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Production of Fuel Oil from Blends of Refinery Products for Powering Heat Exchanger

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ABSTRACT

Fuel oil, also known as furnace oil is a fraction of crude oil obtained when distillation processing is carried out in the refinery. Due to the high viscous of the heavy fuel oil, that makes it difficult to be pump throughout the pipework of the power plant, it is necessary to produce a fuel oil that will meet up the required standard. The aim of this study was to produce fuel oil from the blend of refinery intermediate product which meet certain European fuel specifications outlined in the EN 590:2009 standard alongside NMDPRA Standards. The blending stocks obtained from the Warri Refinery and Petrochemical Company (WRPC) were first filtered to remove some particulate impurities before they were analyzed to determine their properties after which, they were introduced into a mixed-tank that has an agitator connected and the blending was done using the blending ratio obtained from literature. The fuel oil produced was eventually analyzed for properties such as: Specific Gravity, API Gravity, Density, Viscosity, Kinematic Viscosity, Moisture Content, Flash Point, Cloud Point, Pour Point and Sulphur content. The sample with a composition of 33.3% of Decant oil (DCO), 33.3% Heavy gas oil (HGO), 33.3% light cycle oil (LCO) produced fuel oil of specific gravity 0.916, API Gravity 22.95, Density 0.896, Viscosity 40, Kinematic viscosity 4.7, pour point -6.5 and flash point 109, The analysis of the fuel oil meet the standard for blended fuel oil, according to the ISO 8217:2017 Standard. The results confirmed that blending of decant oil with conventional petroleum diesel (heavy and light gas oil) has a highly significant effect on the properties of the resulting fuel blend. The results show that by increasing the heavy gas oil content of the blend, the flash point of the blend increases; while increasing the decant oil content of the blend results in a decrease in Cloud point. The results of the analysis of the produced fuel oil confirms that its properties fall within the acceptable range for Fuel Oil and can be used as fuel for fired heaters and furnaces of the refinery and other process plants.

KEYWORDS: Fuel oil, heat exchanger, blend of refinery products, Blending, fired-heater

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1 | INTRODUCTION

In this modern age, the world at large depends on all sort of energy to power our utilities, whether it is fossils, renewable or kinetic energy sources [1]. Our energy demands have increased greatly since the industrial revolution and fossil fuels produced the amount we require to meet this growing demand. These fossil fuels include coal and natural gas, but in the course of this study, we explored the third-oil also known as fuel oil. Fuel is a substance that is burnt to provide nuclear energy, heat or power [2]. The energy that is released is generally in the form of chemical energy or heat energy is used for various purposes such as boiling in boilers, steaming in heaters, for many industries and manufacturing purposes.

At other times, we use an engine to convert the heat energy into mechanical energy like when we use gasoline to run our cars. The oil which is used as fuel in the engine is known as fuel oil [3]. Fuel oil, also called furnace oil, are fuel consisting of mainly residues from crude oil distillation [4]. It is primarily for steam boilers in power plants, abroad ships and in industrial plants. Fuel oil is used as fuel in an engine or furnace. Commercial fuel oils are usually blended with other petroleum to produce the desired viscosity and flash point. The flash point is usually fractions than that of kerosene. The term fuel oil ordinarily does not include such fuels as kerosene [5].

Fuel oils are yellowish to light brown liquid mixtures produced from crude petroleum by means of different refining processes, depending on their intended use. They generally have a kerosene-like odor and are flammable [6]. Fuel oils are composed of complex and variable mixtures of aliphatic (alkanes, alkenes, cycloalkanes) and aromatic hydrocarbons, containing low percentages of sulfur, nitrogen and oxygen compounds. The exact chemical composition of each of the fuel oils may vary depending on the source, the refinery involved, the presence of additives or modifiers, and other factors. The composition can be further affected by weathering or biological modification on release to the environment [3],[7].

Fuel oil differs from one another primarily by their hydrocarbon compositions, boiling point ranges, chemical additives, and uses. Fuel oils may be generally classified into two main types: distillate fuel oils and residual fuel oils [8]. Distillate fuel oils are vaporized and condensed during a distillation of thermal cracking, and are generally more complex in composition and impurities than distillate fuel oils.

Small molecules, such as those in propane, naphtha, gasoline for cars, and jet fuel (kerosene), have relatively low boiling points, and are removed at the start of the fractional distillation process. Heavier petroleum products like diesel fuel and lubricating oil are much less volatile and distill out more slowly, while bunker oil is literally the bottom of the barrel [1],[7],[9]. In oil distilling, the only components denser than bunker fuel are carbon black feedstock and bituminous residue (asphalt), which is used for paving roads and sealing roofs.

Fuel oil covers all residual fuel oils, including those obtained by blending. It is divided into two categories depending on its sulfur content; low sulfur fuel oil, where the sulfur content is lower than 1% and high sulfur fuel oil where the sulfur content is 1% higher. Residual fuel oils contain residues from crude distillation of thermal cracking, and are generally more complex in composition and impurities than distillate fuel oils. The American Society for Testing and Materials (ASTM) D396 standard divides fuel oils into several classes, from fuel oil no. 1 to fuel oil no. 6, based on boiling range, composition, and other physical properties. Usually, fuel oils nos. 1 and 2 are distillate fuels; fuel oils nos. 5 and 6 are residual fuels, and fuel oil no. 4 is a blend of distillate and residual fuels. Fuel oils have a moderately broad range of volatility and solubility; thus, fuel oils nos. 1 and 2 are moderately soluble and volatile, while fuel oils nos. 4, 5, and 6 are not very soluble. All diesel oils are considered types of fuel oils. Fuel oils no. 1-D and no. 2-D (diesel oils) are similar in chemical composition to fuel oils no. 1 and no. 2, respectively, with the exception of the additives.

Determining the optimal blend ratio of decant oil, light cycle oil, and heavy gas oil to achieve the desired properties and characteristics of the fuel oil one of the major problems. This involves evaluating the individual properties of each component and finding the right combination to meet regulatory specifications and market demands. Furthermore, addressing environmental concerns related to fuel oil production, including emissions of greenhouse gases and other pollutants is also key. Developing strategies to reduce the environmental footprint of the production process is crucial for sustainability and regulatory compliance.

In addition, sulfur and vanadium are present in high concentrations in heavy fuel oil and therefore require the addition of special treatment chemicals to reduce the corrosion effects on boilers and storage tanks. Large storage tanks are required and must be kept full to prevent moisture build up from condensate. Moisture converts the sulfur content of the fuel to an acidic form which rapidly corrodes metal tanks.

Due to the lack of storage facility for refinery intermediate products such as light cycle oil, vacuum residue and decant oil, refinery intermediate products cannot be stored, thereby leading to the disposal of refinery intermediate products into the environment which causes environmental pollution, which is harmful to human health.

2 | MATERIALS AND METHOD

This study is divided into four steps which are:

2.1 Materials

The following is a list of materials used for the production of the Fuel oil: 1-Light Decant Oil, 2-Heavy Gas Oil, 3-Light cycle oil

Figure 1:Refinery intermediate products (Decant oil, Heavy gas oil, light cycle oil)

The blending stocks were acquired from the Warri Refining and Petrochemical Company (WRPC), Ekpan, Delta State, Nigeria.

2.2 Experimental Procedure

The blending stocks obtained from the WRPC (Warri Refinery and Petrochemical Company) were first filtered to remove some particulate impurities before they were analyzed to determine their properties after which, they were introduced into a mixed-tank that has an agitator connected and the blending was done using the blending ratio obtained from literature. The fuel oil produced was eventually analyzed for properties such as: Specific Gravity, API Gravity, Density, Viscosity, Kinematic Viscosity, Moisture Content, Flash Point, Cloud Point, Pour Point and Sulphur content.

2.3 Analytical Procedure

American Petroleum Institute established (API) gravity measure as a measure of the density of petroleum liquids relative to water. The greater the API gravity, the less dense the liquid. The scale of API gravity was adjusted so that most petroleum liquids fall between 10 and 70 degrees API gravity. The formula can be reversed to find the density of the petroleum liquid. Add 131.5 to the API gravity. The formula for API gravity is API = (141.5/SG) -131.5 where SG is the specific gravity of the petroleum liquid being measured.

Some of the key parameters are defined below and formulae for obtaining required results from the experiments:

Specific Gravity and Density: 25ml of pyrometer bottle was washed, dried and weighed. The bottle was filled with water and weighed. The bottle was emptied, dried and filled with the extracted watermelon seed oil and weighed.

Calculation:

$$\text{Specific Gravity} = \frac{\text{weight of 50 ml of oil}}{\text{weight of 50 ml of water}} \quad [1]$$

$$\text{Density (g/l)} = \frac{\text{weight of 50 ml of oil}}{\text{Volume of 50 ml of oil}} \quad [2]$$

Dynamic Viscosity: This is the opposite of flow of liquid. It is expressed in mm^2/sec or Pa/s or kg/ms. The viscosity of the oil was determined using Brookfield Digital rotational viscometer.

Kinematic Viscosity: It's the ratio of dynamic viscosity to density

$$\text{Kinematic viscosity} = \frac{\text{Dynamic viscosity}}{\text{Density}} \quad [3]$$

Flash Point (ASTMD 93): The flash point was determined using a small strong heat resistance glass cup and a heating mantle. The sample was poured into the cup and heated gradually while being stirred to distribute heat uniformly in the cup and the temperature was monitored using a thermometer. At regular interval temperatures, the cup was exposed to naked flame, the temperature at which the sample increases the flame like a flash but does not supports combustion was recorded, which was the flash point of the sample. The temperature at which the sample catches fire (supports combustion) was noted and recorded which gives the fire point of the sample.

Figure 2: Closed - cup flash point tester

Cloud Point and Pour Point: The sample was poured in a test tube to a certain level and a thermometer was inserted and sealed alongside with the test tube. It was then placed in the Cloud point/Pour point tester and monitored at intervals, the temperature at which some traces of cloudy suspension appear in the test tube was noted which is the cloud point of the sample and the temperature at which the sample solidifies (freezes) was noted which is the pour point of the sample.

2.4 Experimental Design

In order to have the best proportion of components which will yield the standard fuel that is required, it is necessary for experimental design of the component mixture. To achieve this, sample A to H was formulated and the best of the mixture component was selected. Table 1 shows the different sample.

Table 1: **Composition of Samples**

Sample	% vol of component Composition			Volume Ratio		
	Decant oil	Heavy gas Oil	Light Cycle oil	Decant oil	Heavy gas oil	Light cycle oil
A	50	25	25	0.5279	0.2639	0.2639
B	25	50	25	0.2639	0.5279	0.2639
C	25	25	50	0.2639	0.2639	0.279
D	40	30	30	0.4390	0.3293	0.3293
E	30	40	30	0.3389	0.4519	0.3389
F	30	30	40	0.913	0.3285	0.3285
G	60	30	10	0.7573	0.3787	0.1262
H	33.3	33.3	33.3	0.3717	0.3717	0.3717

3 | RESULTS AND DISCUSSION

The tables below highlight the results obtained after the analysis of fuel oil from blends of the feed stocks (decant oil, heavy gas oil, and light cycle oil) using the ASTM D2622 method. Physicochemical analysis on petroleum products before blending is presented in Table 2.

Table 2: Physicochemical analysis on petroleum products before blending.

S/N	Properties	Light cycle oil	Heavy gas oil	Decant oil	ASTM standard fuel oil
1	Specific Gravity (@ 30°C)	1.006	0.899	0.904	0.860
2	API Gravity (@ 30°C)	9.137	25.758	24.870	30
3	Density (g/cm^3) (@ 30°C)	0.984	0.880	0.885	0.890
4	Viscosity (mPas) (@ 30°C)	152	27	83	40
5	Kinematic Viscosity	13.1	1.6	7.9	5.8

	(mm^2/sec) (@ 100°C)				
6	Moisture Content (%)	6.4	4.2	4.9	<10
7	Flash Point (°C)	115	85	101	130
8	Cloud Point (°C)	-4.54	-0.3	-2.2	-16
9	Pour Point (°C)	-18	-3.9	-6.3	-7
10	Sulphur (mg/l)	6.3	1.3	2.9	0.5
11	Sedimen	2.1	3.2	2.8	1.0

The properties of Fuel Oil obtained from Sample A is presented in Table 3. The table shows the physicochemical analysis on the fuel oil sample, the Specific Gravity (@ 30°C) obtained was 0.968 which is above the minimum standards for a marketable fuel oil of 0.82 – 0.95. The API Gravity (@ 30°C) obtained was 14.632 and this was used to classify the fuel oil, as heavy oil. The Density (g/cm3) (@ 30°C) obtained was 0.947. The product density is an important factor in the onboard purification of the fuel oil, the higher the density, the more critical it becomes. The Viscosity (mPas) (@ 30°C) obtained was 33 while Kinematic Viscosity (mm2/sec) (@ 100°C) was 4.3. The analysis of the fuel oil does not meet the standard for blended fuel oil as the minimum viscosity is 5.80 mm²/s at 100°C, according to the ISO 8217:2017 Standard. The Moisture Content (%) of the fuel obtained was 5.1 while the Flash Point (°C) obtained was 106 and this further makes the fuel oil classifiable as DMX- Marine Distillate fuel X. The cloud point and pour point obtained was -2.3 and -5.4 respectively and this is the major disadvantage of blended fuel oil as they tend to have unfavorable cold flow properties since it begins to gel at low temperature which can clog filters or even become so thick that it cannot be pumped from fuel tank to the engine and this phenomenon is the result of saturated heavy component in the fuel oil and by the addition of pour point depressants this can corrected [2]. The fuel oil has some traces of Sulphur and further justifies the need to look at the composition [6].

Table 3: Properties of Fuel Oil Obtained From Sample A

S/N	**Properties**	**Fuel Oil Value**	**ASTM standard fuel oil**
1	Specific Gravity (@ 30°C)	0.968	0.860
2	API Gravity (@ 30°C)	14.632	30
3	Density (g/cm^3) (@ 30°C)	0.947	0.890
4	Viscosity (mPas) (@ 30°C)	33	40
5	Kinematic Viscosity (mm^2/sec) (@ 100°C)	4.3	5.8
6	Moisture Content (%)	5.1	<10
7	Flash Point (°C)	106	130
8	Cloud Point (°C)	-2.3	-16
9	Pour Point (°C)	-5.4	-7
10	Sulphur (mg/l)	3.1	0.5
11	Sediment(%)	2.1	1.0

The properties of Fuel Oil Obtained From Sample B is presented in Table 4. The table shows the physicochemical analysis on the fuel oil sample, the Specific Gravity (@ 30°C) obtained was 0.965 which is above the minimum standards for a marketable fuel oil as explain in chapter of 0.82 – 0.95. The API Gravity (@ 30°C) obtained was 15.096 and this was used to classify the fuel oil has been heavy oil. The Density (g/cm3) (@ 30°C) obtained was 0.947 The product density is an important factor in the onboard purification of the fuel oil the higher the density, the more critical it becomes. The Viscosity (mPas) (@ 30°C) obtained was 38 while Kinematic Viscosity (mm2/sec) (@ 100°C) was 4.7. The analysis of the fuel oil does not meet the standard for blended fuel oil as the minimum 5.80 mm²/s at 100°C, according to the ISO 8217:2017 Standard.

The Moisture Content (%) of the fuel obtained was 5.2 while the Flash Point (°C) obtained was 106 and this further makes the fuel oil classifiable as DMX. The cloud point and pour point obtained was -2.1 and -5 respectively and this is the major disadvantage of blended fuel oil as they tend to have unfavorable cold flow properties since it begins to gel at low temperature which can clog filters or even become so thick that it cannot be pumped from fuel tank to the engine and this phenomenon is the result of saturated heavy component in the fuel oil and by the addition of pour point depressants this can corrected. The fuel oil has some traces of Sulphur and further justifies the need to look at the composition.

Table 4: Properties of Fuel Oil Obtained From Sample B.

S/N	Properties	Fuel Oil Value	ASTM standard fuel oil
1	Specific Gravity (@ 30°C)	0.965	0.860
2	API Gravity (@ 30°C)	15.096	30
3	Density (g/cm^3) (@ 30°C)	0.947	0.890
4	Viscosity (mPas) (@ 30°C)	38	40
5	Kinematic Viscosity (mm^2/sec) (@ 100°C)	4.7	5.8
6	Moisture Content (%)	5.2	<10
7	Flash Point (°C)	106	130
8	Cloud Point (°C)	-2.1	-16
9	Pour Point (°C)	-5.0	-7
10	Sulphur (mg/l)	3.5	0.5
11	Sediment(%)	0.4	1.0

The Properties of Fuel Oil obtained From Sample C is presented in Table 5. The Table shows the physicochemical analysis on the fuel oil sample, the Specific Gravity (@ 30°C) obtained was 0.944 which is above the minimum standards for a marketable fuel oil. The API Gravity (@ 30°C) obtained was 18.432 and this was used to classify the fuel oil has been heavy oil, the Density (g/cm3) (@ 30°C) obtained was 0.923. The product density is an important factor in the onboard purification of the fuel oil the higher the density, the more critical it becomes. The Viscosity (mPas) (@ 30°C) obtained was 67 while Kinematic Viscosity (mm2/sec) (@ 100°C) was 7.1. The analysis of the fuel oil meet the standard for blended fuel oil as the minimum viscosity is 5.80 mm^2/s at 100°C C, according to the ISO 8217:2017 Standard.

The Moisture Content (%) of the fuel obtained was 5.3 while the Flash Point (°C) obtained was 107 and this further makes the fuel oil classifiable as DMX. The cloud point and pour point obtained was -2.1 and -5.3 respectively and this is the major disadvantage of blended fuel oil as they tend to have unfavorable cold flow properties since it begins to gel at low temperature which can clog filters or even become so thick that it cannot be pumped from fuel tank to the engine and this phenomenon is the result of saturated heavy component in the fuel oil and by the addition of pour point depressants this can corrected. The fuel oil has some traces of Sulphur and further justifies the need to look at the composition.

Table 5: Properties of Fuel Oil obtained from Sample C

S/N	Properties	Fuel Oil Value	ASTM standard fuel oil
1	Specific Gravity (@ 30°C)	0.944	0.860
2	API Gravity (@ 30°C)	18.432	30
3	Density (g/cm^3) (@ 30°C)	0.923	0.890
4	Viscosity (mPas) (@ 30°C)	67	40
5	Kinematic Viscosity (mm^2/sec) (@ 100°C)	7.1	5.8
6	Moisture Content (%)	5.3	<10
7	Flash Point (°C)	107	130

8	Cloud Point (°C)	-2.1	-16
9	Pour Point (°C)	-5.3	-7
10	Sulphur (mg/l)	3.3	0.5
11	Sediment(%)	0.2	1.0

The Properties of Fuel Oil obtained From Sample D is presented in Table 6. Table 6 shows the physicochemical analysis on the fuel oil sample, the Specific Gravity (@ 30°C) obtained was 0.931 which is above the minimum standards for a marketable fuel oil. The API Gravity (@ 30°C) obtained was 20.407 and this was used to classify the fuel oil has been heavy oil, the Density (g/cm3) (@ 30°C) obtained was 0.911. The product density is an important factor in the onboard purification of the fuel oil the higher the density, the more critical it becomes. The Viscosity (mPas) (@ 30°C) obtained was 72 while Kinematic Viscosity (mm2/sec) (@ 100°C) was 7.3. The analysis of the fuel oil does meet the standard for blended fuel oil as the minimum viscosity is 5.80 mm²/s at 100°C, according to the ISO 8217:2017 Standard.

The Moisture Content (%) of the fuel obtained was 5.1 while the Flash Point (°C) obtained was 110 and this further makes the fuel oil classifiable as DMX. The cloud point and pour point obtained was -2.8 and -6.8 respectively and this is the major disadvantage of blended fuel oil as they tend to have unfavorable cold flow properties since it begins to gel at low temperature which can clog filters or even become so thick that it cannot be pumped from fuel tank to the engine and this phenomenon is the result of saturated heavy component in the fuel oil and by the addition of pour point depressants this can corrected. The fuel oil has some traces of Sulphur and further justifies the need to look at the composition.

Table 6: Properties of Fuel Oil Obtained From Sample D

S/N	**Properties**	**Fuel Oil Value**	**ASTM standard fuel oil**
1	Specific Gravity (@ 30°C)	0.931	0.860
2	API Gravity (@ 30°C)	20.407	30
3	Density (g/cm^3) (@ 30°C)	0.911	0.890
4	Viscosity (mPas) (@ 30°C)	72	40
5	Kinematic Viscosity (mm^2/sec) (@ 100°C)	7.3	5.8
6	Moisture Content (%)	5.1	<10
7	Flash Point (°C)	110	130
8	Cloud Point (°C)	-2.8	-16
9	Pour Point (°C)	-6.8	-7
10	Sulphur (mg/l)	3.1	0.5
11	Sediment(%)	0.3	1.0

The Properties of Fuel Oil obtained From Sample E is presented in Table 4.6. Table 4.6 shows the physicochemical analysis on the fuel oil sample, the Specific Gravity (@ 30°C) obtained was 0.905 which is above the minimum standards for a marketable fuel oil. The API Gravity (@ 30°C) obtained was 24.870 and this was used to classify the fuel oil has been heavy oil, the Density (g/cm3) (@ 30°C) obtained was 0.885. The product density is an important factor in the onboard purification of the fuel oil the higher the density, the more critical it becomes. The Viscosity (mPas) (@ 30°C) obtained was 80 while Kinematic Viscosity (mm2/sec) (@ 100°C) was 7.8. The analysis of the fuel oil does meet the standard for blended fuel oil as the minimum viscosity is 5.80 mm²/s at 100°C, according to the ISO 8217:2017 Standard.

The Moisture Content (%) of the fuel obtained was 5.3 while the Flash Point (°C) obtained was 109 and this further makes the fuel oil classifiable as DMX. The cloud point and pour point obtained was -2.3 and -10 respectively and this is the major disadvantage of blended fuel oil as they tend to have unfavorable cold flow properties since it begins to gel at low temperature which can clog filters or even become so thick that it cannot be pumped from fuel tank to the engine and this phenomenon is the result of saturated heavy component in the fuel oil and by the addition of pour point depressants this can corrected. The fuel oil has some traces of Sulphur and further justifies the need to look at the composition.

Table 7: Properties of Fuel Oil Obtained From Sample E

S/N	Properties	Fuel Oil Value	ASTM standard fuel oil
1	Specific Gravity (@ 30°C)	0.905	0.860
2	API Gravity (@ 30°C)	24.870	30
3	Density (g/cm^3) (@ 30°C)	0.885	0.890
4	Viscosity (mPas) (@ 30°C)	80	40
5	Kinematic Viscosity (mm^2/sec) (@ 100°C)	7.8	5.8
6	Moisture Content (%)	5.3	<10
7	Flash Point (°C)	109	130
8	Cloud Point (°C)	-2.3	-16
9	Pour Point (°C)	-10	-7
10	Sulphur (mg/l)	3.3	0.5
11	Sediment(%)	0.3	1.0

The Properties of Fuel Oil obtained From Sample F is presented in Table 8. The table shows the physicochemical analysis on the fuel oil sample, the Specific Gravity (@ 30°C) obtained was 0.934 which is above the minimum standards for a marketable fuel oil .The API Gravity (@ 30°C) obtained was 20.074 and this was used to classify the fuel oil has been heavy oil, the Density (g/cm3) (@ 30°C) obtained was 0.913. The product density is an important factor in the onboard purification of the fuel oil the higher the density, the more critical it becomes. The Viscosity (mPas) (@ 30°C) obtained was 68 while Kinematic Viscosity (mm2/sec) (@ 100°C) was 7.2. The analysis of the fuel oil does not meet the standard for blended fuel oil as the minimum viscosity is 2.0 mm²/s at 30°C, according to the ISO 8217:2017 Standard.

The Moisture Content (%) of the fuel obtained was 5.1 while the Flash Point (°C) obtained was 110 and this further makes the fuel oil classifiable as DMX. The cloud point and pour point obtained was -3.8 and -10 respectively and this is the major disadvantage of blended fuel oil as they tend to have unfavorable cold flow properties since it begins to gel at low temperature which can clog filters or even become so thick that it cannot be pumped from fuel tank to the engine and this phenomenon is the result of saturated heavy component in the fuel oil and by the addition of pour point depressants this can corrected. The fuel oil has some traces of Sulphur and further justifies the need to look at the composition.

Table 8: Properties of Fuel Oil Obtained From Sample F

S/N	Properties	Fuel Oil Value	ASTM standard fuel oil
1	Specific Gravity (@ 30°C)	0.934	0.860
2	API Gravity (@ 30°C)	20.074	30
3	Density (g/cm^3) (@ 30°C)	0.913	0.890
4	Viscosity (mPas) (@ 30°C)	68	40
5	Kinematic Viscosity (mm^2/sec) (@ 100°C)	7.2	5.8
6	Moisture Content (%)	5.1	<10
7	Flash Point (°C)	110	130
8	Cloud Point (°C)	-3.8	-16
9	Pour Point (°C)	-10	-7
10	Sulphur (mg/l)	3.1	0.5

11	Sediment(%)	0.4	1.0

The Properties of Fuel Oil obtained From Sample G is presented in Table 9. The table shows the physicochemical analysis on the fuel oil sample, the Specific Gravity (@ 30°C) obtained was 0.8101 which meets the minimum standards for a marketable fuel oil. The API Gravity (@ 30°C) obtained was 43.17 and this was used to classify the fuel oil as a light oil, the Density (g/cm3) (@ 30°C) obtained was 0.7922 and this density gives an indication of the ignition quality of the fuel oil within the certain product class. This is particularly the case for the low-viscosity IFOs. The product density is an important factor in the onboard purification of the fuel oil the higher the density, the more critical it becomes. The Viscosity (mPas) (@ 30°C) obtained was 3.93 while Kinematic Viscosity (mm2/sec) (@ 100°C) was 4.97 it should be noted that the Kinematic viscosity is the only accepted method, expressed as mm^2/s at a certain temperature (note: 1 mm^2/s = 1 cSt). SSU, SSF and RW1 (Saybolt Seconds Universal, Saybolt Seconds Furol and Redwood No. 1) are obsolete units.

The analysis of the fuel oil meets the standard for blended fuel oil as the minimum viscosity is 2.0 mm^2/s at 30°C, according to the ISO 8217:2017 standard, although cooling or chilling may be required to maintain the required minimum viscosity before the fuel oil injection pump, it was also observed that the viscosity of a fuel oil decreases with increasing temperature at the end it was classified as a DMX fuel oil. The Moisture Content (%) of the fuel obtained was 6.21 while the Flash Point (°C) obtained was 110 and this further makes the fuel oil classifiable as DMX since the flash point for all fuels to be used in bulk onboard vessels is set at Pensky–Martens closed-cup 60°C minimum. The cloud point and pour point obtained was -8.7 and -4.3 respectively and this is the major disadvantage of blended fuel oil as they tend to have unfavorable cold flow properties since it begins to gel at low temperature which can clog filters or even become so thick that it cannot be pumped from fuel tank to the engine and this phenomenon is the result of saturated heavy component in the fuel oil and by the addition of pour point depressants this can corrected. The fuel oil was Sulphur free and further justifies the previously reviewed literature.

Table 9: Properties of Fuel Oil Obtained From Sample G

S/N	**Properties**	**Fuel Oil Value**	**ASTM standard fuel oil**
1	Specific Gravity (@ 30°C)	0.8101	0.860
2	API Gravity (@ 30°C)	43.17	30
3	Density (g/cm^3) (@ 30°C)	0.7922	0.890
4	Viscosity (mPas) (@ 30°C)	3.93	40
5	Kinematic Viscosity (mm^2/sec) (@ 100°C)	4.97	5.8
6	Moisture Content (%)	6.21	<10
7	Flash Point (°C)	110	130
8	Cloud Point (°C)	-8.7	-16
9	Pour Point (°C)	-4.3	-7
10	Sulphur (mg/l)	2.6	0.5
11	Sediment	0.5	1.0

The Properties of Fuel Oil obtained From Sample H is presented in Table 10. The table shows the physicochemical analysis on the fuel oil sample, the Specific Gravity (@ 30°C) obtained was 0.916 which is above the minimum standards for a marketable fuel oil. The API Gravity (@ 30°C) obtained was 22.95 and this was used to classify the fuel oil has been heavy oil, the Density (g/cm3) (@ 30°C) obtained was 0.896. The product density is an important factor in the onboard purification of the fuel oil the higher the density, the more critical it becomes. The Viscosity (mPas) (@ 30°C) obtained was 40 while Kinematic Viscosity (mm2/sec) (@ 100°C) was 4.7. The analysis of the fuel oil does not meet the standard for blended fuel oil as the minimum viscosity is 2.0 mm^2/s at 30°C, according to the ISO 8217:2017 standard. The Moisture Content (%) of the fuel obtained was 5.2 while the Flash Point (°C) obtained was 109 and this further makes the fuel oil classifiable as DMX. The cloud point and pour point obtained was -2.3 and -6.5 respectively and this is the major disadvantage of blended fuel oil as they tend to have unfavorable cold flow properties since it begins to gel at low temperature which can clog filters or even become so thick that it cannot be pumped from fuel tank to the engine and this phenomenon is the result of saturated heavy component in the fuel oil and by the addition of pour point depressants this can corrected. The fuel oil has some traces of Sulphur and further justifies the need to look at the composition.

Table 10: Properties of Fuel Oil Obtained From Sample H

S/N	Properties	Fuel Oil Value	ASTM standard fuel oil
1	Specific Gravity (@ 30°C)	0.916	0.86
2	API Gravity (@ 30°C)	22.95	30
3	Density (g/cm^3) (@ 30°C)	0.896	0.89
4	Viscosity (mPas) (@ 30°C)	40	40
5	Kinematic Viscosity (mm^2/sec) (@ 100°C)	4.7	5.8
6	Moisture Content (%)	5.2	<10
7	Flash Point (°C)	109	130
8	Cloud Point (°C)	-2.3	-16
9	Pour Point (°C)	-6.5	-7
10	Sulphur (mg/l)	3.1	0.5
11	Sediment (%)	0.2	1

4| CONCLUSION AND RECOMMENDATION

Conclusion

1. Several key findings have emerged as a result of this study, Firstly, it can be confirmed that blending of decant oil with conventional heavy gas oil and light gas oils has a highly significant effect on the properties of the resulting fuel blend. The results show that by increasing the heavy gas oil content of the blend, the Flash point of the blend increases. While increasing the decant oil content of the blend results in a decrease in Cloud point.

2. The evaluation of compliance and marketability of the fuel blends in relation to NMDPRA specifications and EN 590 specifications has shown differing results. The specific gravity, API gravity, kinematic viscosity, moisture content and flashpoint of the fuel blends are in compliance with EN 590 specifications. However, the density, pour-point and cloud-point falls below EN 590 specifications for the Fuel oil and this can be corrected with the addition of pour point depressants while the density would be increasing the volume ratio of the heavy gas oil. This analysis shows that the blend is in compliance with 70% of the EN 590 specifications examined, and as such could be placed on the European fuel market (after correction of the requirements for the other properties in the EN 590 specification). This finding highlights the potential for fuel blends to be incorporated into the European and national renewable energy targets.

3. The sample with a composition of 33.3% of Decant oil (DCO), 33.3% Heavy gas oil (HGO), 33.3% light cycle oil (LCO) produced fuel oil of specific gravity 0.916, API Gravity 22.95,Density 0.896, Viscosity 40, Kinematic viscosity 4.7, pour point -6.5 and flash point 109, The analysis of the fuel oil meet the standard for blended fuel oil, according to the ISO 8217:2017 Standard.

Recommendation

Based on the challenges encountered in the course of the research, it can be recommended that for subsequent research on the production of fuel oil, a pilot scale set-up should be designed and fabricated to ease the achievement of a successful and stress-free blending process. An in-line blending process may also be considered.

By using the experimental data from this study work, the complete characterization of fuel oil could be done using simulation software's such as Aspen plus, Hysys, or Unisim. For design and simulation of any blender for fuel oil, as it requires a basic characterization data. So that, one can design an automatic blender tower for fuel oils using the results presented in this work.

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