Development and Validation of Linear Programming Models for Gasoline and Fuel Oil Blending

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ABSTRACT-Petroleum fuels typically gasoline and fuel oils are manufactured by blending two or more different fractions whose quantities and qualities depend on the crude oil type, the way and conditions of processing. The Oil Refiner is faced with difficulty in calculating accurate quantities of these blendstocks subjected to limitations on finished product qualities, blendstock qualities and quantities. This study was aimed at developing linear programming models plus a computer software that enable prediction of optimum qualities and quantities for gasoline and fuel oil blend. The linear programming (LP) models were formulated using refinery blending results obtained from Port Harcourt Refinery. The proposed LP models were solved using newly developed computer software (Petroblend Optimizer) written in python, which uses the two-phase simplex algorithm. The maximized and minimized objectives of gasoline LP models predicted Fluid Catalytic Cracking Gasoline and Reformate as the major blending stock for gasoline production. Similarly, the maximized objectives of fuel oil LP models predicted Main Column Bottom, Heavy Gas Oil and Atmospheric Residue as the major blending stock for fuel oil production. Whereas the minimized objectives of fuel oil LP models predicted Main Column Bottom, Heavy Gas Oil and Light Cycle Oil as the major blending stock for fuel oil production. Furthermore, the gasoline LP models predicted specific gravity of 0.73-0.77, vapor pressure of 0.40-0.60 $kgcm^{-2}$ and octane number of 89-95 while the fuel oil LP models predicted specific gravity of 0.95-1.03, flash point of 76-143^{o}C, sulphur of 0.28-0.47%wt and viscosity of 18-37cst. The models predicted qualities for gasoline and fuel oil blend fall within the range of refinery actual qualities used for this study; and these results were approximately the same compared to similar results calculated using Microsoft excel solver.

Keywords: Gasoline Blending, Fuel Oil Blending, Linear Programming Model, Python.

1.0 INTRODUCTION

Petroleum blending is a physical operation which consists of mixing precise amounts of two or more refined products in such a way as to meet product demand quantities and market qualities at the least cost with attendant maximization of overall refinery profit [8]. The blending operation is usually complemented by the addition of chemicals known as additives to improve certain blend qualities of finished petroleum products [8]. Thus the final properties of the finished products depend on the properties of the source crude oil as well as the process conditions and final treatments [6]. Some blendstock quality properties do blend linearly while others do not blend linearly [10]. These non-linear properties are represented with blending indexes, which have linear additivity characteristics [9]. The accurate estimation of blendstock quantities subject to specified product qualities is often a difficult task in petroleum refineries. Some of the numerous studies on linear programming models used for blending petroleum products are discussed as follows. Singh et al. [10] addressed the problem of blending optimization for in-line blending for the case of stochastic disturbances in feedstock qualities. They presented a real- time optimization method that can provide significantly improved profitability.

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Symonds [11] developed an LP model for solving a simplified gasoline refining and blending problem. Allen [1] presented an LP model for a simple refinery that consists mainly of three units: distillation, cracking and blending. Li et al. [4] conducted a study on integrating crude distillation, FCC and product blending models into refinery-planning models. They presented a refinery-planning model utilizing simplified empirical nonlinear process models with considerations for crude oil characteristics, product yields and qualities. Khosla et al [3] presented multi-objective optimization of fuel oil blending using the jumping gene adaptation of genetic algorithm. This study enabled the improvement of fuel oil blending process to maximize profit and minimize quality give-away by way of reducing the use of lighter products such as LCO and kerosene. Glismann and Gruhn [13] proposed a mixed-integer linear programming model (MILP), which is based on a resource-task network representation, to solve the task of short-term scheduling of blending processes. The recipe optimization problem is then formulated as a nonlinear program, and the results are returned to the scheduling problem, so that an overall optimization can be achieved. Zahed et al. [12] proposed a model with five independent variables for predicting the octane number of gasoline blends. Pasadakis et al. [5] used Artificial Neural Network (ANN) models to predict octane rating of gasoline blends by employing the volume fractions of streams used for blending of gasoline. Oduola and Iyaomolere [7] developed model equations for predicting gasoline-blending properties specifically the research octane number, reid vapour pressure and the specific gravity.

Ristic et al [9] developed models for optimum products blending which satisfy the requirements for the oil products quality and quantity using the available fractions. Most of the reported LP models are centered on gasoline blend rather than fuel oil blend. The key objective is usually to maximize the sales of blended products or minimize the costs of blending these products with little consideration for the estimation of optimum blend qualities. This study has been carried out with the objective to develop and validate linear programming models for predicting blend qualities and ratios for gasoline and fuel oil.

2.0 METHODOLOGY

Presently in Nigerian Refineries, the major refinery products produced by blending are liquefied petroleum gas (LPG), premium motor spirit (PMS) and fuel oils. The kerosene and diesel fuels are direct refinery products with high demand/sale price and they are seldom used as blending components in Nigerian Refineries. This philosophy guided the selection of gasoline and fuel oil blends for modeling in this research project. Figure 1 represents the blending operation as obtainable in a typical petroleum refinery.

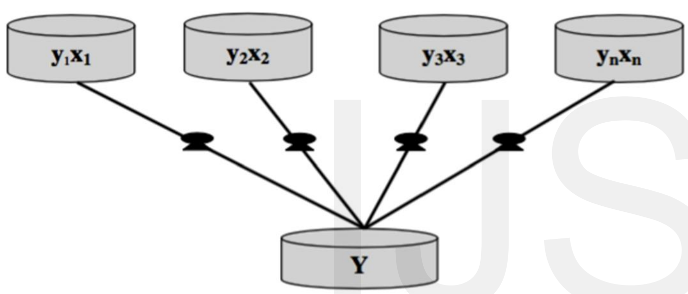

Figure 1.0: Schematic showing blending process in a typical petroleum refinery.

Where *'Y'* represents the finished property of blended petroleum product, *'y_i'* represents the property of the blend components estimated from laboratory tests and *'x_i'* represents the volumetric ratio of the blend components. The proposed LP models for Gasoline and Fuel Oil blending based on Figure 1 above can be written as:

2.1 GASOLINE BLEND LP MODEL

Max or Min Gasoline Quality (Y_g) = $\sum_{i=1}^{n}(y_{gi}x_i)$ (1)

Subject to:

Specific Gravity (G): $G_{min} \leq \sum_{i=1}^{n}(G_i x_i) \leq G_{max}$ (2)

Reid Vapor Pressure (P): $P_{min} \leq \sum_{i=1}^{n}(P_i x_i) \leq P_{max}$ (3)

Octane Number (R): $R_{min} \leq \sum_{i=1}^{n}(R_i x_i) \leq R_{max}$ (4)

Total Blend Ration: $\sum_{i=1}^{n}(x_i) = 1$ (5)

Non Negative Constraint: $x_i \geq 0$, $(i = 1,..n)$. (6)

The Equation (1) represents the proposed model objective function subject to the constraint equations (2-6). Where *'Y_g'* is the optimized quality of blended gasoline representing the independent variable. *'y_{gi}'* is the coefficient of selected gasoline quality. *'x_i'* is the blendstock ratio representing the dependent variable. *'n'* is the number of blend components. *$(G,P,R)_{min/max}$* is the gasoline actual quality specifications (See Table 3.0). *(G_i, P_i, R_i)* is the blend components' quality specifications (See Table 1.0).

2.2 FUEL OIL BLEND LP MODEL

Max or Min Fuel Oil Quality (Y_f) = $\sum_{i=1}^{n}(y_{fi}x_i)$ (7)

Subject to:

Specific Gravity (G): $G_{min} \leq \sum_{i=1}^{n}(G_i x_i) \leq G_{max}$ (8)

Flash Point (F): $F_{min} \leq \sum_{i=1}^{n}(F_i x_i) \leq F_{max}$ (9)

Sulphur (S): $S_{min} \leq \sum_{i=1}^{n}(S_i x_i) \leq S_{max}$ (10)

Viscosity (V): $V_{min} \leq \sum_{i=1}^{n}(V_i x_i) \leq V_{max}$ (11)

Total Blend Ration: $\sum_{i=1}^{n}(x_i) = 1$ (12)

Non Negative Constraint: $x_i \geq 0$, $(i = 1,..n)$. (13)

Similarly, the Equation (7) represents the proposed model objective function subject to the constraint equations (8-13). Where *'Y_f'* is the optimized quality of blended fuel oil representing the independent variable. *'y_{fi}'* is the coefficient of selected fuel oil quality. *'x_i'* is the blendstock ratio representing the dependent variable. '*n*' is the number of blend components. *$(G,F,S,V)_{min/max}$* is the fuel oil actual quality specifications (See Table 3.0). *(G_i, F_i, S_i, V_i)*: is the blend components' quality specifications (See Table 2.0).

2.3 GASOLINE BLENDING DATA

Table 1.0 presents five data sets on gasoline blending results using four blend components collected from Port Harcourt Refinery. The four blending components are Straight Run Gasoline (SRG), Straight Run Naphtha (SRN), Reformate (REFM) and Fluid Catalytic Cracking Gasoline (FCCG). Furthermore, the gasoline oil blending data indicates three blending qualities, which include the specific gravity (G), reid vapor pressure (P) and octane number (R).

Table 1.0: Gasoline Blending Results

CASE 1

Blendstocks	Tankage (m^3)	Vol Fraction (X_i)	S.G (G_i)	RVP (P_i)	RON (R_i)
SRG	2000	0.1000	0.6601	1.1100	73.0000
FCCG	10000	0.5000	0.7656	0.3600	93.6000
SRN	1000	0.0500	0.7697	0.1500	60.0000
REFM	7000	0.3500	0.7600	0.4600	92.0000
Total	20000	1.0000	0.7533	0.4595	89.3000

CASE 2

Blendstocks	Tankage (m^3)	Vol Fraction (X_i)	S.G (G_i)	RVP (P_i)	RON (R_i)
SRG	1000	0.0500	0.6601	1.1000	73.0000
FCCG	9000	0.4500	0.7612	0.4500	94.8000
SRN	1000	0.0500	0.7703	0.1500	61.0000
REFM	9000	0.4500	0.7713	0.5000	89.0000
Total	20000	1.0000	0.7611	0.4900	89.4100

CASE 3

Blendstocks	Tankage (m^3)	Vol Fraction (X_i)	S.G (G_i)	RVP (P_i)	RON (R_i)
SRG	2000	0.1000	0.6600	0.9000	76.0000
FCCG	8000	0.4000	0.7600	0.5000	95.0000
SRN	2600	0.1300	0.7700	0.2200	61.0000
REFM	7400	0.3700	0.7600	0.4500	96.0000
Total	20000	1.0000	0.7513	0.4851	89.0500

CASE 4

Blendstocks	Tankage (m^3)	Vol Fraction (X_i)	S.G (G_i)	RVP (P_i)	RON (R_i)
SRG	600	0.0300	0.6599	1.0500	73.0000
FCCG	10000	0.5000	0.7656	0.4500	94.0000
SRN	400	0.0200	0.7577	0.1100	63.4000
REFM	9000	0.4500	0.7611	0.5500	90.0000
Total	20000	1.0000	0.7602	0.5062	90.9580

CASE 5

Blendstocks	Tankage (m^3)	Vol Fraction (X_i)	S.G (G_i)	RVP (P_i)	RON (R_i)
SRG	990	0.0495	0.6519	1.1700	74.0000
FCCG	9240	0.4620	0.7767	0.3600	95.2000
SRN	770	0.0385	0.7708	0.1400	61.0000
REFM	9000	0.4500	0.7512	0.4500	93.0000
Total	20000	1.0000	0.7588	0.4321	91.8439

2.4 FUEL OIL BLENDING DATA

Similarly, Table 2.0 presents five data sets on fuel oil blending results using four blending components collected from Port Harcourt Refinery. The four blending components are Main Column Bottoms (MCB), Light Cycle Oil (LCO), Heavy Gas Oil (HGO) and Atmospheric Residue (AR). Furthermore, the fuel oil blending data indicates four blending qualities, which include the specific gravity (G), flash point (F), sulphur (S) and kinematic viscosity (V).

Table 2.0: Fuel Oil Blending Results

CASE 1

Blendstocks	Tankage (m^3)	Vol Fraction (X_i)	S.G (G_i)	FLASH POINT (F_i)	SULPUR (S_i)	KINEMATIC VISCOSITY (V_i)
MCB	3077	0.1538	1.0621	64	0.494	10.7
LCO	8225	0.4113	0.9501	112	0.24	1.75
HGO	7644	0.3822	0.9088	132	0.24	47
AR	1054	0.0527	0.9388	114	0.344	36.6
Total	20000	1.0000	0.9509	112.3651	0.2846	22.2578

CASE 2

Blendstocks	Tankage (m^3)	Vol Fraction (X_i)	S.G (G_i)	FLASH POINT (F_i)	SULPUR (S_i)	KINEMATIC VISCOSITY (V_i)
MCB	1728	0.0864	1.059	66	0.472	9.82
LCO	9493	0.4746	0.9553	116	0.216	1.65
HGO	7446	0.3723	0.9088	133	0.23	45
AR	1333	0.0666	0.9481	137	0.348	19.77
Total	20000	1.0000	0.9465	119.4083	0.2521	19.7035

CASE 3

Blendstocks	Tankage (m^3)	Vol Fraction (X_i)	S.G (G_i)	FLASH POINT (F_i)	SULPUR (S_i)	KINEMATIC VISCOSITY (V_i)
MCB	2096	0.1048	1.0596	74	0.493	10.24
LCO	8496	0.4248	0.9695	112	0.215	1.67
HGO	7115	0.3557	0.9022	132	0.394	47
AR	2292	0.1146	0.9582	130	0.369	18.05
Total	20000	1.0000	0.9537	117.1946	0.3255	20.5712

CASE 4

Blendstocks	Tankage (m^3)	Vol Fraction (X_i)	S.G (G_i)	FLASH POINT (F_i)	SULPUR (S_i)	KINEMATIC VISCOSITY (V_i)
MCB	3905	0.1952	1.0416	62	0.394	10.45
LCO	7794	0.3897	0.9432	107	0.237	1.74
HGO	5800	0.2900	0.908	130	0.256	46
AR	2500	0.1250	0.9376	152	0.359	22.56
Total	20000	1.0000	0.9515	110.5106	0.2884	18.8798

CASE 5

Blendstocks	Tankage (m^3)	Vol Fraction (X_i)	S.G (G_i)	FLASH POINT (F_i)	SULPUR (S_i)	KINEMATIC VISCOSITY (V_i)
MCB	4839	0.2420	1.0588	70	0.389	10.43
LCO	8014	0.4007	0.953	104	0.253	1.72
HGO	5086	0.2543	0.896	132	0.236	46
AR	2061	0.1030	0.9443	143	0.345	32.6
Total	20000	1.0000	0.9632	106.9125	0.2911	18.2699

2.5 FINISHED GASOLINE AND FUEL OIL QUALITY SPECIFICATION DATA

The blending of refined petroleum products is usually carried out in accordance with the limits of product quality specifications. The qualities specification data for finished gasoline and fuel oil blend adhere to in this study are presented in Table 3.0.

Table 3.0: Finished Gasoline and Fuel Oil Quality Specification Data.

Gasoline Blend Qualities (G, P, R)			
Specific Gravity	Research Octane Number		Reid Vapour Pressure (kg/cm²)
$0.720 \leq G \leq 0.780$	$89 \leq R \leq 100$		$0.40 \leq P \leq 0.60$
Fuel oil Blend Qualities (G,F,S,V)			
Specific Gravity	Flash Point (°C)	Sulphur (%wt)	Kinematic Viscosity (cst)
$0.950 \leq G \leq 1.040$	$65 \leq F \leq 155$	$0.10 \leq S \leq 0.50$	$18 \leq V \leq 40$

2.6 MODEL TRANSLATION AND SOLUTION TECHNIQUE

The collected data on blendstock qualities and finished product qualities as presented in Table 1-3 were used to translate the proposed LP models. Table 4.0 shows the translated model equations with maximize or minimize model objective of Gasoline Octane Number *(Y_{ON})* and Fuel Oil Viscosity *(Y_{VSC})* using the first blending results for gasoline and fuel oil *(Cases1).* Similar translations were repeated for the other remaining qualities of gasoline and fuel oil in all the five refinery-blending cases.

Table 4.0: Translated LP Models for Gasoline and Fuel Oil Blend

Gasoline Blend LP model	Fuel Oil Blend LP Model
Maximize or Minimize Octane Number (Y_{ON}):	**Maximize or Minimize Viscosity (Y_{VSC}):**
$Y_{ON}=73X_{11}+93X_{12}+60X_{13}+92X_{14}$	$Y_{VSC}=10.7X_{21}+1.75X_{22}+47X_{23}+36.6X_{24}$
Subject to:	***Subject to:***
Specific gravity (SG):	***Specific gravity (SG):***
$0.66X_{11}+0.77X_{12}+0.77X_{13}+0.76X_{14} \geq 0.72$	$1.06X_{21}+0.95X_{22}+0.91X_{23}+0.94X_{24} \geq 0.95$
$0.66X_{11}+0.77X_{12}+0.77X_{13}+0.76X_{14} \leq 0.78$	$1.06X_{21}+0.95X_{22}+0.91X_{23}+0.94X_{24} \leq 1.04$
Octane Number (ON):	***Flash Point (FP):***
$73X_{11}+93X_{12}+60X_{13}+92X_{14} \geq 89$	$64X_{21}+112X_{22}+132X_{23}+114X_{24} \geq 65$
Reid Vapor Pressure (RVP):	$64X_{21}+112X_{22}+132X_{23}+114X_{24} \leq 155$
$1.11X_{11}+0.36X_{12}+0.15X_{13}+0.46X_{14} \geq 0.40$	***Sulphur(SUL):***
$1.11X_{11}+0.36X_{12}+0.15X_{13}+0.46X_{14} \leq 0.60$	$0.49X_{21}+0.24X_{22}+0.24X_{23}+0.34X_{24} \leq 0.50$
Total Blend Ration:	$0.49X_{21}+0.24X_{22}+0.24X_{23}+0.34X_{24} \geq 0.10$
$X_{11}+X_{12}+X_{13}+X_{14}=1$	***Viscosity(VSC):***
Non Negative Constraint:	$10.7X_{21}+1.75X_{22}+47X_{23}+36.6X_{24} \geq 18$
$X_{11}, X_{12}, X_{13}, X_{14} \geq 0$	***Total Blend Ration:***
	$X_{21}+X_{22}+X_{23}+X_{24}=1$
	Non Negative Constraint:
	$X_{21}, X_{22}, X_{23}, X_{24} \geq 0$
LEGEND: *X_{11}-Straight Run Gasoline (SRG); X_{12}-Fluid Catalytic Cracking Gasoline (FCCG); X_{13}-Straight Run Naphtha (SRN), X_{14}-Reformate (REFM)*	***LEGEND:*** *X_{21}-Main Column Bottom (MCB); X_{22}-Light Cycle Oil (LCO); X_{23}-Heavy Gas Oil (HGO); X_{24}-Atmospheric Residue (AR).*

The solution technique used to solve the above translated model equations is the two-phase simplex algorithm implemented by development of a computer software (Figure 2.0) written in python code as described in the main work [2].

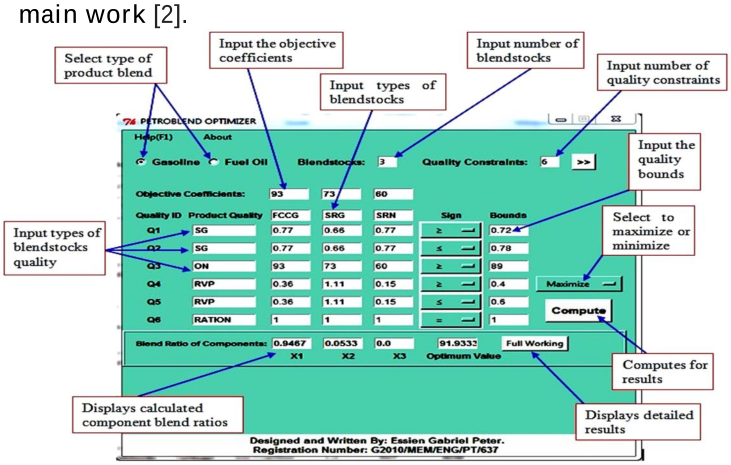

Figure 2.0: The Software User Interface

3.0 RESULTS AND DISCUSSIONS

3.1 Gasoline LP Models Prediction: The results of the predicted gasoline qualities and blend ratios against the corresponding actual values from the refinery blending data (Case 1) are shown in Table 5.0. Other model predicted results for the remaining refinery blending data (Cases 2-5) are presented in the main work [2].

Table 5.0: Gasoline LP Models Prediction

Maximized Objective Models' Prediction of Gasoline Qualities and Blend Ratios							
CASE #1	SG	RVP	ON				
Actual Qualities	0.72-0.78	0.40-0.60	89-100	SRG(X_1)	FCCG (X_2)	SRN(X_3)	REFM(X_4)
Refinery Blend	0.75	0.46	89.30	0.1000	0.5000	0.0500	0.3500
SG Model	0.77	0.40	93.00	0.0000	0.6000	0.0000	0.4000
ON Model	0.76	0.40	92.60	0.0000	0.6000	0.0000	0.4000
RVP Model	0.74	0.56	89.00	0.1579	0.0000	0.0000	0.8421
Minimized Objective Models' Prediction of Gasoline Qualities and Blend Ratios							
CASE #1	SG	RVP	ON				
Actual Qualities	0.72-0.78	0.40-0.60	89-100	SRG(X_1)	FCCG(X_2)	SRN(X_3)	REFM(X_4)
Refinery Blend	0.75	0.46	89.30	0.1000	0.5000	0.0500	0.3500
SG Model	0.74	0.56	89.00	0.1579	0.0000	0.0000	0.8421
ON Model	0.76	0.40	89.00	0.0746	0.8494	0.0760	0.0000
RVP Model	0.76	0.40	90.00	0.0746	0.8494	0.0760	0.0000

From Table 5.0, it can be seen that all the predicted qualities obtained either by maximizing or minimizing the quality LP models fall within the actual standard range of gasoline quality values as obtained from the refinery. These gasoline LP models predicted specific gravity of 0.73-0.77, vapor pressure of 0.40-0.60 $kgcm^{-2}$ and octane number of 89-95. The model predicted results were almost the same compared with similar results calculated using Microsoft excel solver as presented in the main work [2]. Both the minimized and maximized gasoline LP models predict two or more optimum alternative blend qualities and ratios for gasoline. The model predicted blend ratios showed FCCG (≥50%) and REFM (≥40%) as the major gasoline blending components, which agree with the reported five cases of refinery blend results used in this study. Furthermore, the minimized quality LP models presented more component blends (>2) compared to maximized LP models; this finding agrees with the philosophy of blending to reduce quality give-away with attendant increment in product volume for maximization of refinery profits.

3.2 Fuel Oil LP Models Prediction: Similarly, the results of the predicted fuel oil qualities and blend ratios against the corresponding actual values from the refinery blending data (Case 1) are shown in Table 6.0. The model predicted results for the remaining refinery blending data (Cases 2-5) are presented in the main work [2].

Table 6.0: Fuel Oil LP Models Prediction

Maximized Objective Models' Prediction of Fuel Oil Qualities and Blend Ratios								
CASE #1	SG	FP	SUL	VSC				
Actual Qualities	0.95-1.04	65-155	0.10-0.50	18-40	MCB(X_1)	LCO(X_2)	HGO(X_3)	AR(X_4)
Refinery Blend	0.95	112.37	0.28	22.26	0.1538	0.4113	0.3822	0.0527
SG Model	1.03	77.67	0.44	18.00	0.7989	0.0000	0.2011	0.0000
FP Model	0.95	113.87	0.31	37.32	0.2667	0.0000	0.7333	0.0000
SUL Model	1.03	78.10	0.45	18.00	0.7181	0.0000	0.0000	0.2819
VSC Model	0.95	113.86	0.31	37.32	0.2667	0.0000	0.7333	0.0000
Minimized Objective Models' Prediction of Fuel Oil Qualities and Blend Ratios								
CASE #1	SG	FP	SUL	VSC				
Actual Qualities	0.95-1.04	65-155	0.10-0.50	18-40	MCB(X_1)	LCO(X_2)	HGO(X_3)	AR(X_4)
Refinery Blend	0.95	112.37	0.28	22.26	0.1538	0.4113	0.3822	0.0527
SG Model	0.95	112.85	0.27	18.00	0.1218	0.5432	0.3350	0.0000
FP Model	1.03	77.68	0.44	18.00	0.7989	0.0000	0.2011	0.0000
SUL Model	0.95	112.85	0.27	18.00	0.1218	0.5432	0.3350	0.0000
VSC Model	1.03	77.67	0.44	18.00	0.7989	0.0000	0.2011	0.0000

From Table 6.0, it can be seen that all the predicted qualities obtained either by maximizing or minimizing the Fuel Oil LP models fall within the actual standard range of fuel oil quality values as obtained from the refinery. These Fuel oil LP models predicted specific gravity of 0.95-1.03, flash point of 76-143^{o}C, sulphur of 0.28-0.47 %wt and viscosity of 18-37cst. The model predicted results were approximately the same compared with similar results calculated using Microsoft excel solver as presented in the main work [2]. As with the gasoline model predictions, the minimized and maximized fuel oil LP models also predicted more than two optimum alternative blend qualities and ratios for fuel oil. The prediction from maximized fuel oil quality LP models excluded LCO as a blending component in all the results; this finding may be attributed to LCO being the lowest viscous component among others as depicted in the field data (Table 2.0). Apparently, the HGO, AR, MCB are the heavier blend components compared to LCO and this makes them suitable for maximizing blend SG, FP, SUL and VSC. Likewise, the prediction from minimized fuel oil quality LP models excluded AR as a blending component in all the results; this finding may be attributed to AR being the heaviest blend component among others as shown in the field data (Table 2.0). The minimized LP models for specific gravity and sulphur predicted blend ratios that indicated LCO (≥40%) and HGO (≥30%) as the major blending components, which agree with the refinery blend ratios. However, the minimized LP models for flash point and viscosity predicted MCB (≥77%) and HGO (≥20%) as the major blending components. The minimized fuel oil quality LP models presented more component blends (>2) compared to the maximized LP models; a similar trend noted with the minimized gasoline quality LP models.

4.0 CONCLUSION

This study proposes quality LP models plus computer software for blending of gasoline and fuel oil in petroleum refineries. The model predictions presented optimum alternative blend qualities and blend ratios for gasoline and fuel oil. The LP models predicted blend qualities were within the range of refinery actual qualities used for this study; and these results present analytical and economic blending solutions compared to the empirical calculations as obtained from the refinery blending results. From the results obtained and subject to Operator decisions, the minimized LP models for both the gasoline and fuel oil blending is fit for purpose because of its allowance for the addition of more blendstocks. The future works for this research will be to extend the quality LP modeling to include other gasoline and fuel oil qualities such as pour point, water content, boiling points, stability and energy content. Finally, the deployment and application of the proposed LP models and software to Nigerian Refineries will enhance blending operations with the attendant maximization of refining profit margins.

5.0 ACKNOWLEDGEMENT

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6.0 REFERENCES

[1] Allen, D.H. (1971). Linear programming models for plant operations planning. British Chemical Engineering, Vol. 16, pp.685–691.

[2] Essien, G.P. (2016). Development and Validation of Linear Programming Models for Gasoline and Fuel Oil Blend (Unpublished MSc Thesis). University of Port Harcourt, Nigeria.

[3] Khosla, Dinesh K., Santosh K. Gupta, and Deoki N. Saraf."Multi-objective optimization of fuel oil blending using the jumping gene adaptation of genetic algorithm. Fuel Processing Technology 88.1(2007): 51-63.

[4] Li, W., Hui, C.W. and Li, A. (2005) Integrating CDU, FCC and product blending models into refinery planning', Computers and Chemical Engineering, Vol. 29, pp.2010–2028.

[5] N. Pasadakis, V. Gaganis, Ch. Foteinopoulos: "Octane number prediction for gasoline blends", Fuel Processing Technology, 87, (2006) 505-509.

[6] Odebunmi E.O., Ogunsakin E.A., Ilukhor P.E.P. (2002).Characterization of Crude Oils and Petroleum Products: Elution Liquid Chromatographic Separation

and Gas Chromatographic Analysis of Crude Oils and Petroleum products. Bull. Chem. Soc. Ethiop., 16(2), 115-132.

[7] Oduola, M.K., Iyaomolere, A.I. (2015). Development of model equations for predicting gasoline-blending properties. American Journal of Chemical Engineering 3.2-1: 9-17.

[8] Parkash, S. (2009). Petroleum fuels manufacturing handbook. Europe: McGraw-Hill Education.

[9] Ristic, J., Tripceva-Trajkovska, L., Rikaloski, I., Markovska, L. (1999). Optimization of Refinery Products Blending. Bulletin of the Chemists and Technologists of Macedonia, 18(2), 2-171.

[10] Singh, A.; Forbes, J.F., Vermeer, P.J., Woo, S. S. (2000). Model- based real-time optimization of automotive gasoline blending operations. J. Process Control, 10, 43.

[11] Symonds, G. (1956) 'Linear programming solves gasoline refining and blending problems', Industrial and Engineering Chemistry, Vol. 48, No. 3, pp.394–401.Watkins, R.N. (1979) Petroleum Refinery Distillation, 2nd ed., Gulf Pub. Co.,Book Division, Houston, USA.

[12] Zahed, A.H., S.A. Mullah, and M. D. Bashir. Predict Octane Number for Gasoline Blends. Hydroc Proc, 72(5), 1993, 85-87.

[13] Glismann K., Gruhn G. (2001). Short-Term Scheduling and Recipe Optimization Of Blending Processes. Comp. Chem. Eng., 25, 627.