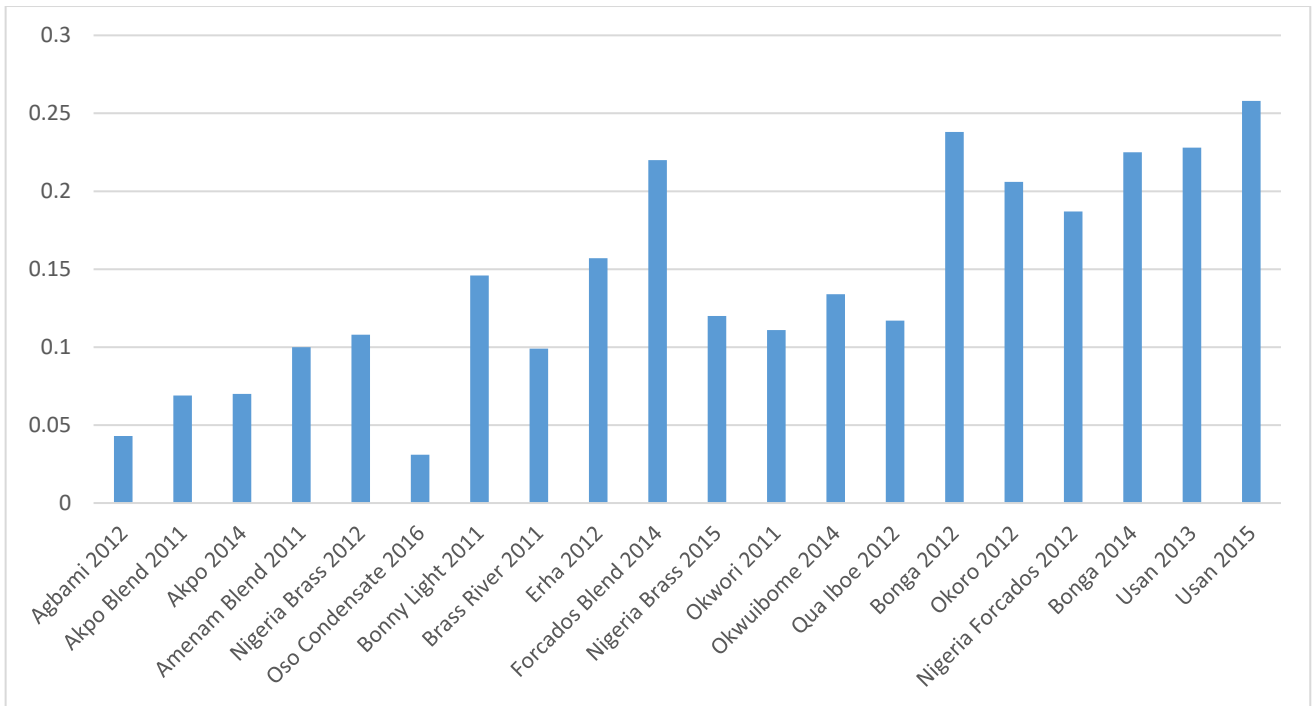


Fig. 2 Sulphur Contents Weight Percent of Nigerian Crude Oil Types

3.1. Group A Nigerian Crude Oil Types

Group A Nigerian crude oil types referred to crude oil with a high recovery volume of eighty percent (80%) and above and relatively low sulphur contents below 20%, as shown in Figures 3 and 4, respectively. These crude oil types include Nigerian Brass 2012, Brass River 2011, Oso Condensate 2016, Agbami 2012, Erha 2012, Akpo 2014, Akpo Blend 2011, and Forcados Blend 2014.

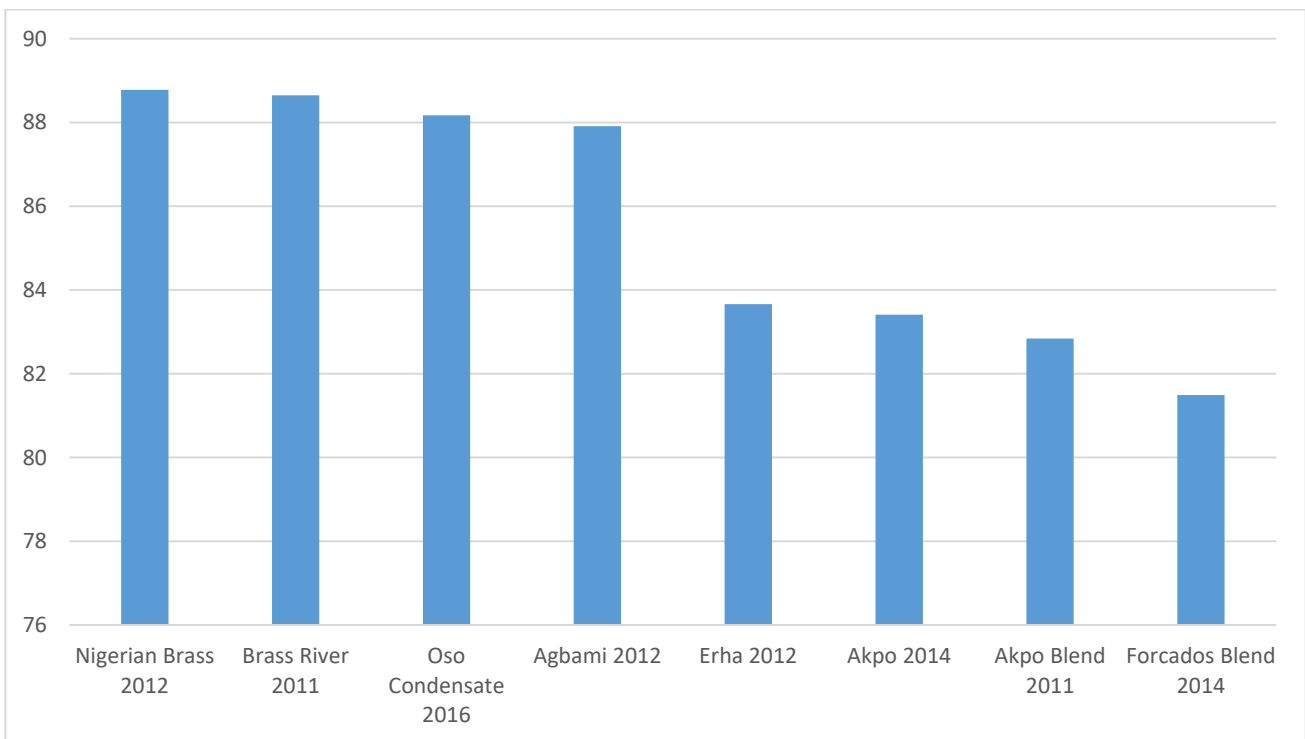


Fig. 3 Group A Nigerian Crude Oil Types Recovery Volume

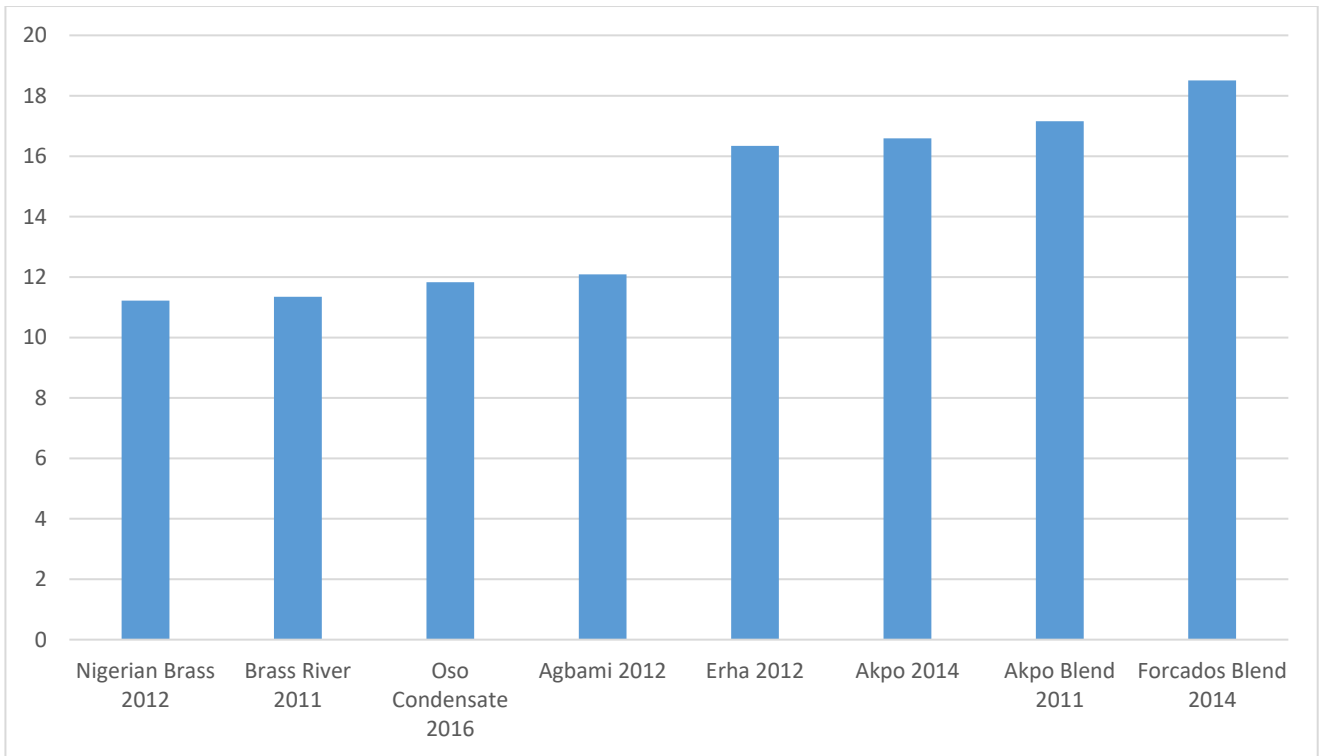


Fig. 4 Group A Nigerian Crude Oil Types Residual Percent

3.2. Group B Nigerian Crude Oil Types

Also, Nigerian crude oil types with recovery volume percent between 70 and 79 and residual percent less than 30% are categorised as Group B as shown in Figures 5 and 6, respectively. The group B Nigeria crude oil types are Nigerian Brass 2015, Okwori 2011, Amenam Blend 2011, Bonny Light 2011, and Qua Iboe 2012.

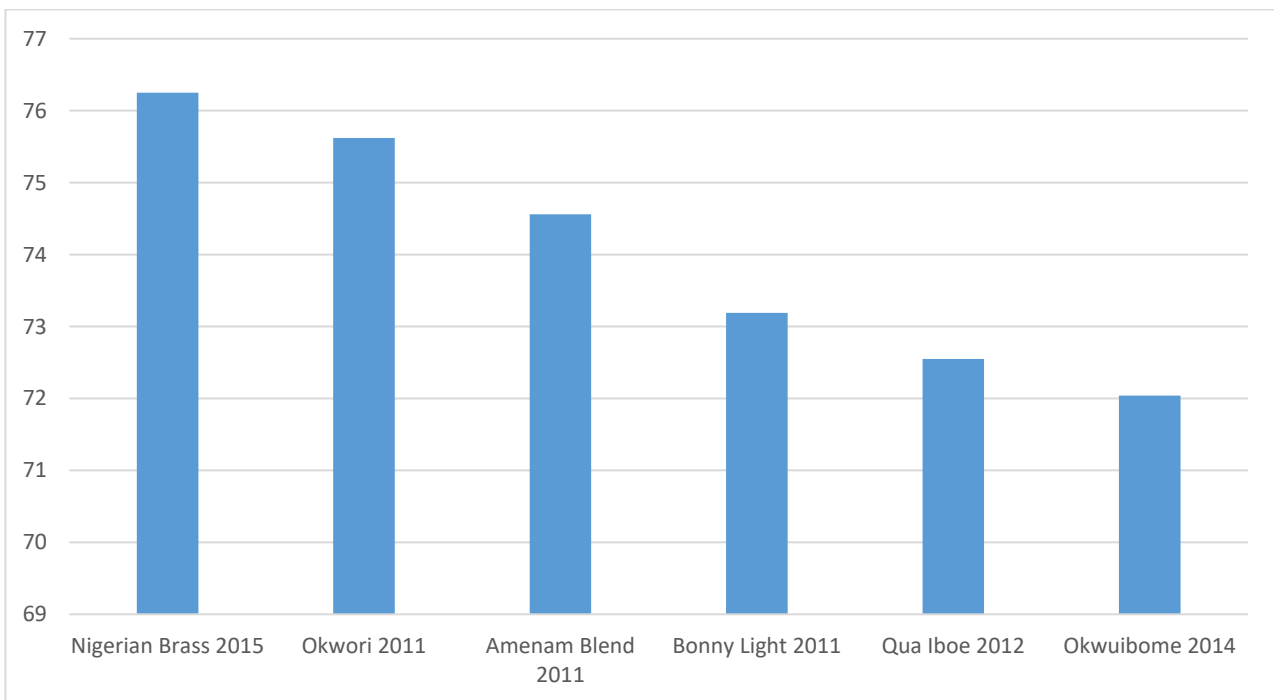


Fig. 5 Group B Nigerian Crude Oil Types Recovery Volume

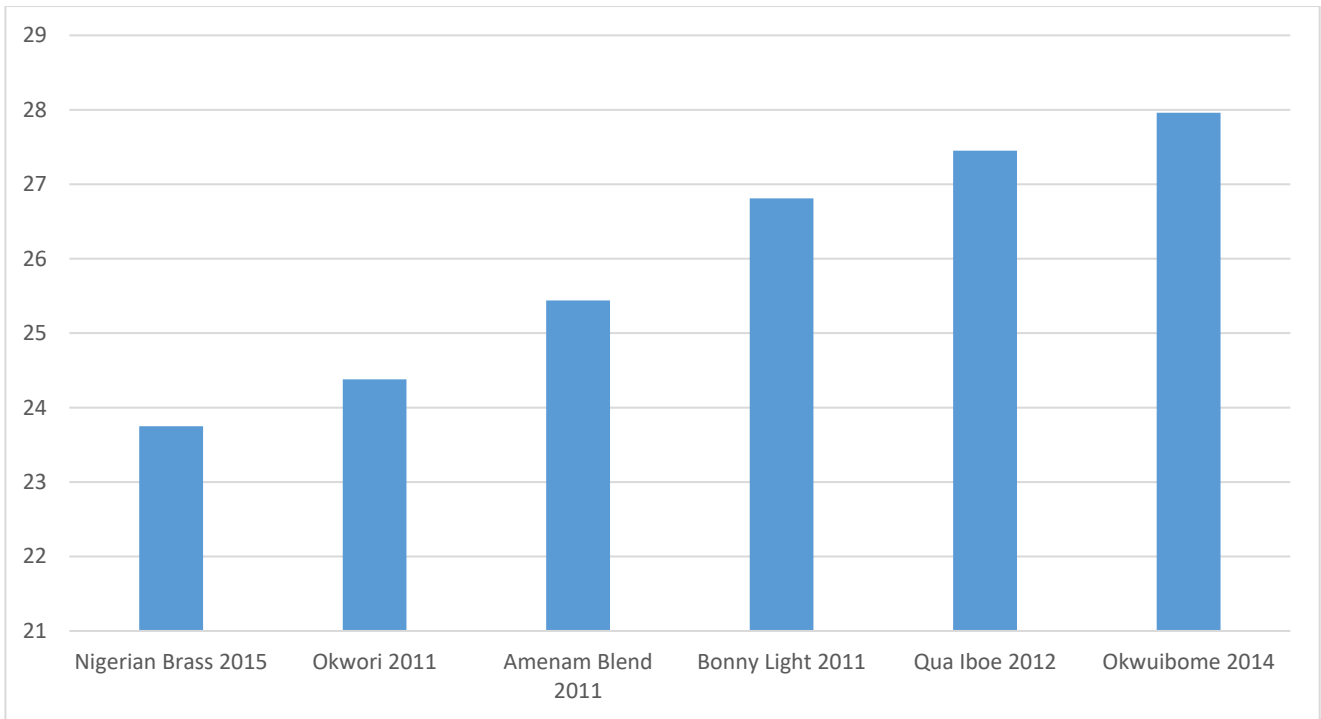


Fig. 6 Group B Nigerian Crude Oil Types Residual Percent

3.3. Group C Nigerian Crude Oil Types

Besides, Nigerian crude oil types with percentage recovery volume below 70%, and residual percentages of 30% and above are categorised as Group C, as shown in the figures thus. These crude oil types include Nigerian Forcados 2012, Bonga 2012, Bonga 2014, Usan 2013, Usan 2015, and Okoro 2012.

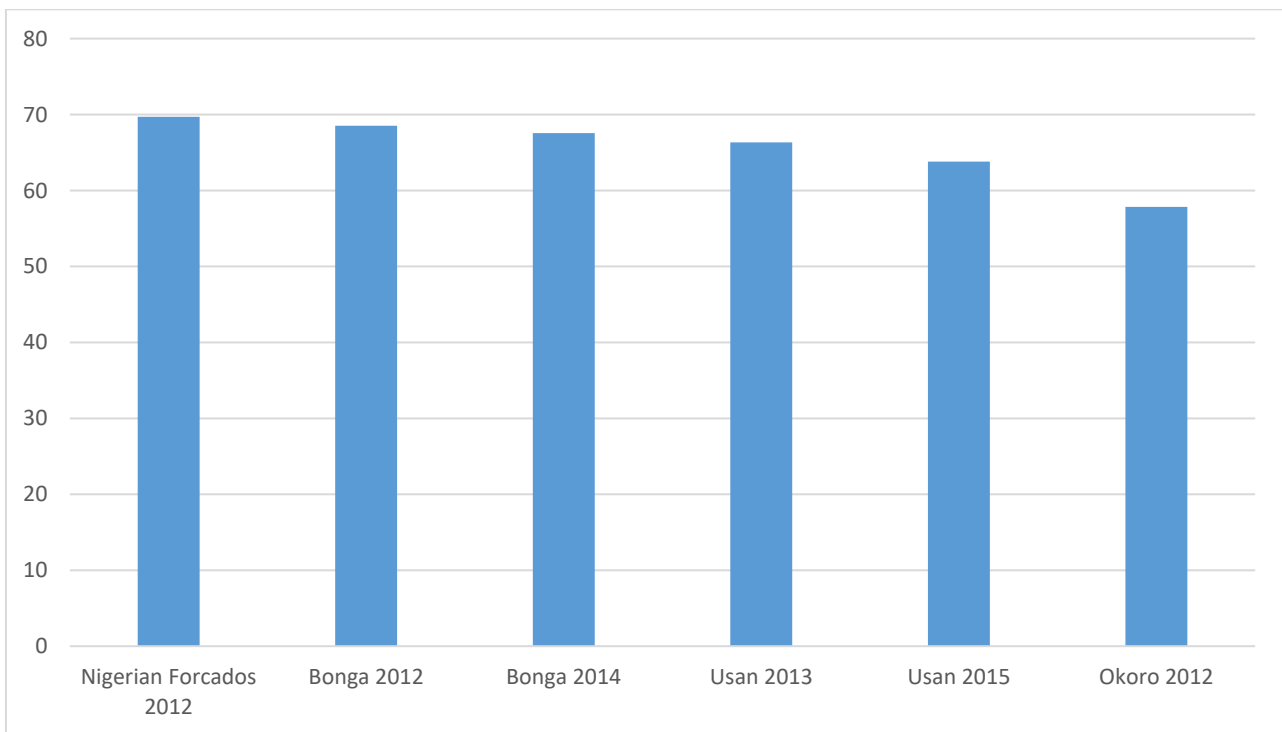


Fig. 7 Group C Nigerian Crude Oil Types Recovery Volume

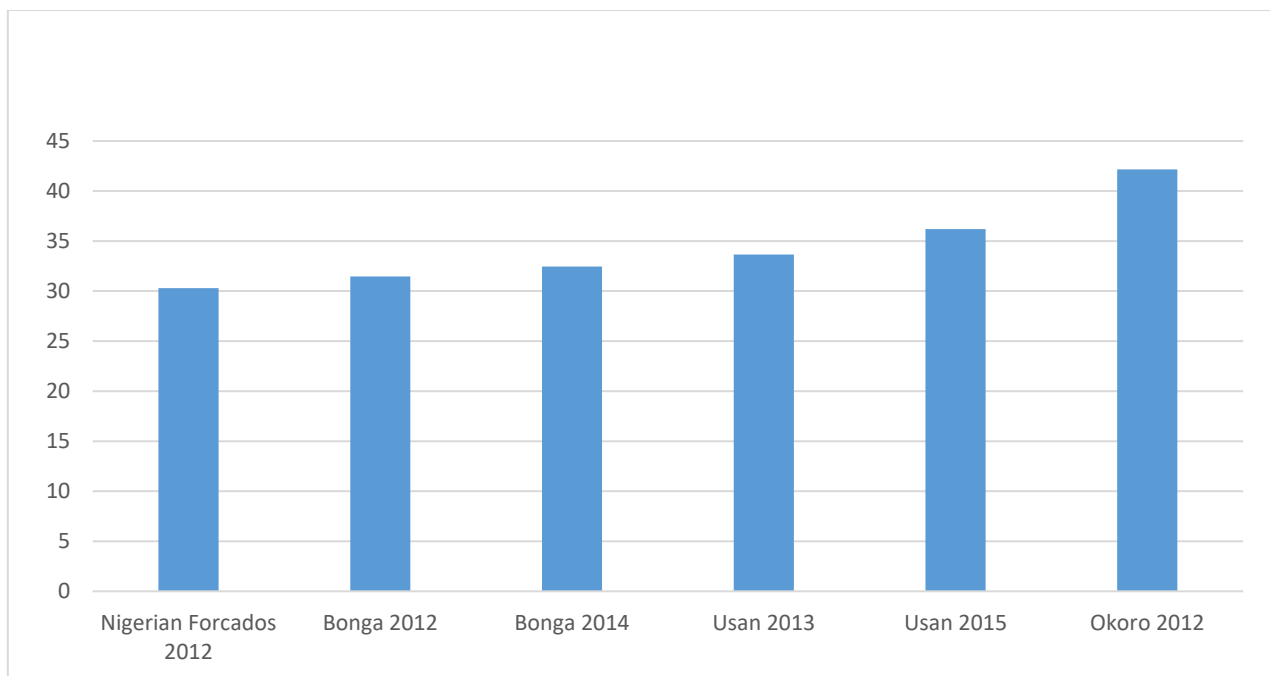


Fig. 8 Group C Nigerian Crude Oil Types Residual Percent

Therefore, it can be deduced from the above figures that Group B and Group C of Nigerian crude oil types with recovery volume generally less than eighty percent (below 80%) consist of a high percentage of residue (above 20%). Thus, these crude oil types can be processed by conventional modular refineries (Topping plant). Still, their high percentage residual volume is a major constraint or restriction and the need to process the residue into more valuable products. Hence, Group B and Group C Nigerian crude oil types are more suitable and recommended for modified modular (topping plant) refinery operations or application of pipeline networks or tankers for transporting these residues to major conventional refineries refinery operational processes to more valuable petroleum finished products.

4. Conclusion

Twenty (20) different types of Nigerian crude oil were analysed and classified for modular refinery operations in Nigeria as a panacea to reduce the scarcity of petroleum

finished products and importation of finished products in oil-producing nations. The analysis results of the crude oil types (crude oil assay and classification) were carried out using Aspen Hysys. The results shown above reviewed that most Nigerian crude oil types are light, medium, sweet, and moderate crude oil (neither highly paraffinic nor highly naphthenic) but no heavy crude oil among the twenty types investigated based on API values, sulphur contents, and Watson characterization factors respectively. Also, the results of this study grouped the twenty crude oil types into three based on their recovery volume and residual percent, which are in tandem with other previous studies' results [8, 13, 14, 15]. Still, it should be noted that this research study only analysed twenty different Nigerian crude oil types, as the other study's analysis was maximally based on four crude oil types. Thus, Nigeria crude oil Group A types are good, suitable, efficient, and recommended for conventional modular refineries. In contrast, Group B and C are recommended mainly for modified modular refinery operations, respectively.

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