CHARACTERIZATION OF NIGERIAN CRUDE OIL FROM WARRI, DELTA STATE USING ASPEN HYSYS FOR PROCESS MODELING AND SIMULATION

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Abstract

The research work is aimed at characterizing Nigerian crude oil (Escravos) from Warri, Delta State. The density, sulphur and salt content of the Escravos Crude Oil were determined to be 35 API 0.182 and 5.00 per thousand barrel respectively as shown in Table 1. This shows that the crude oil is light and sweet. The cut input information in Figure 3 shows the name of the components that are obtained from the crude oil sample and also the True Boiling Point temperatures at which each components of the crude oil are to be obtained. This was often useful to extend the boiling point data to higher temperatures than are possible in the fractionating distillation method for the crude oil and also gives useful comparative and reproducible results that are often accurate enough for refinery purposes. The True Boiling Point Curve makes it possible to investigate the yields of the products that will be obtained in the refineries, as well as to establish operational strategies and process optimization.

Introduction

Crude grades vary considerably from each other - in yield and properties. Crude characterization is essential to estimate feedstock properties for refinery units, produce an optimal amount of finished products, meet product quality specifications and to provide an economic assessment for crude oils. Users can gain a competitive advantage utilizing the best quality information (Fusco, 2004).

Crude oil is a mixture of liquid hydrocarbons, often found together with natural gas. The main characteristics of crude oil are density; measured by its API Gravity, the sulphur content, and a new method of characterizing crude oils based on the shape of the True Boiling Point distillation curves (Leonardo, 2005).

The characterization of crude oil (Escravos Crude Oil) into discrete hypothetical components provides the basis for the package to predict the remaining thermodynamic and transport properties necessary for fluid modeling (Hague, 2006). Crude oil data is utilized by the upstream planning to determine the economic viability of new fields/discoveries; supply organizations to assign crude value for individual grades; refinery operations to schedule crude receipts and determine product yields; Model engineers to optimize refinery crude slates; research and development to design equipment and process planning (Hague, 2006).

The use of a process simulator is beneficial in all the three stages of a plant. It is used in research and development, design and production. In research and development they help to cut down on laboratory experiments and pilot plant runs. In design stage they enable a speedier development with simpler comparisons of various alternatives. Finally, in the production stage they can be used for risk-free analysis of various what-if scenarios (Hague, 2006).

Background

Crude oil or Petroleum (derived from a Greek word: petra (rock) + Latin word: oleum (oil), is a naturally occurring, flammable liquid consisting of a complex mixture of hydrocarbons of various molecular weights and other liquid organic compounds, that are found in geologic formations beneath the Earth's surface. Crude oil is a mixture of liquid hydrocarbons, it is often found together with natural gas. In its strictest sense, petroleum includes only crude oil, but in common usage it includes all liquid, gaseous, and solid (e.g., paraffin) hydrocarbons. Under surface pressure and temperature conditions, lighter hydrocarbons methane, ethane, propane and butane occur as gases, while pentane and heavier ones are in the form of liquids or solids. However, in an underground oil reservoir the proportions of gas, liquid, and solid depend on subsurface conditions and on the phase diagram of the petroleum mixture (Leonardo, 2005).

The proportion of light hydrocarbons in the petroleum mixture varies greatly among different oil fields, ranging from as much as 97% by weight in the lighter oils to as little as 50% in the heavier oils and bitumens (James, 1999).

Chemical Simulator

These are software written by software engineers used to simulate the material and energy balances of chemical processing plants. They include CHEMCAD by Chemstations, COCO simulator, PIPE-FLO Professional by Engineered Software, Inc, PRO/II and DYNSIM by the SimSci-Esscor division of Invensys, Chemsep by Harry Kooijman, Aspen HYSYS, (Aspen Custom Modeler) by Aspen Technology (Fishwick, 2005).

Aspen HYSYS™

This is a process simulation environment designed to serve the Oil & Gas and Refining industries. Using HYSYS you can create rigorous steady state and dynamic models for plant design, performance monitoring, troubleshooting, operational improvement, business planning, and asset management. Through the interactive HYSYS interface, you can easily manipulate process variables and unit operation topology, as well as fully customize your simulation using HYSYS customization and extensibility tools (Fusco, 2004).

Advantages of Aspen Hysys

The computer-aided simulation has several advantages, for example it:

- Allows the designer to quickly test the performance of proposed synthesized flow sheet.
- Minimizes experimental efforts and scale up issues.
- Helps in modeling, optimization, business planning, asset management and monitoring tools in oil and gas production.
- Allows improved hydrate prediction.
- Sheds insights on conceptual design and performance improvement on simulation processes.
- Tests the performance with various thermodynamics models (Hague, 2006).

Crude Oil Characterization

The main characteristics of crude oil are density measured by its API gravity in the oil industry, Sulphur content and a new method of characterizing crude oils based on the shape of True Boiling Point distillation curves is proposed. A gamma distribution is used to characterize the True Boiling Point distillation curve, and the parameters of the fitted distribution are used as characterization parameters (Leonardo, 2005).

Density

The American Petroleum Institute (API) density in the oil industry is usually measured by its API Gravity, the API density of crude oil is the measure of how heavy or light the crude oil is compared to water. If its API gravity is greater than 10, it is lighter and floats on water; if less than 10, it is heavier and sinks.

Sulphur Content

The sulphur content of crude oil is the amount of sulphur contained in the crude oil, and this is measured using a sulphur-in-oil analyzer, which measures the average value of the crude oil in centistokes (cSt) (Leonardo, 2005). Crude oil is normally described as sweet (low sulphur) or sour (high sulphur) and light or heavy (depending on its density). Heavier oils may also be described as medium and bitumen (so heavy, it is solid). The instrument used in measuring sulphur is the sulphur-in-oil analyzer (Leonardo, 2005).

True Boiling Point

Petroleum is evaluated mainly in terms of its True Boiling Point (TBP) curve, this makes it possible to investigate the yields of the products that will be obtained in the refineries, as well as to establish operational strategies and process optimization (Wolf, 2004).

Oil Characterization in Hysys

There are three steps involved in characterizing any oil in HYSYS:

1. Characterizing the assay.
2. Generating hypocomponents.
3. Installing the oil in the flow sheet (Norman, 2001).

The assay contains all of the petroleum laboratory data, boiling point curves, light ends, property curves, and bulk properties. HYSYS uses the supplied assay data to generate internal True Boiling Point, molecular weight, and density and viscosity curves (referred to as Working Curves).

Materials

The crude oil sample was taken from Escravos Warri, Delta State Nigeria, which will be a standardized parameter for validating this research work. The materials and equipment used in the course of carrying out this research work are Horiba SLFA-2100/2800 X-ray Fluorescence Sulfur-in-Oil Analyzer, Hydrometer, Water bath, Viscometer, True Boiling Point Distillation Equipment, Apple MacBook laptop, Aspen Hysys 2008,Version 7.0.

Methods

Process Description

This work addresses the modeling of crude oil processing facility that uses Escravos crude oil to characterize the true boiling point of the feed then passed to a separator from which the raw crude is separated into pre-flash vapour leaving at the top and pre-flash liquid leaving at the bottom. The pre-flash liquid is then sent to a crude heater at a temperature of 38^0C and a pressure of 0.285 Kg/cm^2. Finally the hot crude and the vapour leaving from the separator are then combined together in a mixer where the atmospheric feed leaves.

Determination of Sulphur Content in Crude Oil

The sample cells are interconnected together and a transparent polyethylene was placed in the connected sample cells to prevent the crude oil sample from staining the sample cells. The crude oil sample was then poured into the sample cells. The sulpur-in-oil analyzer was then switched on, and the sample cells placed inside a circular sample cell opening and then the lid cover closed. The measure button was then pressed to measure the sulphur content of the crude oil sample automatically.

Determination of Specific Gravity

The measuring cylinder in which the crude oil sample would be poured was first cleaned with a light sample such as kerosene. The crude oil sample was then poured into the measuring cylinder and the hydrometer inserted into the measuring cylinder and the value of the lower meniscus of the hydrometer above the measuring cylinder was then measured. The temperature of the sample was also measured and recorded. The value of the viscosity measured was then compared with the standard at that particular temperature. The standard value is now the measured specific gravity. The API gravity was then calculated using equation (1) API = $\frac{141}{specific\ \ gravity} \times \frac{131.5}{}$ --- (1)

Determination of Viscosity

In general, the viscosity used for opaque liquids are of the reverse-flow type. The sample is heated in the original container in an oven at 60± 2^0C for 1 hour. The sample was then thoroughly stirred with a suitable stirrer of sufficient length to reach the bottom of the container. The stirring is continued until there is no sludge or wax adhering to the rod. The container is recap tightly and shook vigorously for 1 minute to complete the mixing.

The viscometer is then charged with the sample of the crude oil in the water bath and allowing the viscometer to remain in the water bath for a period of 30 minutes to allow the sample to flow freely. With the sample flowing freely, the time taken is measured to within 0.1 seconds the time required for the advancing ring of contact to pass from the first timing mark of the ring to the second.

Determination of True Boiling Point by modeling using Aspen Hysys

HYSYS uses the concept of the Fluid Package to contain all necessary information for performing flash and physical property calculations.

This approach allows one to define all information (property package, components, interaction parameters, reactions, tabular data, hypothetical components, etc.) inside a single entity. These petroleum hypo components provide the basis for the property package to predict the remaining thermodynamic and transport properties necessary for fluid modeling.

The component list includes the pseudo components that will be used to represent the C5+ portion of the crude oil. The Oil Characterization procedure in HYSYS will be used to convert the laboratory data into petroleum pseudo components.

On completion of the design in the column, the column environment was clicked and a process flow diagram showing the whole tower with side strippers as shown below:

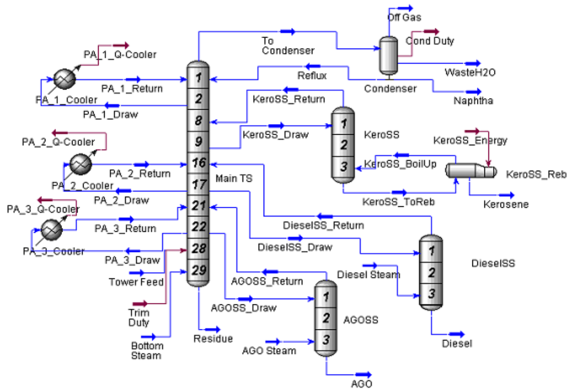

Figure 1: Diagram of the Entire Atmos Tower

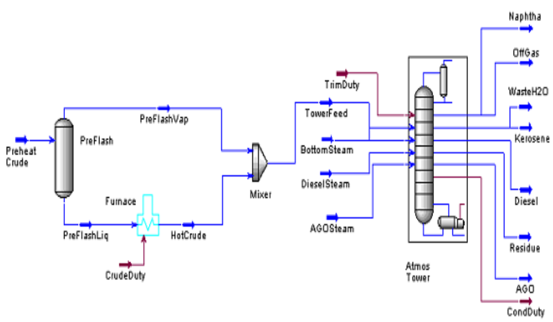

Figure 2. Process Flow Diagram of a Crude Distillation Unit

Results and Discussion of Results

Table 1 shows the values of the results obtained from the laboratory analysis carried out on Escravos crude oil.

Table 1: Results for sulphur content, API density and Viscosity of the Escravos Crude oil.

Component	**Measured Value**
Specific gravity	0.8486
Sulphur content (%wt)	0.182
Viscosity @ 40^0C (cSt)	3.03
API gravity	35

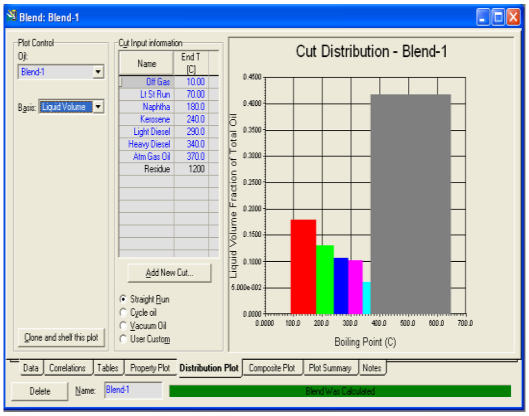

Figure 3: Results of the Cut Input Information and the Cut Distribution of the Blend

In Figure 3 the oil distributions of the cut input information, their beginning temperatures, end temperatures and the fraction of each cut.

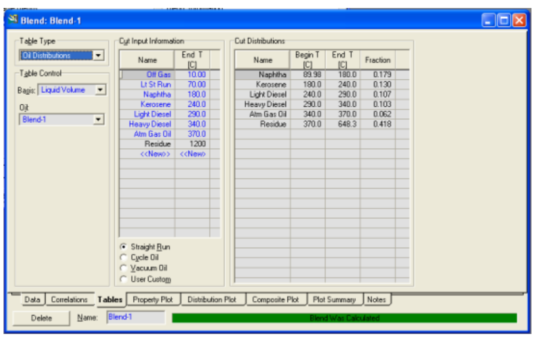

Figure 4: Results of the Oil Distributions of the Cut Input Information.

In figure 4, the names of the individual cut distributions were shown with their respective beginning temperature, end temperature and the fraction respectively. Naphtha has a beginning temperature of 89.98^{0}C, end temperature of 160^{0}C and a fraction of 0.179 while the residue has a beginning temperature of 370^{0}C, end temperature of 648.3^{0}C and fraction of 0.418 respectively.

The plot of the input true boiling point distillation is shown in figure 5.
This shows the plot of the temperature against the liquid assay percent.

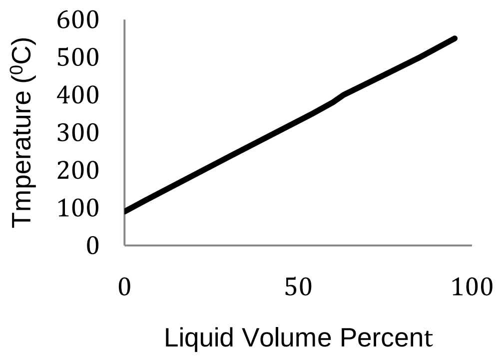

Figure 5: Graph of the Input True Boiling Point Distillation.

In Figure 5, the temperature was plotted against the liquid volume percent for the hypocomponents generated. As the temperature increases, the liquid volume percent also increases, hence showing a linear relationship between them. The temperature of any component generated could be obtained from the curve, if the liquid volume percent is known by tracing it upwards and vice-versa. The curves extend the boiling point data to higher temperatures than are possible in the fractionating distillation method.

The Graph of the Input True Boiling Point Distillation of the viscosity (cP) plotted against the normal boiling point (^{0}C) is given in figure 6.

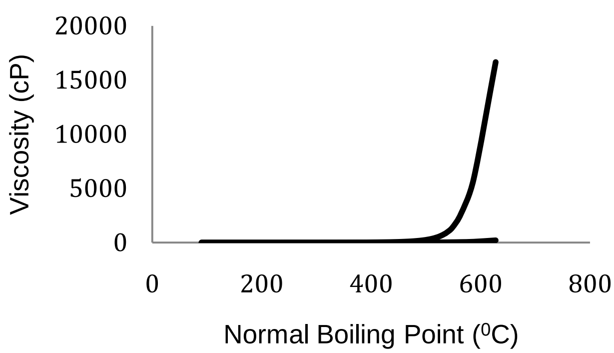

Figure 6: Graph of the Input True Boiling Point Distillation.

In Figure 6, the viscosity was plotted against the normal boiling point for the hypo components generated. At the beginning of the plot, there was no change in the viscosity against the normal boiling point from the temperature of 0^0C to almost 500^0C, but at a temperature of 500^0C and above, the viscosity increases as the normal boiling point increases. This shows that the viscosity of a crude oil was affected by the increase in temperature, since heating the liquid decreases the viscosity of the liquid and thus tends to flow. The viscosity of any component generated could be obtained from the curve by tracing it upwards, if the normal boiling point is known and vice-versa.

Figure 7 shows the graph of Input True Boiling Point Distillation of the Mass density plotted against the normal boiling point (^{0}C).

Table 2: Boiling Point Range of Crude Oil

Product	**Standard Boiling Range (^{0}C)**	**Simulated Boiling Range (^{0}C)**
Off gas	-161.5 - 36.1	-273.1 - 30
Gasoline	36.1 - 200	30 - 180
Kerosene, Jet Fuel, #1 Diesel	170 - 270	180 - 240
#2 Diesel, Furnace Oil	180 - 340	290 – 340
Lube Oils	340 - 540	340 - 370
Residual Oil	340 - 650	370 - 648.3
Asphalt	540 +	540+
Petroleum Coke	Solid	Solid

Source: Schmidt, G.K. and Forster, E.J., "Modern Refining for Today's Fuels and Lubricants," SAE Paper 861176, 1986

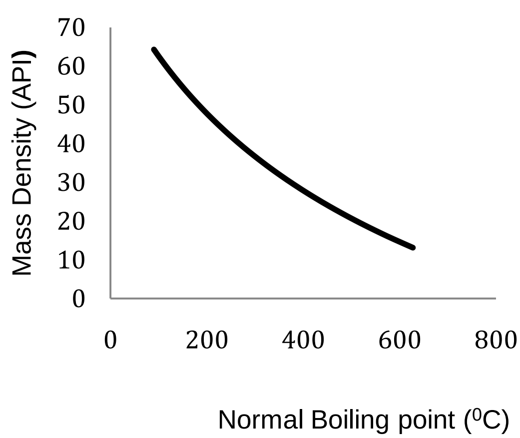

Figure 7: Graph of the Input True Boiling Point Distillation.

In Figure 7, the mass density was plotted against the normal boiling point for the hypo components generated. As the mass density increases, the normal boiling point decreases. This shows increase in temperature leads to decrease in mass density of crude oils. The mass density of any component generated could be obtained from the curve by tracing it upwards and vice-versa, if the normal boiling point is known.

Figure 8 shows the pressure profile on the plates in the Atmos Tower, it could be deduced that the pressure in the plates increases as the number of plates increases but from the sides strippers the pressures reduces a little.

Figure 8: Pressure profile on the plates in the Atmos Tower

Figure 9 shows the temperature profile on the plates in the Atmos Tower, it could be seen that the temperature increases progressively as the number of plates increases but later reduces as side strippers were installed due to recycle to obtain maximum separation.

Figure 9: Diagram of Temperature Profiles vs Position of Plates from Top in the Atmos Tower

Conclusion

The density, sulphur content, and salt of the crude oil sample from Escravos Warri, Delta State were determined to be 35 API, 0.182 and 5.00 per thousand barrel respectively as shown in Table 6, this shows that the crude oil is light and sweet.

The simulated results revealed that atmospheric Residue had the highest volumetric flow rate of 4.502×10^4 (barrel/day) while Diesel had the lowest value of volumetric flow rate of 5002 (barrel/day). This shows the column needed to be optimized in order to convert more of the atmospheric residue into other premium products like diesel, kerosene, and naphtha.

The cut input information in Figure 3 shows the name of the components that are obtained from the crude oil sample and also the True Boiling Point temperatures at which each components of the crude oil was to be obtained. This was often useful to extend the boiling point data to higher temperatures than are possible in the fractionating distillation method for the crude oil and also gives useful comparative and reproducible results that are often accurate enough for refinery purposes.

The cut distribution shows the plot of the liquid volume fraction of the total oil against the boiling point in graphical form. As the liquid volume fraction increases the boiling point also increases showing a linear relationship between them. Also, the True Boiling Point Curve makes it possible to investigate the yields of the products that will be obtained in the refineries, as well as to establish operational strategies and process optimization.

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