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Mathematical Modelling of Oil Products Blending Process*

The problem of oil products blending arises alongside with other problems that must be solved in a refinery. It is associated to the optimization of all the plant production processes and, at the same time, is part of the refinery model.

In previous papers [3], [8] we have dealt with the drawing up of the physical model of gasoline blends, that is the ascertainment of functional relationships between the characteristics of one blend and the characteristics of the constituents using statistical-mathematical methods. The functional relationships thus obtained will make up the quality relationships of the general model of the blends. This model, beside quality relationships, also contains quantity relationships as well as the function(s) to be optimized.

The restraints appearing in blends modelling problems may vary in number and structure and include indicators such as:

— qualitative characteristics of oil products indicated by the standards (octane number, distillation, density, etc.);

— production costs, qualitative technical conditions concerning the products;

— pumping and storage capacities for oil products;

— availabilities of constituents which may enter the blends;

— quantities of products obtainable through blending;

— a strict necessity for using a constituent in a set quantity, etc.

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A function objective reflecting the purpose intended through the solving of the problem is attached to the system of restraints. This purpose is mathematically expressed through a linear or non-linear function and may represent the cost price to be minimized, the profit to be maximized or any other target. In this paper we describe three models as applied in the refinery of the Borzeşti Oil Industrial Group for the following three circumstances:

1. When one gasoline is prepared, disregarding the existence of a buffer stock;

2. When a few gasolines are prepared, disregarding the existence of a buffer stock;

3. When one gasoline is prepared, taking into account the buffer stock.

1. THE MATHEMATICAL MODEL OF THE BLENDS

We shall state the general model of the blends assuming to be concerned with the qualitative characteristics of the blends: the octane number and distillation for 10 cc, 50 cc, 90 cc and final. A generalization for other characteristics can easily be done.

We introduce the following notations:

1. $L_i^{(C0)}$ $(i = 1, ..., n)$ the octane number of constituent i;

2. $L_i^{(10)}$, $L_i^{(50)}$, $L_i^{(90)}$, $L_i^{(f)}(i = 1, ..., n)$ the distillation of constituent i, respectively for 10, 50, 90 and 100 cubic centimeters (the distillating temperature for 10 cc, 50 cc, 90 cc and 100 cc of constituent i).

3. $A_i^{(C0)}$, $B_i^{(C0)}$, $A_i^{(10)}$, $B_i^{(10)}$, $A_i^{(50)}$, $B_i^{(50)}$, $A_i^{(90)}$, $B_i^{(90)}$, $A_i^{(f)}$ $B_i^{(f)}$ $(i = 0 \ldots n)$ are regression coefficients achieved through REMUS program [9];

4. L^{C0}, $L^{(10)}$, $L^{(50)}$, $L^{(90)}$, $L^{(f)}$ the characteristics of the blend;

5. x_i is the quantity percentantage of constituent i participating in the blend;

6. x_i^M, x_i^m are the maximal quantities (percentage), respectively minimal, which may be taken in the blend as indicated by statistical processing;

7. D_i is the available quantity of each constituent;

8. Q_i is the minimal necessary quantity to be used;

9. Q is the quantity to be prepared;

ci is the cost price of constituent i;

p is the selling price of turned out gasoline;

c' are other expenses.

The extended linear model gasoline blends shall contain the following restraints.

I. Restraints concerning the quality.

— Condition referring to the octane number:

$$A_0^{(C0)} + \sum_{i=1}^{n} A_i^{(C0)} x_i + \sum_{i=1}^{n} B_i^{(C0)} L_i^{(C0)} \geqslant L^{(C0)} \qquad (1)$$

— Condition referring to distillation:

$$A_0^{(10)} + \sum_{i=1}^{n} A_i^{(10)} x_i + \sum_{i=1}^{n} B_i^{(10)} L_i^{(10)} \leqslant L^{(10)} \tag{2}$$

$$A_0^{(50)} + \sum_{i=1}^{n} A_i^{(50)} x_i + \sum_{i=1}^{n} B_i^{(50)} L_i^{(50)} \leqslant L^{(50)} \tag{3}$$

$$A_0^{(90)} + \sum_{i=1}^{n} A_i^{(90)} x_i + \sum_{i=1}^{n} B_i^{(90)} L_i^{(90)} \leqslant L^{(90)} \tag{4}$$

$$A_0^{(f)} + \sum_{i=1}^{n} A_i^{(f)} x_i + \sum_{i=1}^{n} B_i^{(f)} L_i^{(f)} \leqslant L^{(f)} \tag{5}$$

II. Restraints concerning the quantity.

$$\sum_{i=1}^{n} x_i = 100 \tag{6}$$

$$x_i \leqslant min\left(\frac{100\, D_i}{Q},\ x_i^M\right),\quad i = 1, 2, ..., n \tag{7}$$

$$x_i \geqslant max\left(\frac{100\, Q_i}{Q},\ x_i^M\right),\quad i = 1, 2, ..., n \tag{8}$$

III. The efficiency function

— Minimal cost price:

$$F_1(x_1, ..., x_n) = \sum_{i=1}^{n} c_i x_i \tag{9}$$

— Maximal profit:

$$F_2(x_1, ..., x_n) = p \sum_{i=1}^{n} x_i - \sum_{i=1}^{n} c_i x_i - c' \tag{10}$$

In the described mathematical model, out of the characteristics of the constituents participating in the gasoline blends, only the octane number and distillation have been considered because only these were involved in the concrete example of the refinery of the Borzeşti Oil Industrial Group.

Obviously, the model may be filled up with some other restraints concerning other characteristics of gasolines. It is necessary to find out statistically for the new characteristics the functional relationship between the characteristic of the blend and the respective characteristics of the constituents.

As far as the efficiency function is concerned, this may be assumed to be either the cost price, or the maximal profit. Depening on the purpose one has in view, some other functions may be chosen. For instance, one may ask for the obtainment of a maximal quantity of gasoline possessing specific qualities.

The model becomes very intricate if the problem is approached in a dynamic and stochastic way. In such case, the properties and characteristics of the products turned out in the refinery, the claims of payment, are not supposed to have one sole value but several values, each of which being assumed with a certain probability. Following this course we come nearer to the real situation existing in the refineries. The problem is so intricate that it cannot be approached at present, even with big computers.

For the described model we have assumed that we have to prepare one blend (for instance CO 75 gasoline) with the available constituents.

However, in practice refineries prepare several final products with the available constituents. In this case, after finding out statistically the functional relationships for each final product, the model (1) — (10) is altered as follows.

The notations corresponding to this situation are:

1. L_i^k is characteristic k of constituent i

$$k = CO,\ 10,\ 50,\ 90,\ f$$
$$i = 1, 2, ..., n$$

2. A_{ij}^k, B_{ij}^k are the coefficients of the functional characteristic k for blend j corresponding to constituent i

$$k = CO,\ 10,\ 50,\ 90, f$$
$$i = 0,\ 1,\ 2,\ ...,\ n$$
$$j = 1, 2, ..., n$$

3. $L^{k,j}$ is is characteristic k of blend j
   Q_j^* is the quantity to be prepared of blend j
4. x_{ij} is the quantity percentage of constituent i going in blend j.

$$(i = 1, 2, ..., n)\ (j = 1, 2, ..., m)$$

5. x_{ij}^m, x_{ij}^M — is the minimal quantity, respectively maximal, of constituent i going in blend j.

The mathematical model in this case will be:

$$A_{0j}^k + \sum_{i=1}^{n} A_{ij}^k\ x_{ij} + \sum_{i=1}^{n} B_{ij}^k\ L_i^k \begin{matrix} \leqslant \\ > \end{matrix} L^{k,j} \qquad (11-15)$$

($\geqslant$ is used for *C.O.* and $\leqslant$ for $k = 10, 50, 90, f$)

$$k = CO,\ 10,\ 50,\ 90,\ f$$
$$j = 1,\ 2,\ ...,\ m$$

$$\sum_{i=1}^{n} x_{ij} = 100,\ j = 1, 2, ..., m \qquad (16)$$

$$\sum_{j=1}^{m} x_{ij} \leqslant \sum_{j=1}^{m} \frac{100 \cdot D_i}{Q_j^*} \quad i = 1, ..., n \qquad (17)$$

$$\sum_{j=1}^{m} x_{ij} \geqslant \sum_{j=1}^{m} \frac{100\ c_i}{Q_j^*} \qquad (18)$$

$$x_{ij}^m \leqslant x_{ij} \leqslant x_{ij}^M \qquad (19)$$

with the efficiency function

$$min\, F_1 = \sum_{i=1}^{n} \sum_{j=1}^{m} c_i x_{ij} \tag{20}$$

or

$$max\, F_2 = \sum_{j=1}^{m} \sum_{i=1}^{n} p_j x_{ij} - \sum_{j=1}^{m} \sum_{i=1}^{n} c_i x_{ij} - c' \tag{21}$$

For industrial purposes,it is advisable not to use percentages but quantities (tons). To this end, model (1) — (10) is altered by replacing variables x_i by y_i defined like this:

$$x_i = \frac{100\, y_i}{Q} \quad \text{or} \quad y_i = \frac{x_i \cdot Q}{100} \tag{22}$$

where y_i stands for the quantity (tons) of constituent i participating in the blend.

The substitution for the generalized model is

$$x_{ij} = \frac{100\, y_{ij}}{Q_j^*} \quad \text{or} \quad y_{ij} = \frac{x_{ij} \cdot Q_j^*}{100} \tag{23}$$

where y_{ij} is the quantity (tons) of constituient i participating in blend j.

The general model of the blends in this form may be used under condition that the tanks where the respective blend is taking place shall not contain other blends, which is not always possible.

In case that in the respective tank there already is a blend, of a known quantity and quality, the blend problem is solved in two stages.

a). In a model with characteristics assumed to be additive (this hypothesis may be assumed because the quantity to be prepared and the quantity existing in the tank have very close values of characteristics), we ascertain what characteristics shall have the quantity to be added in order to obtain, together with the quantity existing in the tank, the required quality of the final blend.

1. An example. We assume that the tank contains 150 t with CO 88 and we wish to obtain 1,200 t with CO 90. Writing x for the octane number of the 1,200 t to be added to the existing 150 t, the subsequent relationship will follow:

$$\frac{150 \times 88 + 1{,}200 \times x}{150 + 1{,}200} = 90 \tag{24}$$

from where $x = 90.3$

(We shall add 1,200 t in order to maintain in the tank the stock of 150 t).

Similarly, we compute also the other characteristics of the 1,200 t.

b) In order to obtain the desired quantity having the characteristics achieved at point a), we ascertain in the general model the optimal blend recipe of the constituents.

Now we shall alter model (1) — (10) in order to include also this situation. To this end we shall write:

1. $L'^{(C0)}$, $L'^{(10)}$, $L'^{(50)}$, $L'^{(90)}$, $L'^{(f)}$ for the characteristics of the quantity in the tank;

2. Y for the quantity existing in the tank;

3. $L^{(C0)}$, $L^{(10)}$, $L^{(50)}$, $L^{(90)}$, $L^{(f)}$ for the characteristics of the blend to be prepared;

4. X for the quantity to be prepared;

5. T for the buffer stock in the tank;

6. A_i^*, D_i^* for the percentage limitations of constituent i (following from the statistical processing);

7. B_i for the quantitative limits of constituent i (available).

Taking into account that in the tank there is a quantity Y, in order to meet demand X securing at the same time a buffer stock T, it is necessary to prepare a quantity

$$X^* = X - Y + T.$$

Quantity X^* blended with quantity Y existing in the tank must secure the required quantities X and T, and also to meet the qualitative standard limitations.

Consider $L_*^{(C0)}$, $L_*^{(10)}$, $L_*^{(50)}$, $L_*^{(90)}$, $L_*^{(F)}$ to be the characteristics of quantity X^*. They must be obtained assuming that the additivity hypothesis is met. For instance, for the octane number we have.

$$L'^{(C0)} \cdot Y + X_* \cdot L_*^{(C0)} = L^{(C0)}(Y + X^*)$$

or, taking into account that $X^* = X - Y + T$, there follows

$$L_*^{(C0)} = \frac{L^{(C0)}(X + T) - L'^{(C0)} \cdot Y}{X + T - Y}$$

Relationship (1), altered for the variable representing quantities X_i expressed in tons, becomes

$$\left(A_0^{(C0)} + \sum_{i=1}^{n} A_i^{(C0)} x_i + \sum_{i=1}^{n} B_i^{(C0)} L_i^{(C0)}\right) \frac{X - Y + T}{100} \geqslant L_*^{(C0)} \frac{X - Y + T}{100}$$

or

$$\sum_{i=1}^{n} A_i^{(C0)} x_i \geqslant \left(\frac{L^{(C0)}(X + T) - L'^{(C0)} Y}{X - Y + T} - A_0^{(C0)} - \sum_{i=1}^{n} B_i^{(C0)} L_i^{(C0)}\right) \cdot \frac{X - Y + T}{100}$$

We alter similarly relationships (2—5).

The general model of the gasolines blend in presence of a buffer stock shall be:

$$\sum_{i=1}^{n} A_i^{(C0)} x_i \geqslant \left(\frac{L^{(C0)}(X+T) - L'^{(C0)} Y}{X-Y+T} - A_0^{(C0)} - \sum_{i=1}^{n} B_i^{(C0)} L_i^{(C0)} \right) \frac{X-Y+T}{100} \quad (1')$$

$$\sum_{i=n}^{n} A_i^{(10)} x_i \leqslant \left(\frac{L^{(10)}(X+T) - L'^{(10)} Y}{X-Y+T} - A_0^{(10)} - \sum_{i=1}^{n} B_i^{(10)} L_i^{(10)} \right) \frac{X-Y+T}{100} \quad (2')$$

$$\sum_{i=1}^{n} A_i^{(50)} x_i \leqslant \left(\frac{L^{(50)}(X+T) - L'^{(50)} Y}{X-Y+T} - A_0^{(50)} - \sum_{i=1}^{n} B_i^{(50)} L_i^{(50)} \right) \frac{X-Y+T}{100} \quad (3')$$

$$\sum_{i=1}^{n} A_i^{(90)} x_i \leqslant \left(\frac{L^{(90)}(X+T) - L'^{(90)} Y}{X-Y+T} - A_0^{(90)} - \sum_{i=1}^{n} B_i^{(50)} L_i^{(50)} \right) \frac{X-Y+T}{100} \quad (4')$$

$$\sum_{i=1}^{n} A_i^{(f)} x_i \leqslant \left(\frac{L^{(f)}(X+T) - L'^{(f)} Y}{X-Y+T} - A_0^{(f)} - \sum_{i=1}^{n} B_i^{f} L_i^{f} \right) \frac{X-Y+T}{100} \quad (5')$$

$$\sum_{i=1}^{n} x_i = X - Y + T \quad (6')$$

$$d_i \leqslant x_i \leqslant D_i \quad i = 1, \ldots, n \quad (7')$$

where

$$d_i = \frac{A_i^* \sum x_i}{100}$$

$$D_i = min\left(\frac{D_i^* \sum x_i}{100}, \; B_i \right)$$

One of the efficiency functions (9) or (10) is added to this system of restraints.

2. A numerical example.

For a concrete illustration of the described model we shall consider the following situation with the refinery of the Borzeşti Oil Industrial Group:

— Characteristics of the gasoline existing in the tank:

$$L'^{(C0)} = 78 \cdot 3, \; L'^{(10)} = 59, \; L'^{(50)} = 115, \; L'^{(90)} = 179, \; L'^{(f)} = 203;$$

— final characteristics of the blend:

$$L^{(C0)} = 75, \; L^{(10)} \leqslant 79, \; L^{(50)} \leqslant 145, \; L^{(90)} \leqslant 195, \; L^{(f)} \leqslant 205;$$

— Quantity existing in the tank:
$Y = 150$ tons;

— Buffer stock in the tank
$T = 150$ tons;
— Quantity to be prepared
$X = 600$ tons;
Quantitative limitations (expressed in tons) of the constituents, ascertained by the availabilities:

$$x_1 \leqslant 350$$
$$x_2 \leqslant 70$$
$$x_3 \leqslant 200$$
$$x_4 \leqslant 128;$$

— Characteristics of the constituents:

$$L_1^{(C0)} = 77.5,\ L_2^{(C0)} = 107,\ L_3^{(C0)} = 68,\ L_4^{(C0)} = 77.8,$$
$$L_1^{(10)} = 79.5,\ L_2^{(10)} = 151,\ L_3^{(10)} = 87.6,\ L_4^{(10)} = 64{,}0,$$
$$L_1^{(50)} = 118.0,\ L_2^{(50)} = 162,\ L_3^{(50)} = 90.0,\ L_4^{(50)} = 78.0,$$
$$L_1^{(90)} = 160.0,\ L_2^{(90)} = 174,\ L_3^{(90)} = 132.0,\ L_4^{(90)} = 95.0,$$
$$L_1^{(f)} = 200.0,\ L_2^{(f)} = 222,\ L_3^{(f)} = 170.0,\ L_4^{(f)} = 205.5.$$

In agreement with relationship (24) we find out the characteristics of the gasoline which is added to the buffer stock:

$$\frac{150 \times 78.3 + 600\,x}{750} = 75$$

Thus we obtain:

$$L^{(C0)} = 74.2,\ L^{(10)} = 84,\ L^{(50)} = 152.5,\ L^{(90)} = 199,\ L^{(f)} = 205.5$$

The mathematical model for this case contains:

I. *Restraints concerning the quality.*

a). Octane number:

$$-181.01 + 3.15\,x_1 + 3.36\,x_2 + 3.03\,x_3 + 3.13\,x_4 + 0.68 \times 77.5 - \\ - 0.82 \times 107 - 0.30 \times 68 - 0.04 \times 77.8 \geqslant 74.2$$

$$-181.01 + 3.15\,x_1 + 3.36\,x_2 + 3.03\,x_3 + 3.13\,x_4 + 0.68 \times 77.5 - \\ - 0.82 \times 107 - 0.30 \times 68 - 0.04 \times 77.8 \leqslant 75.2$$

b) Distillation at 10 cc.

$$-12149.54 + 121.75\,x_1 + 121.88\,x_2 + 121.85\,x_3 + 121.13\,x_4 + 0.07 \times 79 - \\ - 0.005 \times 151.0 + 0.49 \times 87.6 - 0.08 \times 64 \leqslant 84$$

c) Distillations at 50 cc.

$$-34136.38 + 341.02\,x_1 + 341.47\,x_2 + 340.66\,x_3 + 339.83\,x_4 + 0.24 \times 11 - \\ - 0.57 \times 162 + 0.76 \times 90 - 0.85 \times 78.0 \leqslant 152.5$$

d) Distillation at 90 cc.

$$3613.85 - 37.22\,x_1 - 37.00\,x_2 - 37.51\,x_3 - 37.43\,x_4 + 0.71 \times 160 + \\ + 0.99 \times 174 - 0.14 \times 132 - 0.13 \times 95 \leqslant 199$$

e) Final distillation

$$13225.42 - 134.06\,x_1 - 133.93\,x_2 - 134.11\,x_3 - 134.27\,x_4 - 0.25 \times 200 - \\ - 1.83 \times 222 - 0.06 \times 170 - 0.11 \times 111 \leqslant 205.5$$

II. *Restraints concerning the quantity.*

a) $x_1 + x_2 + x_3 + x_4 = 100$

b) Restraints imposed by the statistic model.

$$38 \leqslant x_1 \leqslant 58$$

$$5 \leqslant x_2 \leqslant 15$$

$$16 \leqslant x_3 \leqslant 32$$

$$14 \leqslant x_4 \leqslant 22$$

c) Restraints imposed by the availabilities of each constituent*.

$$x_1 \leqslant 58.33$$

$$x_2 \leqslant 11.66$$

$$x_3 \leqslant 33.33$$

$$x_4 \leqslant 21.33$$

The figures on the right side of these relationships express the percentage of available quantities.

III. The efficiency function representing the cost price

$$min\,F = \min(232\,x_1 + 264\,x_2 + 188\,x_3 + 227\,x_4)$$

The solution yielded by computation when using LPS is

$$x_1 = 38.00\,\%;\ x_2 = 11.34\,\%\ x_3 = 32.00\,\%\ x_4 = 18.83\,\%$$

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*) Restrictions of the type IIb and IIc may be replaced by the following:

$$38 \leqslant x_1 \leqslant min(58;\ 58 \cdot 33),\ 5 \leqslant x_2 \leqslant min(15;\ 11 \cdot 66);$$

$$16 \leqslant x_3 \leqslant min(32;\ 33 \cdot 33),\ 14 \leqslant x_4 \leqslant min(22;\ 21 \cdot 33).$$

When applied on an industrial scale this laboratory recipe led to a blend having characteristics comprised within the limits required by the standards.

3. CONCLUSIONS ON THE MODEL

The functional relationships found out statistically which were not quality restraints in the blends general model can be used with good results only if the constituents participating in the blend have characteristics comprised within the interval $(M - \delta, M +)$, where M is mean, δ is square mean deviation and M, are values found out statistically which have been considered when drawing up the model, and the percentage quantities observe the same limitations. Any extrapolation is risky because it does not offer securities as to the precision of the model.

If the aforestated conditions are not observed, one may use the additive model together with its relevant risks. This model leads, however, to a rational use of gasoline constituents and to blends having minimal cost prices.

The recipe according to the additive model will have 1 or 2 corrections, at the worst.

During the experimental interval, one may go on collecting data leading to a more realistic statistical model since they will cover a longer period.

Likewise, a good model supposes its correlation with the constituents production process modelling in order to secure a better stability of the constituents.

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MODELES MATEMATIQUES TOUCHANT LE PROCESSUS DE MELANGE DES PRODUITS PETROLIERS

Y sont présentés trois des modèles employés à la raffinerie du Groupe Industriel Pétrochimique de Borzeşti, notamment:

1) cas où l'on prépare une seule essence sans tenir compte de l'existence d'un stock tampon;
2) cas où l'on prépare plusieurs sortes d'essences sans tenir compte de l'existence du stock tampon;
3) cas où l'on prépare une seule sorte d'essence en tenant compte de l'existence du stock tampon.

МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ ПРОЦЕССА СМЕШИВАНИЯ НЕФТЕПРОДУКТОВ

В настоящей статье приводятся три модели, применяемые на Борзештском нефтезаводе, а именно:

1) когда производится приготовление одного единственного вида бензина без учета наличия буферного запаса;
2) когда производится приготовление нескольких видов бензина без учета наличия буферного запаса;
3) когда производится приготовление одного единственного вида бензина с учетом наличия буферного запаса.