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Simulation Software for Premium Motor Spirit Major Components Optimal Blending

Akinnuli, Basil Olufemi[1*]; Olutomilola, Emmanuel Olatunji[1]; Babalola, Simeon Ayodele[2]; Atoyebi, Adeyinka Abiodun[3]; Ayanrinde, Ayanniyi Wole[4];
[1,1]Department of Mechanical Engineering, Federal University of Technology, Akure, Nigeria.*
[2]Department of Mechanical and Mechatronics Engineering, Afe Babalola University, Ado-Ekiti, Nigeria.
[3]Department of Mechanical Engineering, Osun State College of Technology Esa-Oke, Nigeria.
[4]Department of Mechanical Engineering, The Ibarapa Polytechnics, Eruwa, Nigeria.
Corresponding Author: Akinnuli, Basil Olufemi

ABSTRACT: - Premium Motor Spirit (PMS) by-products in Nigeria is hazardous. The cause was traced to wrong computation of components for blending. This led to the development of this model and its software to proffer solution. Standard PMS blend specification was identified, percentage by volume required was evolved by developed mathematical models to generate the correct values. The correct specification of Research Octane Number (RON), Reid Vapour Pressure (RVP) and Density (D) after blending were compared with the available set standard to know the accuracy of the blend. Software was developed for implementing these models. Applications of the developed model and its software determined the acceptable values of RVP (9 psi), RON (90) and D (0.7500-0.7600) g/cm^3. These values are within the set specifications for blending. RVP is the common measure of the volatility of gasoline, which should not exceed 9 psi. In Nigeria too, little volatility results in "Vapour Lock" and acceptable PMS pressure is in range of 0.75-0.76 g/cm^{3}due to the climatic tropical nature of the country. The RON of PMS in Nigeria should be within the range of 90-100. The use of PMS with low Octane Number may lead to "Engine Knock"; the higher the Octane Number, the more compression the fuel can withstand before derogating. This model and its software are capable of: predicting right blending; identifying wrong blending; and proposing correct blend that is acceptable. When the developed model and its software were used to simulate the system, the software was able to infer values of: RON, RVP and D if correct or incorrect. This assisted in proffering the expected solution to the problem in existence.

Keywords: Optimization, Blending, Modelling, Premium Spirit, Simulation, Software development

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I. INTRODUCTION

Blending solutions spreads across a wide range of industries ranging from refineries, food processing industries, pharmaceuticals, brewery and a host of others. It is also important to know that blending is important because products cannot be marketable without sailing through quality test, and blending is the means by which this feat is accomplished [1]. Blending is a physical operation which consists of mixing precise amounts of two or more components, generally of the same range, in order to obtain a final product that meets market specifications [2, 3]. In the petroleum industry, it produces marketable products that are suitable for use. Premium Motor Spirit (PMS) is called petrol by Britons and Gasoline by Americans, which means same thing but its nomenclature is Premium Motor Spirit (PMS). The blended components of PMS are: Cracked gasoline (also known as FCC Gasoline), Straight Run Naphtha (also known as Light Naphtha) [4, 5].

Generally, there are two methods in motor spirit blending: batch and inline blending methods. Batch blending is an intermittent operation in which the rate of blending is fixed entirely by the capacity of the transfer/wending pumps, and is quiet independent of plant component production rates. Any batch–blending system requires adequate component storage and a set (generally two) pumps of large capacity for transferring components from component storage to the blend tanks. The blending tanks are carefully calibrated, and the accuracy of this method is regarded as being of a high order. In this respect, it is interesting to note that customs authorities in many countries accept only differences in calibrated tank levels as a true measure for exercise purposes of oil products. Attempts to replace this means of measurement by alternative types of metering devices have so far been successful in only a few countries. When the specific gravity of the components that are successively transferred differ significantly, stratification (layering) occurs [6]. Action has to be taken to eliminate this stratification and it is necessary to provide a means of mixing the tank contents. There are various ways in which the mixing step can be carried out. All of these are based on providing turbulent flows within the tank [7]. The principal danger of batch blending lies in the possibility of static electricity build-up [8]. This in many cases leads to serious explosions and a very thorough study has been made of the problem.

In-line blending has been another technique of blending known to be adopted for proffering solution to the problem caused by batch method. In this adopted method, the in-line blended gasoline enter the tank at vapour pressure specification, so that the risk of space is very remote. However, in-line blending is not restricted to the preparation of gasoline, but can be applied to all kinds of products [9, 10]. In this system, each component is pumped simultaneously into a common discharge header at a predetermined flow rate corresponding to the proportion of each component required in the blend. The blending method has the advantage that the capacity of the blender is independent of the rate of component production. This lather is important when direct shipping of the stream from the blender is applied or may be applied in the future because the loading time for ships should be short, so that large-capacity in-line blending facilities are required for the aforementioned reasons. In-line blending of components from components storage tanks is preferred in most cases to plant stream blending because it is more flexible and it gives a higher blending accuracy [11].

Moreover, the optimum blending ratio of gasoline components at any given volume needs to be determined in order to obtain quality gasoline product, improve Reid vapour pressure (RVP), create acceptable statutory density of the PMS product. The required octane rating will be met, ability to liberate sufficient energy when used will be created and there will be reduction or elimination of adulterated fuel (PMS) products [12, 13]. According to [14], chemical quality of Muti Dahi was prepared from blending of Soya milk with Buffalo milk. Fundamental study of a plasma generating for gasoline ignition applying AC power was carried out by [15] while [16] optimized gasoline engine flywheel using alternative material for improving its performance characteristics.

II. METHODOLOGY

The blending procedure in this research involved identification of the standard PMS blend specifications; calculation of the percentages by volume of the tank to the percentage by volume of the tank to be blended; determination of the correct specification of RON, RVP and blend composition density of the PMS and establishment of acceptability of the blended motor spirit by ensuring that it met the standard set for PMS blend specifications.

Premium Motor Spirit: In this study, the premium motor spirit (PMS) is made up of three major blended components which are: Fluid Catalytic Cracked Gasoline (FCC Gasoline), Straight Run Naphtha (Light Naphatha), and Reformate. These three components were used primarily in Warri Refining and Petrochemical Company (WRPC).

Standard PMS Blend specifications: The set standards for controlling and judging the quality of PMS product blends are as follows: (i) density of PMS = 0.7300 – 0.7600 gram per cm^3; (ii) Reid Vapour Pressure (RVP) = 2 psi Maximum; (iii) Research Octane Number = 90 Minimum [17].

PMS Blending Procedure: After the standard of PMS required blend specification has been identified, the percentage by volume of the tank to be blended was calculated. Then the correct composition of the PMS was determined, considering the standard PMS blend specifications.

Model Development

Nomenclature:

α	=	Volume of Fluid Catalytic Crack Gasoline ($FCCG_V$)
γ	=	Raid Vapour Pressure (Psi) (RVP)
ϱ	=	Density of Motor Spirit
ψ	=	Research Octane Number (RON)
θ	=	Reformate REF
V_{TB}	=	Total Volume of tank required to be blended (10000m^3)
N	=	Light Naphtha
α_{ch}	=	Chosen Fluid Catalytic Crack Gasoline Density (0.72-0.78)g/m^3
γ_{ch}	=	Density of Reid Vapour Pressure.
Nch	=	Light Naphtha Density Chosen (0.69 – 0.71) g/cm^3
θ_{ch}	=	Density of Reformate Chosen (0.72 = 0.77) g/m^3
$\Sigma(\alpha_{ch}, \alpha_{ch}, \theta_{ch})$ =		(0.73 – 0.76) g/m^3
α_{γ}	=	Volume of Fluid Catalytic Crack Gasoline ($FCCG_V$)
θ_{γ}	=	Volume of Reformate Required (m^3)
N_{γ}	=	Volume of Light Naphtha (m^3)
ψ_{γ}	=	Research Octane Number for Fluid catalytic Crack Gasoline
ψ_{θ}	=	Research Octane Number for Reformate
ψ_N	=	Research Octane Number for Light Naphtha

α_{cd}	=	Calculated Fluid Catalytic Crack Gasoline Density
θ_{cd}	=	Calculated Reformate Density
N_{cd}	=	Calculated Light Naphtha Density
$\alpha_{ch\gamma}$	=	Chosen Reid Vapour Pressure for FCCG
$\theta_{ch\gamma}$	=	Chosen Reid Vapour Pressure for Reformate θ
$N_{ch\gamma}$	=	Chosen Reid Vapour Pressure for Light Naphtha
$\alpha_{c\gamma}$	=	Calculated Reid Vapour Pressure for FCCG
$\theta_{c\gamma}$	=	Calculated Reid Vapour Pressure for Reformate θ
$N_{c\gamma}$	=	Calculated Reid Vapour Pressure for Light Naphtha

Blending Procedure for Premium Motor Spirit (PMS)

(a) Identify the standard PMS blend specifications.
(b) Calculate the percentage by volume of the tank to be blended.
(c) Determine the correct specification of RON, RVP and Octane Number (RON), Reid Vapour Pressure (RVP) Research and Density of Premium Motor Spirit (DPMS).
(d) Ensure that the standard PMS blend specifications are met.

Criteria for Blending

(a) The percentage by volume of the tank to be blended must be given; for example: 5,000m^3, 10,000m^3, 8,000m^3 etc.
(b) The various compositions of the Reid Vapour Pressure (RVP), Research Octane Number (RON) and Density of premium motor Spirit (DPMS) must be chosen within their limits.
(c) The final PMS blend is taken to the laboratory and tested in order to ascertain its composition.

Determination of Density Composition of PMS

(a) Determine the volume of tank of PMS to be blended (VTB), which is 10,000 m^3 in most cases.
(b) Determine the blending ratio by percentage.

Scenario for Volume Selection

If 50% of α_v = 5000 m^3; then: θ_v = 30% = 3,000 m^3; N_v = 20% = 2,000 m^3
Otherwise: 70% of α_v = 7,000 m^3; θv= 15% = 1,500 m^3; N_v = 15% = 1,500 m^3

Mathematical Model for the Density Composition

Density (α_{cd})

$$\propto_{cd} = \left(\frac{\alpha_v}{V_{TB}}\right)\alpha_{ch\alpha} \quad (1)$$

Determination of Reformate Density (θ_{cd})

$$\theta_{cd} = \left(\frac{\theta_v}{V_{TB}}\right)\theta_{ch\alpha} \quad (2)$$

Determination of Naphtha Density (N_{cd})

$$N_{cd} = \left(\frac{N_v}{V_{TB}}\right)N_{chN} \quad (3)$$

$$DPMS = \alpha_{cd} + \theta_{cd} + N_{cd} \quad (4)$$

Check: $\Sigma(\alpha_{cd}, \alpha_{cd}, \theta_{cd})$ = (0.73 – 0.76) g/m^3

Determination of Reid Vapour Pressure (RVP)

(a) Determination of Fluid Catalytic Crack Gasoline Reid Vapour Pressure Required ($\propto_{cr}$)

$$\propto_{cr} = \left(\frac{\alpha_v}{V_{TB}}\right)\alpha_{ch\alpha} \quad (5)$$

(b) Determination of Reformate for Reid Vapour Pressure Required (θ_{cr})

$$\theta_{cr} = \left(\frac{\theta_v}{V_{TB}}\right)\alpha\theta_{chr} \quad (6)$$

(c) Determination of Reformate for Light Naphtha (N_{cr})

$$N_{cr} = \left(\frac{N_v}{V_{TB}}\right)N_{chn} \quad (7)$$

$$RVP = \propto_{cr} + \theta_{cr} + N_{cr} \quad (8)$$

$Check: \Sigma(\alpha_{c\gamma};\ \theta_{c\gamma};\ N_{c\gamma}) \leq 9\ Psi$

Determination of Research Octane Numbers (RON)
Scenarios for RON Selection
Chosen RON for FCCG ($\psi_{ch\alpha}$) between 91 – 98
Chosen RON for REF ($\psi_{ch\theta}$) between 91 – 94
Chosen RON for Light Naphtha limited to 76

(a) Determination of Row for FCCG ($\psi_{C\alpha}$)

$$\psi_{c\alpha} = \left(\frac{\alpha_v}{V_{TB}}\right)\psi_{ch\alpha} \quad (9)$$

(b) Determination of Reformate for Reid Vapour Pressure Required (θ_{cr})

$$\psi_{c\theta} = \left(\frac{\theta_v}{V_{TB}}\right)\psi_{ch\theta} \quad (10)$$

(c) Determination of Reformate for Light Naphtha (N_{cr})

$$\psi_{cN} = \left(\frac{N_v}{V_{TB}}\right)\psi_{chN} \quad (11)$$

$RON = \psi_{c\alpha} + \psi_{c\theta} + \psi_{cn}$
$Check: \Sigma(\psi_{c\alpha;}\psi_{c\theta};\ \psi_{cn}) \geq 90$
The computation is left to computer software to carry out the final result obtained from the blending of FCCG; the Reformate and Light Naphtha were used to determine its density, DPMS, RON and RVP and confirm its acceptability.

Flow Chart for Software Development
The flow chart for the software is presented in Fig. 1.

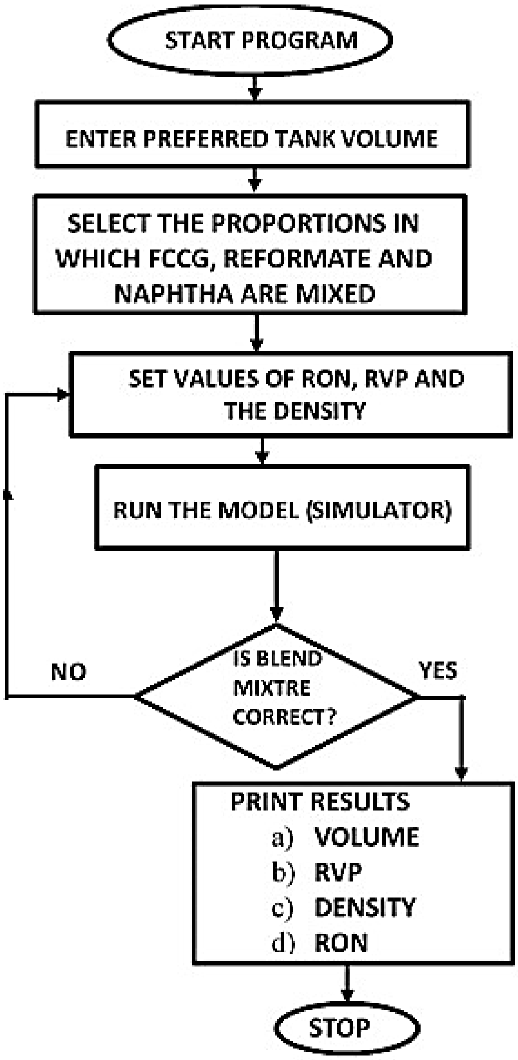

Fig. 1: Flow Chart for Software Development

Hardware requirement: the hardware required for proper and smooth running of the software developed are Pentium IV or above with RAM of 256 MB or above; and a hard disk of 20 GB or above.
Software requirement: DOTNET FRAME WORK, C SHARP programming language.
Operating system: Windows XP and above.

The proportions in which components of PMS are blended are as shown in Table 1.

Table 1. Proportions in which components of PMS are blended

	RVP	RON	DENSITY
FCCG	6.8-7.5	91-98	0.72-0.78
REFORMATE	6.2-7.0	91-94	0.72-0.77
LIGHT NAPHTHA	6.8-7.5	76	0.69-0.71

Source: [17]

The different ratios in which individual components are blended are as shown in Table 2.

Table 2. Difference Ratios in which individual component are blended

FCCG	50%	70%
REFORMATE	30%	15%
LIGHT NAPHTHA	20%	15%

Source: [17]

The application software interface for the reference simulation is seen displayed in Figure 2.

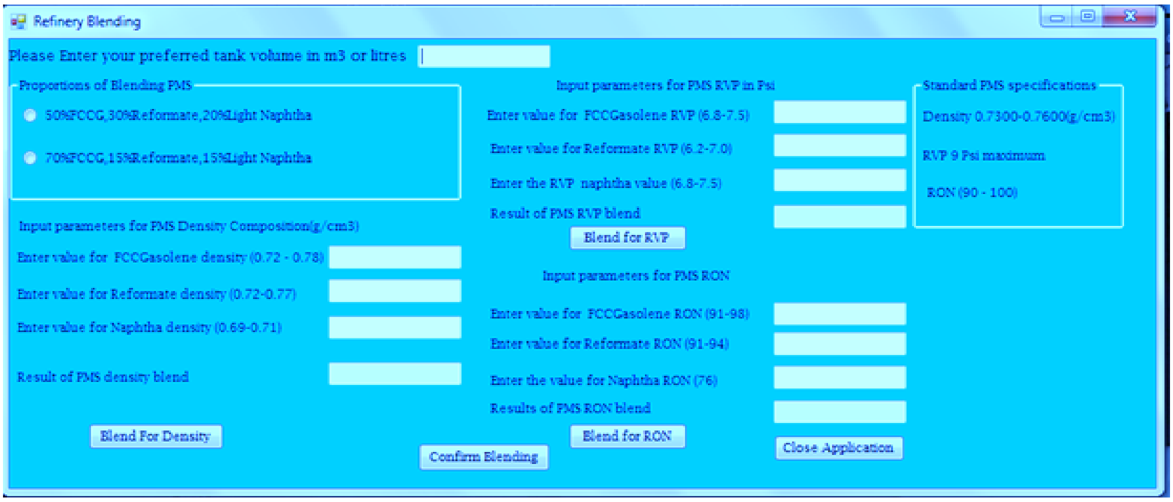

Fig. 2: Application Software Interface

Blending Criteria: The percentages by volume of the tank to be blended must be given. For example, it can be 5,000m^3, 10,000m^3, 8,000m^3 etc. The various compositions of the RVP, RON and the Density must be chosen within their limits. The result of PMS density blend is known when the PMS density button is clicked. Likewise the results of PMS and RVP blend are known when the blend for PMS or RVP button is clicked; also the results of PMS and RON blend are known when the blend for PMS or RON button is clicked.

III. SOFTWARE APPLICATION AND RESULTS

Case Study

Warri Refining and Petrochemical Company Limited is one of the subsidiary companies of the Nigerian National Petroleum Corporation (NNPC) incorporated in November 1988 as a result of the merger of the Warri Refinery and Ekpan Petrochemical Plants in the wake of NNPC's commercialization exercise. The refinery was commissioned in 1978 with an initial nameplate capacity of 100,000 BPSD, and the petrochemical plants, commissioned in March, 1988 are made up of a 35,000 MT/year of polypropylene and 18,000 MT/year of carbon production facilities [18]. Four blending Scenarios were considered in this study which are: density blending, RVP blending, RON blending, and combination of the three scenarios.

Scenario I: Blending for Density

(i) Firstly, 50,000 by volume of the tank to be blended was chosen.
(ii) The proportion of blending PMS was selected.
(iii) The input parameters for PMS density composition was selected.
(iv) The value for FCC Gasoline was chosen to be 0.73, Reformate was chosen to be 0.74, and Naphtha was chosen to be 0.69.
(v) The result of PMS density blend, after the blend for Density button was clicked, is 0.725 and this value does not fall between (0.73 and 0.76) gram per centimetre cube.
(vi) The software inferred that the PMS density blend is incorrect and does not meet density standard; try again.
(vii) The result of this blend simulation infers that the values of the FCC gasoline, Reformate and Light Naphtha that were chosen are incorrect even though they are within the range. Hence, new values or correct values have to be selected within the specified range.

The Software blending result is as shown in Fig. 3.

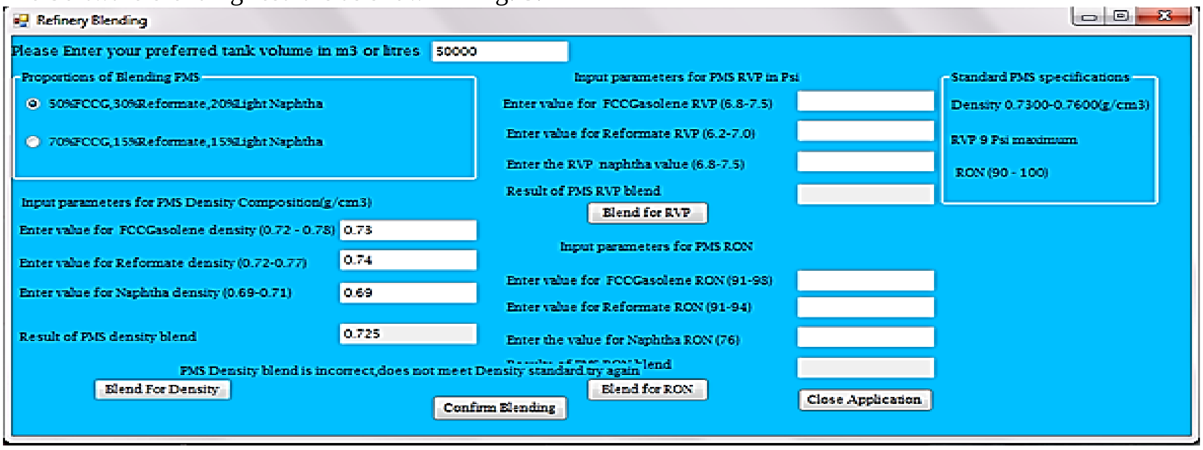

Fig. 3: The Software Blending Result

Correct values for Density Blending

(i) The value for FCC Gasoline was chosen to be 0.76, Reformate was chosen as 0.74, and Naphtha was chosen to be 0.71.
(ii) The result of PMS density blend after the Density button was clicked is 0.744 and this value falls between (0.73 and 0.76) gram per centimetre cube.
(iii) The software inferred that the PMS density blend is correct because it meets density standard.

The correct simulated results are shown in Fig. 4.

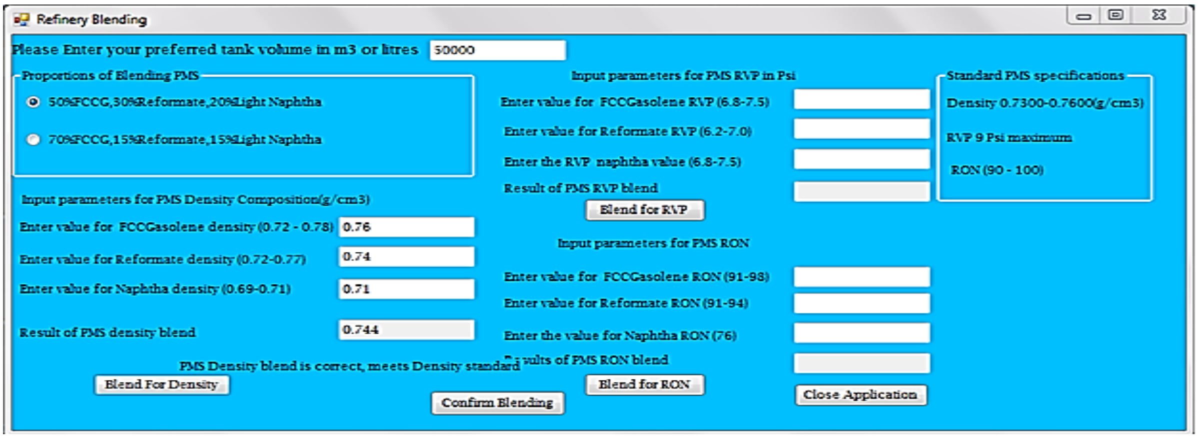

Fig. 4: Software Displaying the Correct Density Blending.

Scenario II: Blending for RVP

(i) Firstly, 50,000 by volume of the tank to be blended was chosen.
(ii) The proportion of blending PMS was selected.
(iii) The input parameters for PMS RVP composition was selected.

(iv) The value for FCC Gasoline was chosen to be 6.9, Reformate was chosen as 6.4, and Naphtha was chosen to be 7.2.
(v) The result of PMS RVP blend after the blend for RVP button was clicked is 6.81 and this value does not correspond to standard RVP range, which must not exceed 9 psi.
(vi) The software inferred that the PMS RVP blend is correct and meets RVP standard.

The Software Simulation results for blending for RVP is seen in Fig. 5.

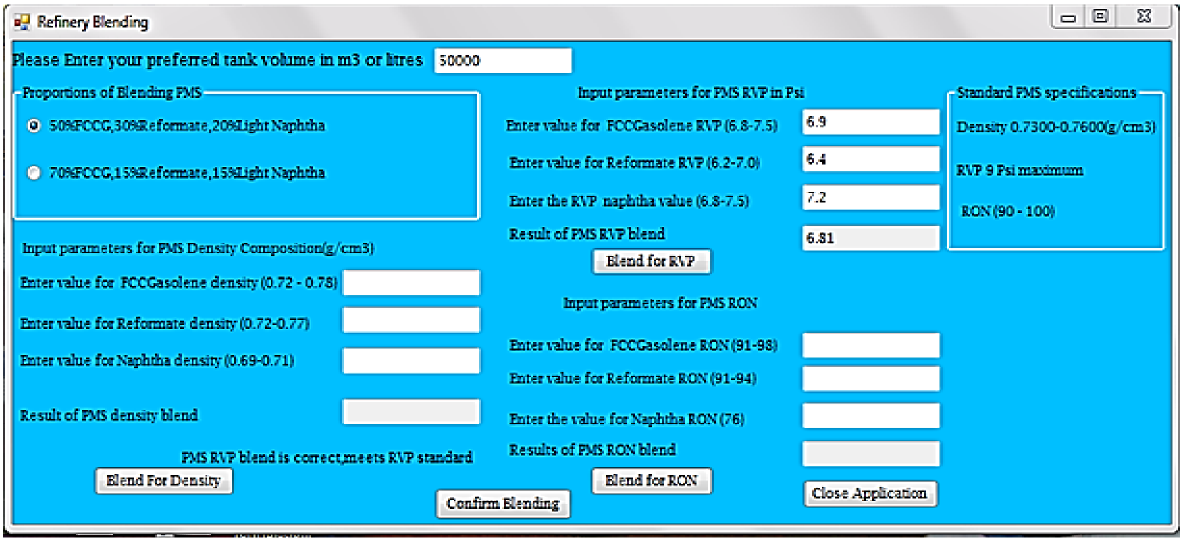

Fig. 5: Software Blending for RVP

Scenarios III: Blending for RON
Blending for RON Case Study

(i) Firstly, 50,000 by volume of the tank to be blended was chosen.
(ii) The proportion of blending PMS was selected.
(iii) The input parameters for PMS RON composition was selected.
(iv) The value for FCC Gasoline was chosen to be 92, Reformate was chosen as 93, and Naphtha was chosen to be 76.
(v) The result of PMS RVP blend, after the blend for RON button was clicked, is 89.1 and this value corresponds to standard RON range, which is between 90 and 100.
(vi) The software inferred that the PMS RON blend is incorrect and does not meet RON standard. Hence, we tried again with new values.
(vii) The result of this blend simulation infers that the values of the FCC Gasoline, Reformate and Light Naphtha that were chosen were incorrect. Hence, new values or correct values have to be selected within the specified range.

The software interface for the incorrect RON blending is shown in Fig. 6

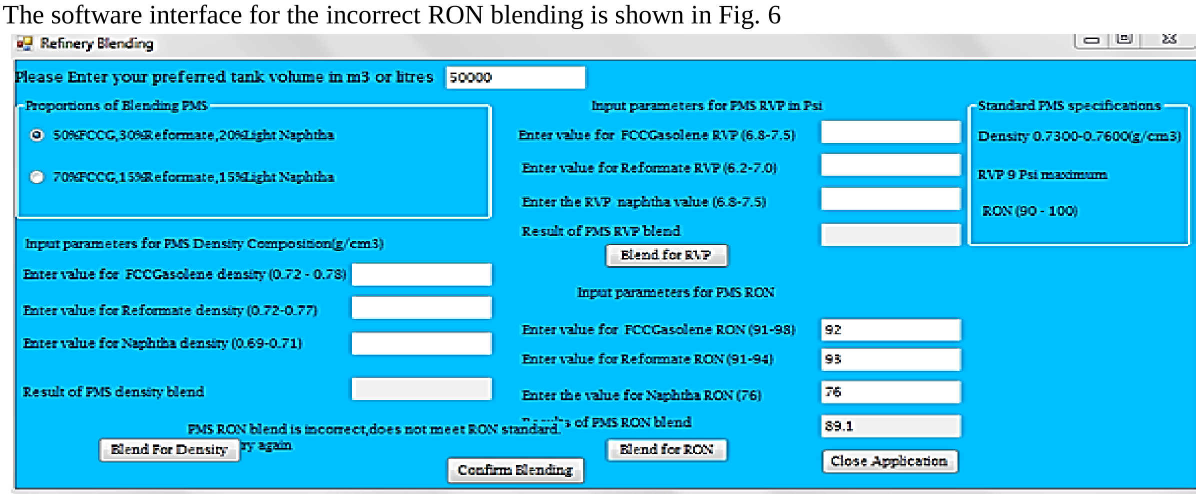

Fig. 6: Incorrect RON Blending Interface

The new values for RON blending computation were reselected and correct result was obtained.

Values for Correct RON Blending

(i) The value for FCC Gasoline was chosen to be 95, Reformate was chosen as 93, and Naphtha was chosen to be 76.

(ii) The result of PMS RON blend, after the blend for RON button was clicked, is 90.6 and this value does fall between 90 and 100.

(iii) The software inferred that the PMS RON blend is correct and meets RON standard.

The correct blending result is also shown in Fig. 7.

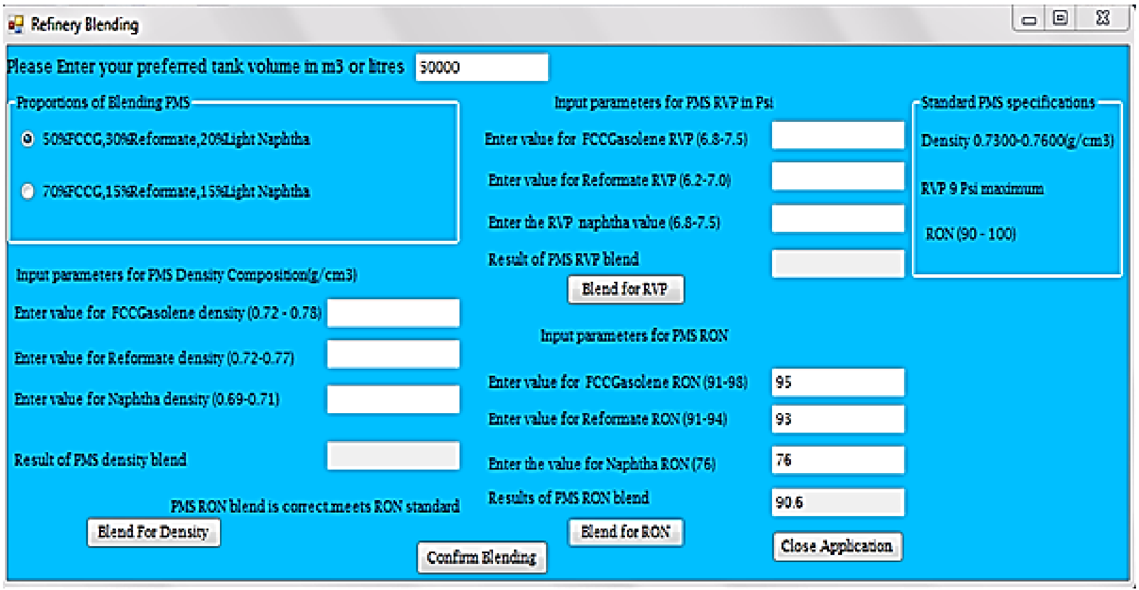

Fig. 7: The Correct Blending Result

Scenario IV: Blending for Density, RVP and RON with correct values

In this scenario, scenarios I to III were simulated together and the result to this simulation is as shown in Fig. 8.

(i) The Density value for FCC Gasoline was chosen to be 0.76, Density value for Reformate was chosen as 0.74, and Density value for Naphtha was chosen to be 0.71. Also, the blend for density button was clicked and the result of PMS Density blend gave 0.744, which is a correct blend.

(ii) The RVP value for FCC Gasoline was chosen to be 6.9, RVP value for Reformate was chosen as 6.4, and RVP value for Naphtha was chosen to be 7.2. The blend for RVP button was then clicked and the result of PMS RVP blend gave 6.81, which is a correct blend.

(iii) The RON value for FCC Gasoline was chosen to be 95, RON value for Reformate was chosen as 93, and RON value for Naphtha was set at 76. Also, the blend for RON button was clicked and the result of PMS RON blend gave 90.6, which is a correct blend.

(iv) The “confirm blending” button was clicked and the software inferred that the PMS blending are in the correct proportion.

The Software interface for Scenario IV is as shown in Fig. 8.

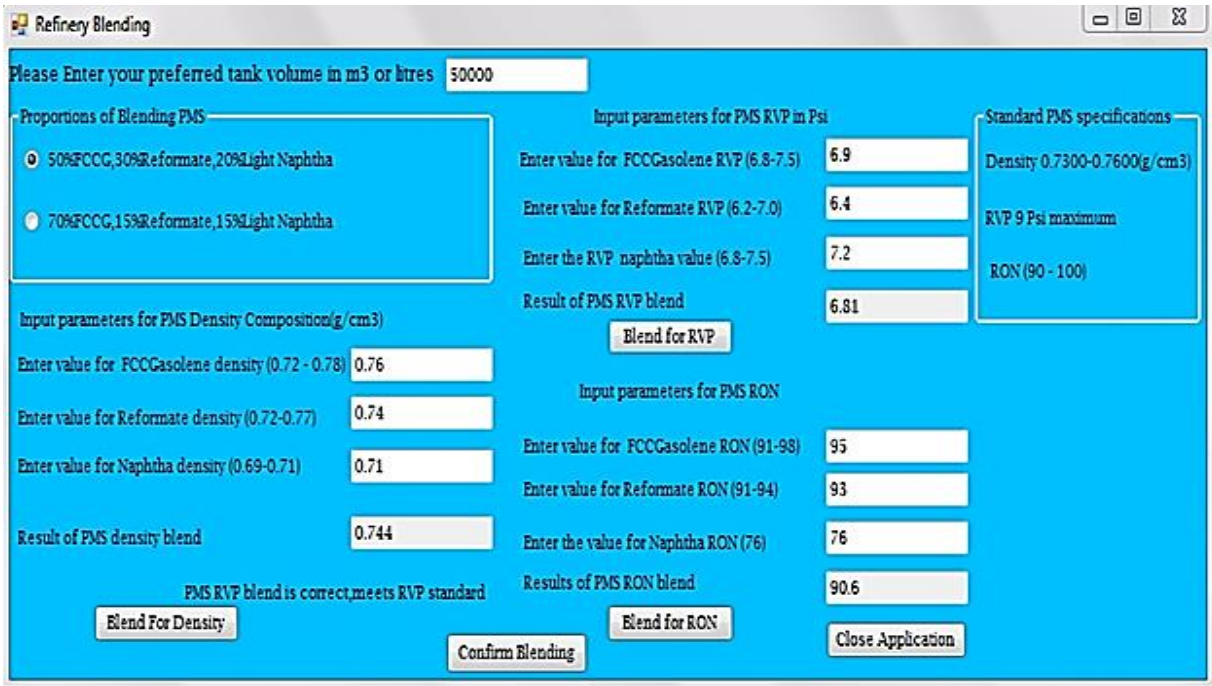

Fig. 8: Software Interface for Scenario IV

IV. CONCLUSION

The developed software model was tested for simulating the PMS blending process in WRPC in Nigeria. The software, whenever the components of RVP, RON and Density were varied, the corresponding mixture of Light Naphtha, FCC Gasoline and Reformate, which gives PMS or Gasoline, varied as well. The software is able to infer if blend is correct or incorrect. Therefore, the optimum blending ratio of the gasoline components at any given volume to achieve a high quality gasoline product is made possible by the aid of the developed simulation software model.

Reid vapour pressure (RVP) is the common measure of the volatility of gasoline. It tells how volatile a gasoline is. It can be referred to as the absolute vapour pressure exerted by a liquid at 100^0F (37.8^0C). Seasonally, oil refineries manipulate the RVP specifically to maintain gasoline engine reliability. The RVP of PMS referred to as gasoline in Nigeria should not exceed 9 psi. It is paramount that the RVP of Nigeria PMS should be within specified range. In hot weather, petrol components of higher molecular weight and lower volatility are used. In cold weather, too little volatility results in “Vapour Lock”. In addition to this, the density range of 0.75-0.76 gram per centimetre cube is accepted in Nigeria petroleum industry due to the tropical nature of Nigeria’s climate.

The Octane rating of the gasoline is the standard measure of the performance of a motor or aviation fuel. The higher the Octane number, the more compression the fuel can withstand before derogating. In broad terms, fuels with a higher Octane rating are used in high compression engines that generally have higher performance. In contract, fuels with low Octane numbers are used for diesel engines. The use of gasoline with low Octane numbers may lead to the problem of engine knocking [18]. Hence, the RON of PMS referred to as gasoline in Nigeria should be within the range of 90 – 100.

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