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# Optimization of Blends of Selected Foreign and Nigerian Crudes for Lubricant Production

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***Abstract*-** A model for prediction of crude oil blend property was chosen for development of a linear programming problem, which was solved to obtain optimum composition of three crude blends (Shell's UQCC, Chevron's ESCRAVOS and Arab light crude) that minimizes cost and meets quality standards required for lubricant production.

Results show that the optimum blend for the two Nigerian crude oils (UQCC & ESCRAVOS) and the foreign crude (Arab light crude) is that with 36.36% by weight of UQCC and 63.64% by weight of Arab light crude, with an API gravity of 31.4091 $^{o}$API.

Although the pure Nigerian crudes are not suitable for lube base oil production, it was found that 36wt% UQCC blended with 64wt% Arab light is suitable for lube base oil manufacture, meeting all the accepted quality standards at minimum cost.

This blend can be used in Nigerian refineries to minimize importation of foreign crudes, with a reduction in the associated economic and technical problems.

***Keywords*-** *crude oil, modeling, blend, property, optimum, linear programming*

## I. Introduction

Crude oil consists of complex and differing hydrocarbon groups. This group includes aromatic, naphthenic and paraffinic groups each with individual sub groupings. Configuration and length of the carbon-carbon structure of crude oils vary from country to country and even within the same country, from field to field. It is a complex mixture of different components consisting of mainly hydrocarbons and some sulfur, nitrogen, oxygen and metals. Crude oils vary widely in their physical and chemical properties. They may be straw coloured, green, brown or black, the last three being the most common colours.

Crude oils are classified based on their individual API's gravities (light, medium and heavy) as well as their hydrocarbon groups.

Nigerian crude oils (Chevron Escravos and Shell's Ughelli Quality Control Crude (UQCC)), which are of major interest to this study, fall mostly under light and medium group while the foreign Arabian Light falls under the heavy group with reference to their API's (Gibson, 1982; Mba, 2005)

The distillate products of crude oil vary. A major point of concern is the base stock (lubrication stock) product generally used for the production of various lubricants.

Base stock (cylinder stock) of petroleum origin is a complex mixture of various hydrocarbon groupings derived from vacuum distillation and the residual of selected crude oils with lubrication potentials.

Base stock is usually made up of two parts; the resin portion and the oily portion of which the oily portion is a major constituent used in manufacturing of a wide variety of finished lubricants of different classes (automobile lubricants, industrial lubricants and many others) which can be used as motor oils, instrument oils, metal working and cutting oils etc.

Nigeria imports crude from Venezuela and Saudi Arabia by swapping Nigerian crude – which fetches higher premium – for heavy crude, which costs less. This is because Nigeria crude, being mixed base crude, yields a base stock that is universally accepted to fall short of the performance parameters of base stock suitable for lube oil production (Adegoke and Ibe, 1982; John, 1982; Coker, 1989). The acceptable range of parameters for base stock suitable for lube oil production (paraffinic base stock) to meet product specifications is a K-factor that lies between 12 and 13, a pour point of less than -6 and a viscosity index that lies between 40 and 85, beside minor factors (NNPC 1988, Ezeaniekwe et al 1992).

The purpose of this work is to determine a blend of local and foreign crude that will meet the above specification at minimum cost, thus minimizing importation of foreign crude to Nigeria.

## II. BLEND PROPERTY MODEL DEVELOPMENT

The properties of crude oil blends may be predicted based on the method of mixtures which may be represented as shown below.

Property of blend = $\sum_{i=1}^{n}$ property of crude * fraction of crude i in blend

Two simple choices for the fraction part are weight fraction and volume fraction (Jose and Wen, 2004; Wen and America, 2005; Esparragoza et al, 2006; Enweremadu et al,2011)

If PB is property of Blend, PCi is property of crude i, Xi is weight fraction and yi is volume fraction, we have:

For weight fraction

$$PB = \sum_{i=1}^{n} PCi * Xi$$ and

For volume fraction

$$PB = \sum_{i=1}^{n} PCi * yi$$

The above equations were used to compute the properties of a blend of 50:50 wt% of UQCC: ESCRAVOS crude and the chi-square technique used to test the validity of the models and a choice eventually made of the better model for crude blend property prediction. The predicted values for weight fraction model, volume fraction model and actual experimental values (NNPC Kaduna) are tabulated in Table 1 below.

For our two component crude oil blend, we have, for each case:

a. Weight fraction model

$$PB = PC_1^* X_1 + PC_2^* X_2$$

b. Volume fraction model

$$PB = PC_1^* y_1 + PC_2^* y_2$$

The relationship between Xi and yi is given below as:

$$y_n = \frac{Xn}{Xn + \sum_{\substack{l=1 \\ l \neq n}}^{N} \frac{\rho n}{\rho i} Xi}$$ for N-component crude blend

N is the total number of components in the blend

n is the component under study

í is every other component in the Crude Blend

ρn is the density or specific gravity of Crude under investigation

ρí is the density of all other crude components in the blend

yn is the volume fraction of the crude under investigation

Xn is the weight fraction of the crude under investigation

Xí is the weight fraction of all other crude in the blend.

For our two component crude blend

$$Y_2 = \frac{X_1}{X_1 + \left(\frac{\rho_2}{\rho_1}\right) X_1}$$

The above equations were used to convert the 50:50 weight fraction (percentage) blends to volume fraction

$X_1 = 0.5$, $X_2 = 0.5$

$y_1 = 0.4911$, $y_2 = 0.5089$

Subscript 1 is for UQCC and subscript 2 for ESCRAVOS.

Table 1: Properties for two Nigerian Crudes and their Blend (50:50wt%)

| | UQCC | ESCRAVOS | 50/50blend |
|---|---|---|---|
| API Gravity, $^{o}$API | 30.3 | 36.3 | 33.3 |
| Specific gravity 15/15$^{o}$C | 0.874 | 0.8433 | 0.8587 |
| Total sulphur, wt% | 0.24 | 0.16 | 0.20 |
| Nickel /PPM | 3.0 | 5.3 | 4.1 |
| Vandium, PPM | 0.7 | 0.9 | 0.8 |
| Pour point, $^{o}$C | -27 | 2 | - |
| Viscosity @ 37.8$^{o}$C | 6.18 | 3.85 | 4.8 |
| Reid vapour pressure @ 37.8$^{o}$C, kg/cm$^2$ | 0.245 | 0.288 | - |

SOURCE: NNPC Kaduna

Table.2: Experimental and Model property prediction for Crude Blend UQCC: ESCRAVOS, 50:50 wt%

| Crude Blend property | Weight fraction model prediction | Volume fraction model prediction | Actual experimental values |
|---|---|---|---|
| API Gravity, $^{o}$API | 33.3 | 33.3534 | 33.3 |
| Specific gravity 15/15$^{o}$C | 0.8587 | 0.8584 | 0.8587 |
| Total sulphur, wt% | 0.20 | 0.1993 | 0.2 |
| Nickel, PPM | 4.15 | 4.1795 | 4.1 |
| Vanadium, PPM | 0.8 | 0.8018 | 0.8 |
| Viscosity @ 37.8$^{o}$C | 5.015 | 4.9943 | 4.8 |

Table 2 above shows property predictions of the two models, based on weight fraction and volume fraction respectively in comparison with the actual experimental property obtained from the blend.

The chi-square technique was used for model validation.

The null Hypothesis Ho is “There is No significant difference between the observed and predicted results”.

***Weight fraction model***

$$X^2 calc = \sum (0 - e)^2 / e$$

$$= \frac{(33.3-33.3)^2}{33.3} + \frac{(0.8587-0.8587)^2}{0.8587} + \frac{(0.2-0.2)^2}{0.2} + \frac{(4.1-4.15)^2}{4.15} + \frac{(0.8-0.8)^2}{0.8} + \frac{(4.8-5.015)^2}{5.015}$$

$$= 0 + 0 + 0 + 0.0006 + 0 + 0.0092 = \underline{0.0098}$$

***Volume Fraction Model***

$X^2calc = \sum (0 - e)^2/e=$

$$\frac{(33.3-33.3534)^2}{33.3534} + \frac{(0.8587-0.8584)^2}{0.8584} + \frac{(0.2-0.1993)^2}{0.1993} + \frac{(4.1-4.1705)^2}{4.1705} + \frac{(0.8-0.8018)^2}{0.8018} + \frac{(4.8-4.9943)^2}{4.9943}$$

$= 0.000085 + 0.000002 + 0.00119 + 0.000004 + 0.007559$

$= \underline{0.0088}$

df = 5 $X^2$tabulated = 1.145 (95% confidence interval)

Based on the above, the difference observed for both methods is not significant, therefore, either of the methods is acceptable because

$X^2calc < X^2$ tabulated for each case.

Based on the values of the chi-square calculated, the volume fraction model looks better because its value for calculated chi-square is less than that of weight fraction model.

On close observation though, it will be seen that the weight fraction model was exact in its prediction for four out of six of the crude blend properties studied, with the volume fraction being better in only one.

The observation of lower calculated chi-square value for volume fraction model is due to one limitation of the chi-square technique, in that, a single value can have much impact and give misleading values for the calculated chi-square.

In view of the above, the weight fraction model was selected as the appropriate model for this study.

## III. FORMULATION OF OPTIMIZATION PROBLEM

The objective at this point is to produce a crude oil blend, that will yield a base stock suitable for lubricants production at the minimum possible cost, using two Nigerian crude (UQCC and ESCRAVOS) and one foreign crude (Arab crude) as case study (Debora et al, 2005).

The cost of crude varies, but is known to be a function of the oAPI of such crude, we will therefore develop an objective function for the cost index of the crude blend as a function of the oAPI of each crude, and its weight fraction in the blend.

Let aí represent the oAPI of crude í and Xí represent the weight fraction of crude í in crude blend, we have:

$$\text{Cost index (CI)} = \sum_{i=1}^{n} a_i X_i \qquad (1)$$

For our three component crude blend

$$CI = a_1X_1 + a_2X_2 + a_3X_3 \qquad (2)$$

is the objective function to be minimized.

### A. K- factor Constraint

Crude that will yield a base stock suitable for lubricants production falls into the parafinic class, with a K – factor between 12 and 13.

If Kf represent the K-factor of crude í and Xí represents the weight fraction of crude í in the crude blend, we have

$$\sum_{i=1}^{n} Kf_i X_i \geq 12 \qquad (3)$$

$$\sum_{i=1}^{n} Kf_i X_i \leq 13 \qquad (4)$$

For blend of n crudes.

For our three component crude blend, we have:

$$Kf_1X_1 + Kf_2 X_2 + Kf_3X_3 \geq 12 \qquad (5)$$

and

$$Kf_1X_1 + Kf_2 X_2 + Kf_3X_3 \leq 13 \qquad (6)$$

### B. Pour-point Constraint

The pour point of a crude that will yield a base stock suitable for lubricants production must be less than or equal to -6. If Pi represents pour points of crude í and Xí represents the weight fraction of crude í in the blend, we have:

$$\sum_{i=1}^{n} P_i X_i \leq -6 \qquad (7)$$

For blend of n crudes.

For our three component crude blend, we have:

$$P_1 X_1 + P_2X_2 + P_3X_3 \leq -6 \qquad (8)$$

### C. Viscosity index Constraint

The viscosity of crude that will yield a base stock suitable for lubricants production must lie between 40 and 85, which is the range required to be classified as paraffinic.

If VIí represents Viscosity index of crude í and Xí represents the weight fraction of crude í in the blend, we have:

$$\sum_{i=1}^{n} VI_i X_i \geq 40 \qquad (9)$$

and

$$\sum_{i=1}^{n} VI_i X_i \leq 85 \qquad (10)$$

For blend of n crudes

For our three components crude blend, we have:

$VI_1 X_1 + VI_2X_2 + VI_3X_3 \geq 40$ (11)

and

$VI_1 X_1 + VI_2X_2 + VI_3X_3 \leq 85$ (12)

Based on the above, we have the following objective function and constraint problem to solve:

Minimize

$$CI = \sum_{i=1}^{n} a_i X_i \quad (13)$$

Subject to

$$\sum_{i=1}^{n} Kf_i X_i \geq 12 \quad (14)$$

$$\sum_{i=1}^{n} Kf_i X_i \leq 13 \quad (15)$$

$$\sum_{i=1}^{n} P_i X_i \leq -6 \quad (16)$$

$$\sum_{i=1}^{n} VI_i X_i \geq 40 \quad (17)$$

$$\sum_{i=1}^{n} VI_i X_i \leq 85 \quad (18)$$

For n – component crude oil blend

For our three component crude oil blend, we have:

Minimize

$CI = a_1X_1 + a_2X_2 + a_3X_3$ (19)

Subject to

$Kf_1X_1 + Kf_2X_2 + Kf_3X_3 \geq 12$ (20)

$Kf_1X_1 + Kf_2X_2 + Kf_3X_3 \leq 13$ (21)

$P_1X_1 + P_2X_2 + P_3X_3 \leq -6$ (22)

$VI_1X_1 + VI_2X_2 + VI_3X_3 \geq 40$ (23)

$VI_1X_1 + VI_2X_2 + VI_3X_3 \leq 85$ (24)

Inserting Numerical values of our constant from Table 3 below, we have;

Table 3: Crude Properties for Optimization Problem (Enekwe, 2011)

| Property/ Name of Crude | UQCC | ESCRAVOS | ARAB LIGHT |
|---|---|---|---|
| K-factor | 11.65 | 11.8 | 12.2 |
| Pour Point $^{O}C$ | 2 | 5 | -28 |
| Viscosity Index | 38 | 42.6 | 76.4 |
| API Gravity $^{O}API$ | 30.9 | 35.1 | 31.7 |

Minimize:

$CI = 30.9X_1 + 35.1X_2 + 31.7X_3$ (25)

Subject to:

$11.65X_1 + 11.8X_2 + 12.20X_3 \geq 12$ (26)

$11.65X_1 + 11.8X_2 + 12.20X_3 \leq 13$ (27)

$2X_1 + 5X_2 – 28X_3 \leq - 6$ (28)

$38X_1 + 42.6X_2 + 76.4X_3 \geq 40$ (29)

$38X_1 + 42.6X_2 + 76.4 X_3 \leq 85$ (30)

Rearranging Equation (25) to (30), we have

Minimize

$CI = 30.9X_1 + 35.1X_2 + 31.7X_3$ (31)

Subject to

$-11.65X_1 – 11.8X_2 – 12.20X_3 \leq - 12$ (32)

$11.65X_1 – 11.8X_2 – 12.20X_3 \leq 13$ (33)

$2X_1 + 5X_2 + - 28X_3 \leq - 6$ (34)

$-38X_1 – 42.6X_2 – 76.4X_3 \leq - 40$ (35)

$38X_1 – 42.6X_2 – 76.4X_3 \leq 85$ (36)

There are two “silent” constraints that must be added to find a conclusive solution to the above optimization problem.

1. The minimum value of the weight fraction for each crude sample is zero. Thus we have,

$X_1 \geq 0, X_2 \geq 0$ and $X_3 \geq 0$ (37)

2. Since weight fraction was used, the sum of the three weight fractions must equal unity, thus;

$X_1 + X_2 + X_3 = 1$ (38)

The earlier will be represented as a lower bound (Lb) and the later as an equality constraint.

The optimization tool box of MATLAB 7.5 was used to solve the linear programming problem, the codes and solution are given below;

*D. Code Assembling*

F = [30.9; 35.1; 31.7];

represents the coefficients of the objective function (cost Index based on crude sample oAPI gravity) from equation 31.

A = [-11.65 –11.8 -12.2; 11.65 11.8 12.2; 2 5 -28; 138 142.6 -76.4; 38 42.6 76.4];

represents coefficients of Xi in inequality constrain (equations 32 to 36)

b = [-12; 13; -6; -40; 85];

represents the right hand side of the inequality constraints relations

Aeq = [1 1 1];

beq = [1]

represent the equality constraint: X1 + X2 + X3 = 1

Lb = zeros (3, 1)

Creates a matrix of three rows and one column with all entries equal to zero, for the lower bound X1 $\geqslant$ 0, X2 $\geqslant$ 0 and X3 $\geqslant$ 0

The command;

[X, fval, exitflag] = linprog (f, A, b, Aeq, beq, Lb)

Solves the linear programming problem with f, A, b, Aeq and beq as inputs and the minimum value for X (that is X1, X2 and X3) and functional evaluation of the cost index at the minimum as output values, with the basis for convergence indicated.

Combining the codes we have;

```
F = [30.9; 35.1, 31.7],
A = [-11.65  -11.8  -12.2; 11.65  11.8  12.2; 2   5   -28;   -38 -42.6 -76.4;  38    42.6   76.4];
b = [-12; 13; -6;  - 40; 85;];
Aeq = [1    1    1];
beq = [1]
Lb = zeros (3, 1)
[X, fral, exitflag] = linprog (f, A, b, Aeq, beq, Lb)
```

## IV. RESULTS AND DISCUSSION

The solution of the optimization problem was:

X =

0.36363636359797
0.000000000033460
0.636363636396747

fval =

31.409090909258023

exitflag =

1.

Thus the solution to four decimal places is

| | | |
|---|---|---|
| X1 (UQCC crude) | = | 0.3636 |
| X2 (Escravos crude) | = | 0.0000 |
| X3 (Arab light crude) | = | 0.6364. |

CI (minimum)= 31.4091

exitflag = 1 (function converged to a solution X)

## V. QUALITY OF OPTIMUM CRUDE BLEND

### *A. K – Factor*

11.65 (0.3636) + 12.20 (0.6364) = 12.0000.

### *B. Pour point*

2(0.3636) + (-28)(0.6364) = -17.0920

### *C. Viscosity – Index*

38 (0.3636) + 76.4 (0.6364) = 62.4378

The K-actor lies between 12 and 13, the pour point is less than -6 and the viscosity Index lies between 40 and 85. The cost equivalent is that for crude with oAPI gravity 31.4091, which is the minimum possible cost Index under the stipulated conditions.

## VI. CONCLUSION

The weight fraction model for prediction of crude oil blend property was found suitable for this study, with a linear programming problem, to obtain optimum composition of the three-crude blend that minimizes cost and meets quality required for lubricant production.

The optimum blend is that with 0.3636 weight fraction UQCC and 0.6364 Arab light crude with a cost index of 31.4091 oAPI. In conclusion, though the Nigerian crude is not suitable for lube base oil production 36wt% UQCC blended with 64wt% Arab light was found suitable for lube base oil manufacture because it is paraffin base with viscosity index of 62.4378, low pour point (-170C) and K-factor of 12.

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