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Software approach on crude oil yields prediction: A case study of Tema Oil Refinery

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Yield prediction is an integral part of every refinery process due to the intricacy of the process and composition of crude oil. Inability to sufficiently predict the yields before refinery process creates challenges such as inadequacy in planning the operating conditions to meet product target, product optimisation failure and inability to meet product market specification. Predicting yields using a yield pattern model practised by the Tema Oil Refinery is economical; however, it is time consuming and tedious. This paper focused on using a Visual Basic 6.0 programming language to predict product yields that is based on kinetic reaction models. A user friendly and efficient software application has been developed to predict product yields within a short time. This software is compatible with all windows platforms and satisfactorily predicts crude oil yields with a certainty range of 94.0 to 99.0%.

Key words: Crude oil, crude oil yield, yield correlations, visual basic 6.0.

INTRODUCTION

Crude oil comes in diverse types depending on how it was formed. After the extraction of crude oil from producing fields, it is transported to the processing units usually via oil tankers or pipelines, with pipelines being the safest and economical means of transportation (Marfo et al., 2018). On average, hundreds of different crude oil are transformed in larger or smaller quantities in the world's refineries (MathPro, 2011). There are more than 660 refineries operating in about 116 countries that generate over 85 million barrels of refined products each day (Haghi and Torrens, 2018). The physico-chemical properties of crude oil determine the level of yields of petroleum products in a refinery. The recoveries, yields, and properties of disparate fractions are the vital variables assessed in a laboratory distillation method for crude oil (Michael et al., 2009). This information is crucial to the refiner in knowing the processes that would be required to generate their desired product yields and help in monetary evaluation in profit margins on these products yet to be obtained. Petroleum yields are physically refined primarily by two methods; ASTM D86 and D1160 with detailed information about the methods found in (Michael et al., 2009; Perumal, 2014). At present, the ASTM processes have been substituted by gas chromatography simulation of distillation which offers more control in the operating conditions of a refinery and product specification (Michael et al., 2009).

Petroleum refineries are large, capital-intensive

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industrial facilities with multifaceted processing systems. Their complexities depend on a fixed configuration that yields defined output reliant on the crude inputs and refinery's capacity (Morsali, 2017). All refineries have distinctive physical configuration, operating characteristics and economics (Gary et al., 2007). A refinery configuration and performance characteristics are determined mainly by its location, funds availability for capital investments, accessible crude oil, product demands, product quality stipulations, environmental rules and standards, and market conditions and specifications of the refined products (Parkash, 2003; MathPro, 2011). The principal economic goal of a refinery is to maximise the value added in transforming crude oil into end products (Ali and Rashid, 2013). Typical products obtained from refinery processes are Liquefied Petroleum Gases (LPG), gasoline, aviation turbine kerosene, diesel, petrochemical feedstocks, lubricating oils and waxes, heating and fuel oil and asphalt (Jones and Pujado, 2006; Morsali, 2017). Crude oil varies significantly with respect to their API gravity, component mixture and level of metals, sulphur and various salts. Crude oil assay descriptions of different crude oil with a distillation range are to indicate the number of components in each boiling point range. This information is used to determine the relative flow out of the atmospheric crude oil fractionating column (Fahim et al., 2009).

The complex refinery processes makes it nearly impossible to develop a thorough model for them. This is because their modelling usually requires the application of mass and heat transfer, fluid mechanics, thermodynamics, and kinetics (Al-Enezi and Elkamel, 2000). The outcome is a system of nonlinear, together with algebraic and differential equation systems. Many equations are typically required for their description and many variables have to be estimated. Nevertheless, refinery processes are essentially flexible processes that can take a variety of feedstock and run at several conditions in order to reach product demand targets (Al-Qahtani and Elkamel, 2010). Increasing feed weight, stringent demands on product qualities and environmental regulations, make it crucial to develop models that can optimise the several processes, and most importantly predict the yields of the refined products during refinery operations (Fisher, 1990; Al-Enezi and Elkamel, 2000). Numerous refinery research scientists have developed kinetic models (Farag and Tsai, 1987) and correlations for predicting yields of crude oil using the fluid catalytic cracking (FCC) processes and taking into account American Petroleum Institute (^{0}API) gravity of the feed and the conversion alone (Gary and Handwerk, 1978); Volumetric Average Boiling Point (VABP), specific gravity, aniline point and feed sulphur content (Castiglioni, 1983), molecular description for catalytic cracking of vacuum gas oil (Pitault et al., 1994). However, these models gave quite unsatisfactory predictions.

Based on the models shortcomings, Maples (2000) developed new correlations for predicting product yields of FCC process independent of variables including Watson characterisation factor K of the feed, the percent conversion, the feed ^{0}API as well as the sulphur content of feed of which gave consistently better predictions. These mathematical correlations have become integral to the refinery processes as refiners have the opportunity to estimate the yield before the actual refining process commences (Ancheyta-Juarez and Murillo-Hernandez, 2000).

Before any refinery goes into production, simulation is done on the type of crude oil about to be fractionated as it gives them the fore knowledge about the yield range of every crude oil type based on the assay. This helps in both the economic aspect of the refinery in obtaining margin profitability of the yields to expect as well as helping refiners on what operating conditions to prepare for to obtain maximum production. The Tema Oil Refinery (TOR) simulates crude oil using the yield pattern model which has been helpful over the years in predicting their yields until December 20, 2016 where they refined ten million barrels of crude oil from the Tweneboa, Enyenra and Ntomme (TEN) fields without yielding Aviation Turbine Kerosene (ATK) (Anon, 2017). Having discovered the flaw in the previous yield model used in predicting the crude oil yields, it has become very necessary to combine other existing yield pattern models together with the yield pattern model in the refinery and then design a friendly-user software application that can simulate the crude oil yield before the actual crude oil refining commences. This paper, therefore, presents a software application using four correlation models to predict the crude oil yields based on their assay to increase the level of certainty in yields predictions and also determine the most sensitive crude oil property to the production of maximum gasoline.

Background study

Tema Oil Refinery (TOR) Limited is located in Tema approximately 24 km east of the Republic of Ghana's capital, Accra. The refinery's main raw material for production which is crude oil reaches the facility's storage tanks for processing into consumable end products through pipeline by importing from Nigeria, a neighbouring country. TOR has the capacity to produce and store 10,560 metric tonnes of LPG. The refinery has a total crude distillation unit (CDU) and residue fluid catalytic cracking (RFCC) capacity of 45,000 and 14,000 bpsd respectively. In addition, the refinery has about 1 million metric tonnes storage capacity for both crude oil and finished petroleum products. Also, the refinery provides other storage services for petroleum distribution companies for a charge depending on the storage space available at the facility (Anon, 2018).
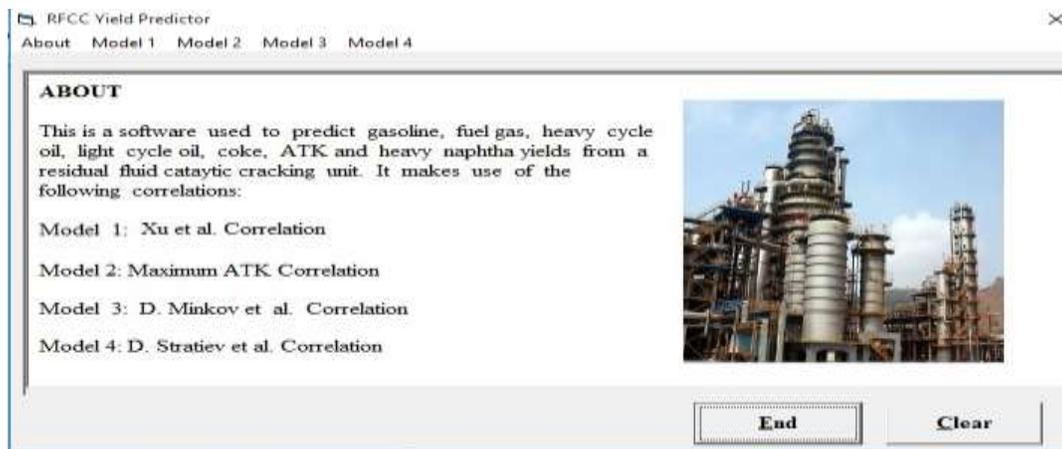
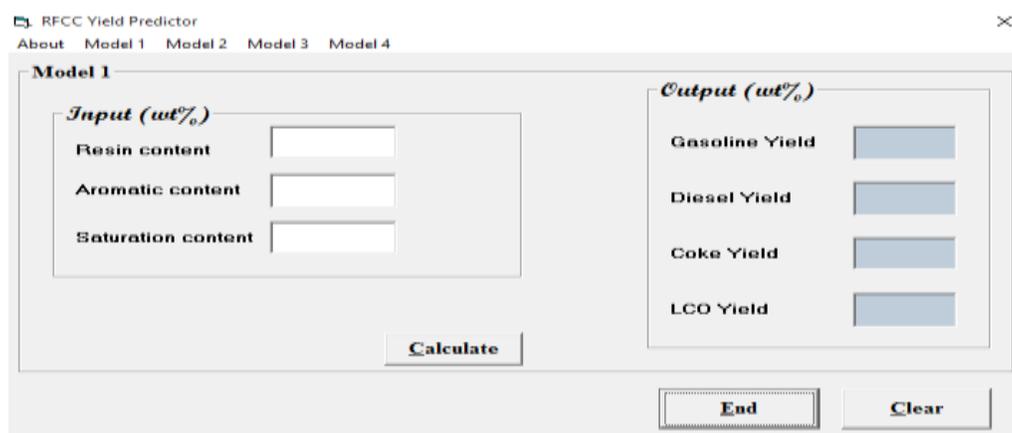**Figure 1.** General software interface.

Figure 2. Interface for Model 1.

MATERIALS AND METHODS

The computer programming language, visual basic 6.0 was used to develop application software for predicting yields from crude oil based on their laboratory assay data. This section provides details about the methods employed in developing the application and functionality testing starting from correlations used to software designing interfaces.

Correlation models employed

Four correlations were used in this study based on their high coefficient of multiple regression in addition to the number of input parameters that would be required in building the model. Most importantly, these four methods were chosen due to number of expertise in the refinery business who have approved of its functional abilities. There are four different models used for this work with different correlations. These models are the Xu et al. (2005) correlation, maximum ATK correlation, Stratiev and Minkov (2000) correlation, and the Stratiev et al. (2012) correlation. The detailed equations for each of these models are presented in Appendix A.

RFFC yield predictor interface

This interface communicates the functions of the software as well as the models used in their functionality. It is user friendly (Figure 1).
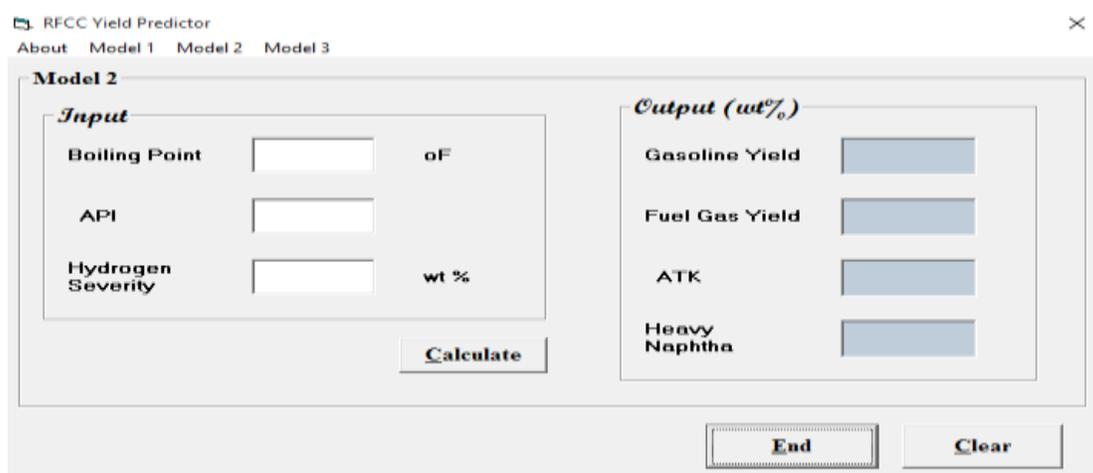
Model 1

This model employs the Xu et al. (2005) correlation to predict the yields of crude oil. These yields are gasoline, diesel, light cycle oil and coke yields. Figure 2 displays the interface for Model 1. This model requires three input parameters namely the Resin content (R), Aromatic content (A) and the Saturation contents (S) of the feedstock or crude oil. The following procedures were adopted in operating the software (Table 1):

(i) The application software (FCC Yield Predictor) was launched displaying the interface (Figure 1).
(ii) The input parameters for Model 1 were added by selecting Model 1 on the menu bar of Figure 1.
(iii) After adding the input parameters, the calculate button was then clicked to display the expected output yields of the crude oil residue

Table 1. Input parameters for test model 1.

Data	Input parameter (wt %)		
	Resin content	Aromatic content	Saturation content
1	8.8	24.7	66.5
2	11.0	25.6	63.4
3	11.1	28.0	60.9
4	18.7	36.2	45.2
5	21.3	39.7	39.0

Data source.

Figure 3. Interface for Model 2.

Table 2. Input parameters for test model 2.

Data	Input parameter (wt %)		
	Boiling point (°F)	API	Hydrogen severity (wt %)
1	575	20	66.5

Data source.

(Figure 6).

Model 2

This model was built using the maximum ATK correlation in the prediction process.   The interface portrayed below (Figure 3) indicates the yield generating properties of the correlation. This model yields gasoline, fuel gas, aviation turbine kerosene and heavy naphtha. The input parameters required for this model are the hydrogen severity (H), API gravity and boiling point (°F) as shown in Table 2. This model followed the same mode of operation as Model 1:

(i) Selecting Model 2 displayed the interface (Figure 3).
(ii)The corresponding input parameters were added to yield output results (Figure 7).

Model 3

This model uses the Stratiev and Minkov (2000) correlation in predicting the yields of crude oil. A pictorial view of this model is presented in Figure 4 showing its interface and its corresponding yields. This model yields gasoline, heavy cycle oil, light cycle oil and coke. This model requires three input parameters as shown in Table 3 and follows the same procedure in Models 1 and 2. The input parameters required for this model are the aromatic content, basic nitrogen and hydrogen content. The resulting output after adding the input parameters and selecting the calculate button is displayed in Figure 8.

Model 4

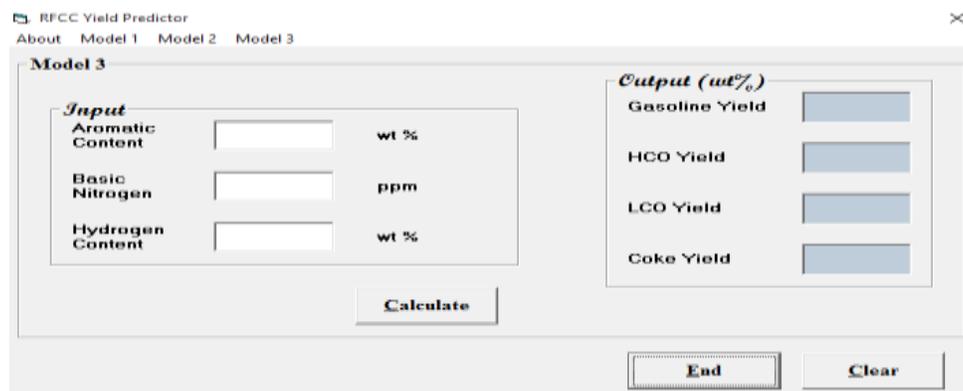This model makes use of the Stratiev et al. (2012) correlation which

Figure 4. Interface for Model 3.

Table 3. Input parameters for test model 3.

Data	Input parameter (wt %)		
	Aromatic content	**Basic nitrogen**	**Hydrogen content**
1	22.3	340	11.8
2	18.3	450	12.5
3	20.4	450	12.0
4	18.8	480	11.9
5	15.8	470	12.4

Data source.

Figure 5. Interface for Model 4.

requires aromatic content and the hydrogen content of crude oil with subsequent yields as gasoline, heavy cycle oil and fuel gas as shown in Figure 5. This model requires two input parameters which are the aromatic content and hydrogen content as displayed in Table 4. Their mode of operation is the same as the other three models and the yields expected are gasoline, HCO and gas yield as portrayed in Figure 9.
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Visual Basic 6.0

This is an event-driven tool that permits one to develop a graphic user interface application. With this application, codes remain inactive till it needs to respond to a particular event and it is also run by event processor. Visual Basic 6.0 is a programming language with unique attributes that makes it preferred coding software due to the following reasons:

(i) The structure of the basic programming is very simple in executing codes.
(ii) This software is not just language but primarily an integrated, interactive environment
(iii) The graphical user interface of visual basic IDE provides intuitively appealing views for the management of the program structure in the large and the various types of entities such as classes, modules, procedures, forms and many others

Table 4. Input parameters for test model 4.

Data	Input parameter (wt %)	
	Aromatic content	Hydrogen content
1	5.09	11.33
2	5.64	11.25
3	5.24	11.20
4	5.14	11.16
5	19.11	10.54

Data source.
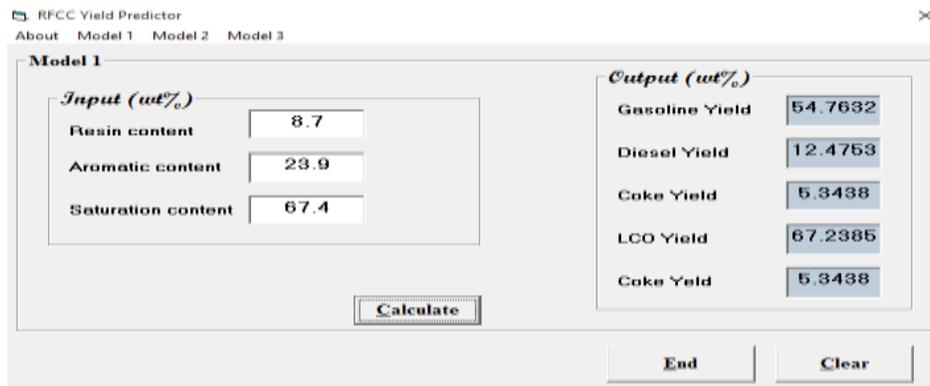
Figure 6. Result display interface for model test 1.

(iv) Visual basic provides a comprehensive interactive and context-sensitive online help
(v) It is easy to develop graphical user interface and connect them to handler functions provided by the application.

Designing interfaces

This software is operated in three modes which are the run mode which is responsible for running the application, the break mode which is used to halt the application and debug it as well and finally the design mode which is used to build the application. The design interface comprises several menu including the main window which indicates the location of the form in progress as well as buttons to access other options in the menu; the form window where the application design is drawn; the toolbox which provides the menu for selecting controls of the application; the property window enables the user to set primary property values for the objects. The project window on the other hand displays the forms (code) and modules making up the application. Detailed information about the designing interface is presented in Appendix B. The codes developed and used to simulate the various crude oil yields can be found in Appendix C.

RESULTS AND DISCUSSION

In this study, a user friendly application software for predicting the yields of crude oil at refineries was developed using Tema Oil Refinery as a case study.

Several tests were conducted for each model and the output results were compared with results from data source. The results obtained are discussed below.

Comparison between data source and software results

Model test 1

Figure 6 displays the results interface for Model Test 1. Tables 5 to 7 show the results of the data source, software and absolute average error for Model Test 1 respectively.

Model test 2

Figure 7 shows the displayed results of Model Test 2 after computation of the input parameters. Tables 8 to 10 present the results of the data source, software and absolute average error for Model Test 2 respectively.

Model test 3

Figure 8 presents the results from the software interface for Model Test 3. Tables 11 to 13 show the results of the

Table 5. Results from model test 1.

Data	Output parameter (wt %)			
	Gasoline yield	Diesel yield	Coke yield	LCO yield
1	56.1	10.9	5.8	67.0
2	53.5	11.3	6.0	64.8
3	52.5	10.4	6.9	62.9
4	42.4	15.8	7.6	58.1
5	41.2	16.2	8.4	57.4

Data source.

Table 6. Results from model test 1 (Software).

Data	Output parameter (wt %)			
	Gasoline yield	Diesel yield	Coke yield	LCO yield
1	54.4	12.7	5.4	67.1
2	52.3	12.6	5.9	64.9
3	51.3	13.4	6.0	64.7
4	42.4	14.6	7.9	57.0
5	40.0	15.3	8.5	54.2

Table 7. Absolute Average Error (AAE) for Model Test 1.

Data	Error (%)			
	Gasoline yield	Diesel yield	Coke yield	LCO yield
AAE	2	14.4	5.4	2.8

Model Test 2.

Figure 7. Result display interface for model test 2.

data source, software and absolute average error (AAE) for Model Test 3 respectively.

Table 8. Results from Model Test 2.

Data	Output parameter (wt %)			
	Gasoline yield	Fuel gas yield	ATK yield	Heavy naphtha yield
1	14.18	6.96	61.92	19.94

Data Source.

Table 9. Results from Model Test 2 (Software)

Data	Output parameter (wt %)			
	Gasoline yield	Fuel gas yield	ATK yield	Heavy naphtha yield
1	14.20	7.00	61.90	19.90

Table 10. Absolute Average Error (AAE) for Model Test 2 (Software).

Data	Error (%)			
	Gasoline yield	Fuel gas yield	ATK yield	Heavy naphtha yield
AAE	1.00	6.00	0.03	2.00

Figure 8. Result display interface for model test 3.

Table 11. Results from Model Test 3 (Data Source).

Data	Output parameter (wt %)			
	Gasoline yield	HCO yield	LCO yield	Coke yield
1	47.2	6.8	21.7	7.0
2	52.8	5.0	17.0	6.4
3	48.4	7.7	19.3	7.0
4	49.0	8.5	18.0	6.8
5	51.7	5.2	17.8	6.6

Table 12. Results from Model Test 3 (Software).

Data	Output parameter (wt %)			
	Gasoline yield	HCO yield	LCO yield	Coke yield
1	47.8	8.2	20.6	6.2
2	51.8	5.6	17.4	6.4
3	48.7	7.3	19.4	6.8
4	48.7	7.1	19.2	7.0
5	52.4	5.2	16.9	6.4

Table 13. Absolute Average Error (AAE) for Model Test 3 (Software).

Data	Error (%)			
	Gasoline yield	HCO yield	LCO yield	Coke yield
AAE	3.2	10.8	4.8	4.00

Table 14. Results from Model Test 4 (Data Source).

Data	Input parameter (wt %)		
	Gasoline yield	HCO yield	Gas yield
1	57.20	7.20	19.6
2	56.10	7.60	19.7
3	53.50	9.70	19.5
4	52.50	7.20	18.9
5	44.20	18.50	15.2

Table 15. Results from Model Test 4 (Software).

Data	Input parameter (wt %)		
	Gasoline yield	HCO yield	Gas yield
1	55.97	5.56	20.0
2	55.07	6.32	19.7
3	54.68	6.37	19.7
4	54.31	6.54	19.6
5	45.13	18.0	15.6

Model test 4

Tables 14 to 16 show the results of the data source, software and absolute average error for Test Model 4 (Figure 9).

## The absolute average error (AAE) for the models

The Absolute Average Error (AAE) in Model 1 for product yields Gasoline, Diesel, Coke and Light Cycle Oil yields had 2, 14.4, 5.4 and 2.8% respectively. This empirical correlation was built as a function of SARA feed composition as shown in Table 7. Model 2 had an Absolute Error for gasoline, fuel gas yield, Aviation Turbine Kerosene and heavy naphtha to 1, 6, 0.03 and 2% respectively. This correlation was built on the feed properties, hydrogen severity and the operating mode of the refinery units as shown in Table 10.

Stratiev and Minkov (2000) correlation was used for Model 3 which was based on the feedstock empirical parameters such as the aromatic content, hydrogen content, paraffinic and naphthenic content. Absolute average error for this model for product yields gasoline,

Table 16. Absolute Average Error (AAE) for Model Test 4 (Software)

Data	Error (%)		
	Gasoline yield	HCO yield	Gas yield
AAE	2.2	17.2	2.2
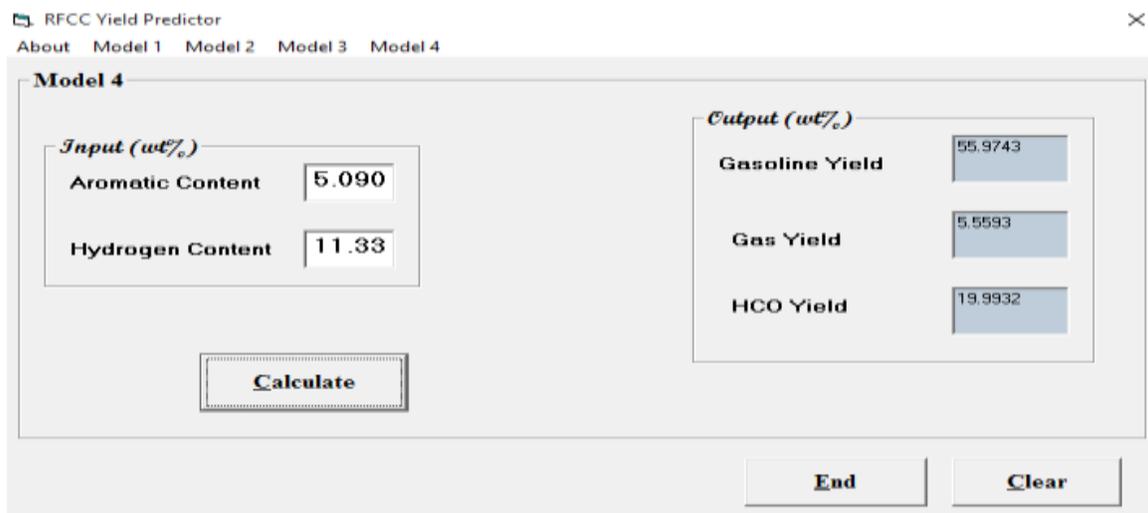
Figure 9. Result display interface for model test 4.

heavy cycle oil, light cycle oil and coke gave 3.2, 10.8, 4.8 and 4% respectively as shown in Table 13. SARA fraction of the crude oil was used to develop the yield correlation for Model 4 which also generated product yields for gasoline, heavy cycle oil and gas yield had Absolute average errors to be 2.2, 17.2 and 2.2% respectively indicated in Table 16.

Comparatively, Model 1 gives an accuracy of 98% of gasoline yield prediction which is relatively higher than the other models. Model 2 has 99% accuracy but the limited test data makes it not reliable compared to Model 1. For light cycle oil yield prediction, Model 1 had an accuracy level of 98.2% which is relatively higher than that of Model 3 with an accuracy of 96.2%. This product yield can be cracked to obtain gasoline, aviation fuel and diesel. Coke yields are essential to the refiner as it deactivates the zeolite catalyst for the catalytic cracking process hence the need to predict it yields. Model 1 has an accuracy of 95.6% and that of model 3 has an accuracy of 96%.

Sensitivity analysis on crude assay of each model

Sensitivity tests were performed on the models to determine the assay of crude oil that is crucial to yielding maximum gasoline. It could be observed that, hydrogen content, API gravity of the crude oil, and crude oil saturation content were the most sensitive to maximum gasoline production.

For Model 1, the most sensitive assay to gasoline production is the crude oil saturation content. The saturation content indicates the paraffinic content of the crude oil which gives a good indication of yield's lighter products such as gasoline, aviation fuel and many other products. API gravity of the crude oil was the most sensitive assay of the crude oil as seen in Model 2. This means that, the higher the API gravity of the crude oil, the lower the yields of gasoline. In model 3, the hydrogen content of the crude oil was the most sensitive to maximum gasoline production. The higher the hydrogen content, the higher the yields of gasoline. The fourth model also had hydrogen content as the most sensitive assay. There are three modes of operating a refinery which are the maximum gasoline mode, ATK mode and diesel mode. The latter (ATK and diesel mode) has their fundamental basis to be maximum gasoline mode on which these correlations (Fahim et al., 2009) used for the software was built hence the gasoline yield for the sensitivity analysis. Figures 10 to 13 show the sensitivity analysis on crude assay for the models developed.

Conclusion
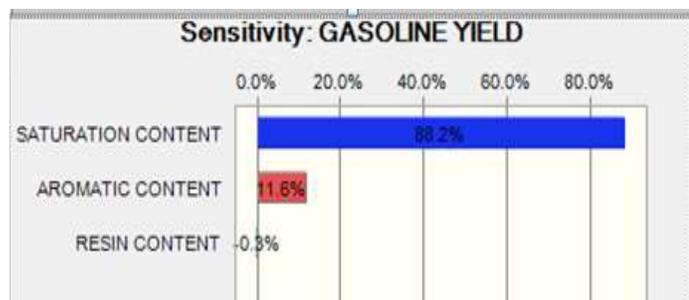
This paper presented a software application which is

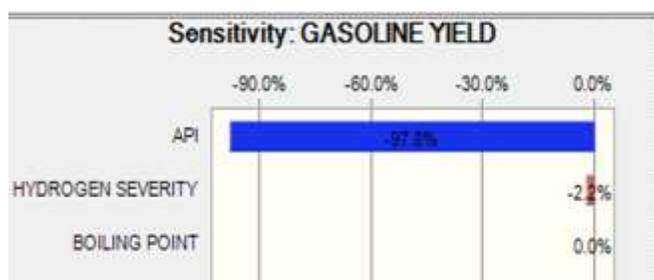**Figure 10.** Sensitive test for model 1.
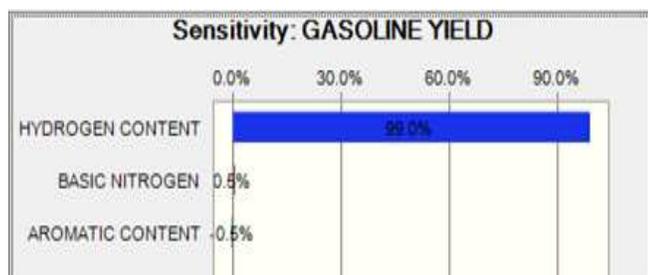

Figure 11. Sensitive test for model 2.

Figure 12. Sensitive test for model 3.

Figure 13. Sensitive test for model 4.

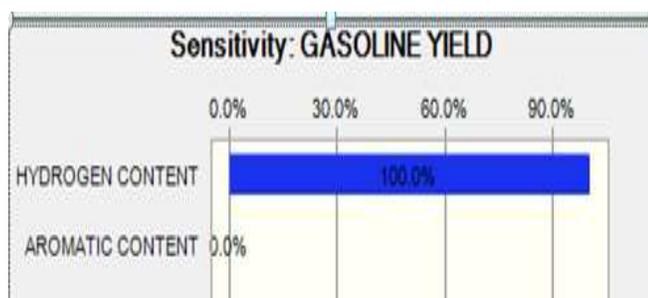based on four correlation models purposefully for predicting crude oil yields and sensitivity analysis of

crude oil properties. It further displayed the impact of the crude oil properties on maximum gasoline yield. From the study and results obtained, it can be concluded that:

(i) A software application has been developed using Visual Basic 6.0 programming language. This software application can be used for crude oil product yield prediction with minimal error.
(ii) Product yields from crude oil samples can be predicted satisfactorily using the four models integrated in the developed software. The accuracy of the models is as follows: Models 1, 2, 3 and 4 have accuracy ranging from 85.6 - 98.0%, 94.0 - 99.0%, 89.0 - 96.9% and 82.8 - 97.8% respectively.
(iii) Among the eleven input parameters used for the software development, the sensitivity analysis revealed that the following were the most sensitive crude oil properties: Saturation content (88.2%) for Model 1, API gravity (97.8%) for Model 2, hydrogen content (99%) for Model 3, and hydrogen content (100%) for Model 4.
(iv) The software application is easy to use and minimises the prediction time as it does not include simulation during the prediction operation.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests

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Appendix A: Yield correlations used

Maximum ATK correlations

The correlations for predicting hydrocracking yields conventionally are governed by feed properties, hydrogen severity and its modus operandi. ATK mode is normally used due to the excess demand for aviation fuels.

Hydrocracking severity, H is given by:

$$H\,(\text{wt\%}) = \frac{\text{lb Hydrogen}}{\text{lb of feed}} \times 100$$

(A-1)

For maximum ATK, $H = 3(wt\%)$

Volume of hydrogen (V_H) is given by;

$$V_H = \frac{thousands\,\text{of ft}^3\,\text{hydrogen}}{\text{bbl feed}}$$

(A-2)

The volume of hydrogen is related to the hydrocracking severity as:

$$V_H = 0.6621 \times H \times Specific\,gravity\,(\text{SG})$$

(A-3)

Liquid volume (LV %) of gasoline can be calculated as:

$$Gasoline\,(LV\%) = -0.03734API_f^2 + 1.57575API_f + 0.014923K - 1.36473V_H - 0.16324\frac{V_H}{K}$$

(A-4)

where; characterisation factor, $K = (T_B)^{\frac{1}{8}} / SG$; API_f is API of fluid   (A-5)

For Butanes (iC$_4$ and nC$_4$),

$$C_4(LV\%) = 0.020359\,(LV\%Gasoline)^2 + 0.04888\,(LV\%Gasoline) + 0.108964\big(API_f\big)$$

(A-6)

For Heavy naphtha (HN) (180 – 380 °F) is given as:

$$HN(LV\%) = 0.10322\,(LV\%Gasoline)^2 + 2.981215\,(LV\%Gasoline) + 0.07898\big(API_f\big)$$

(A-7)

The equation (8) below is used to convert LV% to wt% of hydrocarbon products;

$$\text{Pr}\,oduct\,(wt\%) = 0.8672 \times \text{Pr}\,oduct\,(LV\%) - 09969$$

(A-8)

Therefore ATK yield is presented as:

$$ATK\,\text{Yield} = 100 - C_4(LV\%) - HN(LV\%) - Gasoline\,(LV\%)$$

(A-9)

RFCC yields correlations

Residue fluid catalytic cracking (RFCC) product yields correlated with the content of saturates, aromatics, resins, and asphaltenes (SARA) fractions in RFCC feedstock (Stratiev et al., 2012).

$$Conversion_{350} = -0.57197C_A + 5.5951H + 33.959 \, wt\%$$

(A-10)

where: $C_A = 292.1SG - 0.043T_{50}^F - 212.2$

(A-11)

$$H = 26.25SG - 0.0013T_{50}^F - 35.2$$

(A-12)

$$Gasoline \; Yield = -0.22704C_A + 9.698623H - 52.7555(wt\%)$$

(A-13)

$$Gas \; Yield = -0.18922C_A + 2.246805H - 4.5(wt\%)$$

(A-14)

$$HCO \; Yield = 100 - Conversion_{350}$$

(A-15)

$$HCO \; Yield = Conversion_{350} - Conversion_{210}$$

(A-16)

$$Coke \; Yield = Conversion_{210} - Gasoline \; Yield - Gas \; Yield$$

(A-17)

Stratiev and Minkov empirical method

The feedstock empirical parameters such as the aromatic content, hydrogen content, paraffinic and naphthenic content were found to correlate using Dhulesia's conversion factor to generate maximum gasoline.

$$Conversion = 5.123H_2 - 0.557C_a + 23.18$$

(A-18)

$$Gasoline \; yield = 0.84 \, (conversion) - 0.008 \, (basic \; nitrogen) - 9.3$$

(A-19)

$$Coke \; Yield = 0.0072 \, (basic \; nitrogen) - 0.11 \, (conversion) + 11.6$$

(A-20)

$$LCO \; Yield = 59.73 - 0.55(conversion)$$

(A-21)

$$HCO \; Yield = 100 - LCO - (conversion)$$

(A-22)

Xu et al. Correlations

Generalised empirical correlations were developed in order to predict the FCC yields of gasoline, diesel, gasoil and coke that are dependent on the feedstock SARA (Saturate, Aromatic, Resin and Asphaltene) composition. The predicted yield correlations can be used to set the maximum resins content of the feedstock for commercial FCC operations (Xu et al., 2005):

$$Gasoline \; Yield = -0.1161 + 0.7070 \, S + 0.3304 \, A - 0.0769 \, R$$

(A-23)

$$Diesel \; Yield = -0.6127 + 0.0676 \, S + 0.4067 \, A - 0.1366 \, R$$

(A-24)

$$LCO \; Yield = -0.7288 + 0.7746 \, S + 0.7371 \, A - 0.2135 \, R$$

(A-25)

$$Coke \; Yield = -0.0114 + 0.0287 \, S + 0.0514 \, A - 0.252 \, R$$

(A-26)

where; S is saturates, A is aromatics and R is resin content or coefficient of correlation. Table 1 presents the various coefficient of correlation for the respective equations.

Table A1. Equations with Correlation Coefficient.

| Correlation	Equation	Coefficient of Correlation (R)
	A-10	0.877
Stratiev et al. (2012)	A-13	0.845
	A-14	0.892
Stratiev and Minkov (2000)	A-18	0.990
Xu et al. (2005)	A-23	0.844
	A-25	0.841
	A-26	0.759

Appendix B: Design interface of the software

The main window

This window comprises of a tool bar, menu bar and title bar. The title bar denotes the project name, current form and the present Visual Basic operating mode. The menu bar allows the Visual Basic environment to be operated using a drop-down menu. The toolbar provides buttons in order to access other options in the menu. The main window indicates the location of the form in progress relative to the upper left corner of the screen and the breadth and length of the present form.
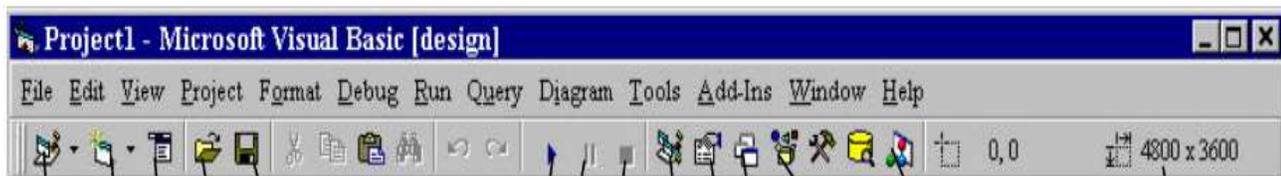
Figure B1. Main Window.

The form window

This window is fundamental to developing Visual Basic applications; where the application design is drawn.
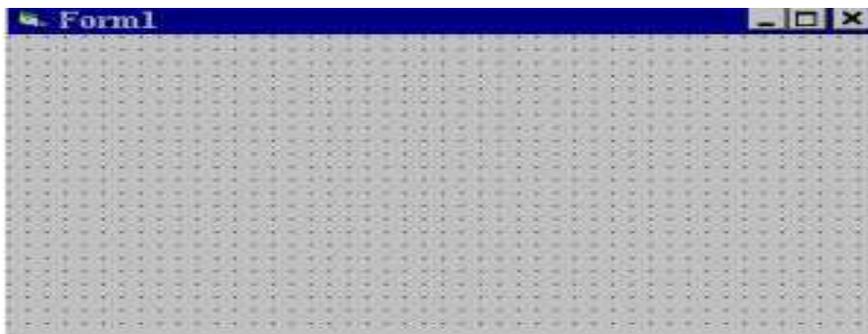
Figure B2. Form Window.

The toolbox

This is where the menu for selecting controls of the application can be found.

Figure B3. Toolbox.

The property window

This window enables the user to set primary property values for the objects. The drop-down box shown at the top of the window catalogues all objects in the present form. The object box shows the name of every single object and its type in the application. Two views are available which are the alphabetic and categorised.
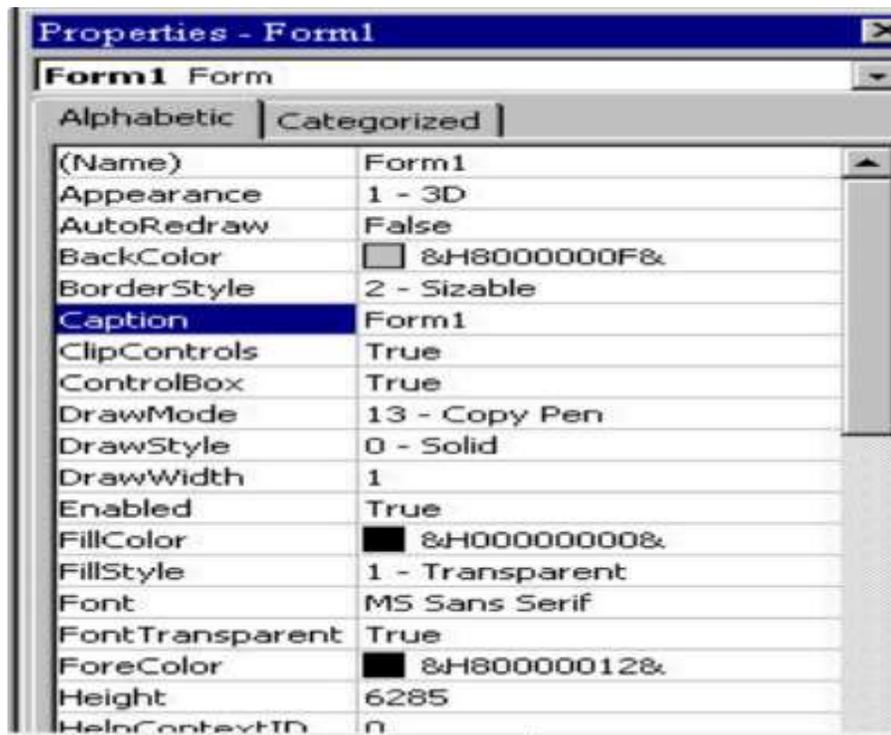

Figure B4. Property window

The Project Window

The forms and modules making up the application is displayed in this window. This also provides a view of the form or code windows from the project window.

Figure B5. Project window.

Appendix C: Correlations and functions used for the design

```
Option Explicit
Dim H As Single
Dim Ca As Single
Dim T As Single
Dim SG As Single
Dim HC As Single
Dim GasolineYield As Single
Dim GasYield As Single
Dim Tf As Single
Dim Conv350 As Single
Dim CONV210 As Single
Dim HCOYield As Single
Dim LCOYield As Single
Dim CokeYield As Single
Dim API As Single
Private Sub Command1_Click()
Dim Ca As Single
Dim H As Single
Dim GasolineYield As Single
Dim GasYield As Single
Dim HCOYield As Single
Dim Conv350 As Single
Ca = Aro.Text
H = H2.Text
Conv350 = -0.57197 * Ca + 5.59515 * H + 33.959
GasolineYield = -0.22704 * Ca + 9.698623 * H - 52.7555
HCOYield = 100 - Conv350
GasYield = -0.18922 * Ca + 2.246805 * H - 4.5
PETROL.Text = Format(GasolineYield, "#####0.0000")
FUELGAS.Text = Format(GasYield, "#####0.0000")
HEAVYNAPHTHA.Text = Format(HCOYield, "#####0.0000")
End Sub

Private Sub Command10_Click()
Dim H2 As Single
Dim Vh As Single
Dim GasolineLV As Single
Dim C4LV As Single
Dim HNLV As Single
Dim ATK As Single
Dim Gasolinewt As Single
Dim C4wt As Single
```

```
Dim HNwt As Single
Dim API As Single
Dim K As Single
Dim SG2 As Single
Dim Tb As Single
Dim Tb1 As Single
API = Val(APIinp(1).Text)
H2 = Val(HSinp(1).Text)
Tb = Val(Tinp(1).Text)
Tb1 = 1.8 * Tb + 32 + 460
SG2 = (141.5) / (131.5 + API)
K = (Tb1) ^ 0.33 / SG2
Vh = 0.6621 * H2 * SG2
GasolineLV = -(0.03734 * API ^ 2) + (1.57575 * API) + (0.014923 * K) - (1.36473 * Vh) - (0.16324 * Vh / K)
C4LV = (0.020359 * GasolineLV ^ 2) + (0.04888 * GasolineLV) + (0.108964 * API)
HNLV = -(0.10322 * GasolineLV ^ 2) + (2.981215 * GasolineLV) - (0.07898 * API)
ATK = 100 + H2 - GasolineLV - C4LV - HNLV
Glyoutp(1).Text = Format(GasolineLV, "#####0.0000")
Gasoutp(1).Text = Format(C4LV, "#####0.0000")
HNoutp(1).Text = Format(HNLV, "#####0.0000")
ATKoutp(1).Text = Format(ATK, "#####0.0000")
End Sub
Private Sub Command2_Click()
End
End Sub

Private Sub Command3_Click()
Glyout.Text = ""
Gasout.Text = ""
Tinp(1).Text = ""
HCOout.Text = ""
LCOout.Text = ""
APIinp(1).Text = ""
HSinp(1).Text = ""
ATKoutp(0).Text = ""
HNoutp(1).Text = ""
txtCok.Text = ""
Glyoutp(1).Text = ""
Gasoutp(1).Text = ""
ATKoutp(1).Text = ""
HNoutp(1).Text = ""
LCOoutp(1).Text = ""
HCOoutp(1).Text = ""
Glyoutp(2).Text = ""
 Aromatics.Text = ""
 Resin.Text = ""
 Saturates.Text = ""
 Aro.Text = ""
H2.Text = ""
PETROL.Text = ""
FUELGAS.Text = ""
HEAVYNAPHTHA.Text = ""
End Sub

Private Sub Command6_Click(Index As Integer)
Dim GasonlineYield As Single
Dim LCOYield As Single
```

```
Dim DieselYield As Single
Dim CokeYield As Single
Dim A As Single
Dim R As Single
Dim S As Single
A = Aromatics.Text
R = Resin.Text
S = Saturates.Text
LCOYield = -0.7288 + 0.7746 * S + 0.7371 * A - 0.2135 * R
GasolineYield = -0.1161 + 0.707 * S + 0.3304 * A - 0.0769 * R
DieselYield = -0.6127 + 0.0676 * S + 0.4067 * A - 0.1366 * R
CokeYield = -0.0114 + 0.0287 * S + 0.0514 * A + 0.252 * R
Glyout.Text = Format(GasolineYield, "#####0.0000")
Gasout.Text = Format(DieselYield, "#####0.0000")
HCOout.Text = Format(CokeYield, "#####0.0000")
LCOout.Text = Format(LCOYield, "#####0.0000")
txtCok = Format(CokeYield, "#####0.0000")
End Sub


Private Sub Command630_Click()
Dim BasicNitrogen As Variant
Dim Hydrogencontent As Variant
Dim Aromaticcontent As Variant
Dim conversion As Variant
Aromaticcontent = SGinp(1).Text
BasicNitrogen = Tinp(2).Text
Hydrogencontent = HSinp(0).Text
Conversion = 5.123 * Hydrogencontent - 0.557 * Aromaticcontent + 23.18
GasolineYield = 0.84 * (conversion) - 0.008 * (BasicNitrogen) - 9.3
CokeYield = 0.0072 * (BasicNitrogen) - 0.11 * (conversion) + 11.6
LCOYield = 59.73 - 0.55 * (conversion)
HCOYield = 100 - LCOYield - conversion
Glyoutp(2).Text = Format(GasolineYield, "#####0.0000")
HCOoutp(1).Text = Format(HCOYield, "#####0.0000")
LCOoutp(1).Text = Format(LCOYield, "#####0.0000")
ATKoutp(0).Text = Format(CokeYield, "#####0.0000")
End Sub
```