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Optimal timeline of the process of crystallization of a Sugar Factory

MSc. José Adilio Aguirre Jarquín
Researcher Teacher
UNAN-MANAGUA, FAREM-CARAZO
jarquin3005@gmail.com

Phd. César de Prada / Phd. Gloria Gutiérrez
Department of Systems Engineering and Automatic
University of Valladolid, Spain
prada@autom.uva.es / gloria@autom.uva.es

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SUMMARY

In the last 20 years there has been significant progress in the area of production planning short-term batch processes [1], which together with sequencing tasks have been useful tools in decision making for maximizing a profit or minimize costs. This project developes the optimal sequencing of first, second and third category distillations of the room of crystallization of a typical sugar industry. It seeks to maximize a cost function that relates the maximum amount of liquor to be processed to obtain the maximum amount of sugar subject to a number of restrictions, Brix, purity, and thus ensure optimum utilization of the equipment within the ranges of time. The resulting mathematical model is MINLP, mixed type because it involves binary variables that assign and decide when a distillation process is in boot, cooking or download and because of the nonlinearities in the equations. GAMS is used for its resolution.

1. INTRODUCTION

The discontinuous process batch or semibatch, according with the definition of standard ISA-S88 (1995), are those processes that lead to the production of limited quantities of product from a cuantity of incoming materials. These incoming materials pass through a set of processing activities over a finite period of time using in those activities one or more parts of the equipments. The difference between batch process or semi batch is depending on whether the entrance of the product is maintained throughout the batch. In the semibatch process there is product infeed during the batch, in the batch process, there is not, [2].

The discontinuous procesing or batch is the oldest known operation process in the procesing industry.

It seems surprising to find today that a high proportion of production volumen of chemical subtances (and an even larger proportion if the economic participation is analized) is performed in batch plants. In addition, there is no evidence that this trend declines (Parakrama, 1985, Rippin, 1993). [3]

Years ago the continuous production was promising, currently manufacturing batch is becoming more important because of the appearance of products with high added value manufactured in small quantities greater market uncertainty in the demand for traditional products, and the need for flexible production systems, plants capable of producing diverse products with different specifications for different customers.

The crystallization process of distillation in a sugar room is discontinuous, semi batch a single product (mono product), although different products are obtained at different stages, the end of the sugar is to produce premium sugar or commercial sugar with good quality, uniformly sized crystals with high economic value. To this end it is necessary to program different sequences of distillations in each of the stages to process as many standard liquor, which is the raw material, subject to available resources on the plant.

In this paper is formulated and solved the problem of optimal sequencing of the crystallization room of a sugar plant, specifically the distillations, blenders and centrifugal, using mathematical programming methods to solve the model that describes the problem. In the first section the case study is introduced, in the second the production planning and sequencing batch are defined, the sugar process is detailed in the third, in the fourth the mathematical model of the sugar plant is described and resolved, the results are explained in the fifth, and in the last the conclusions are given.

2. PRODUCTION PLANNING AND SEQUENCING BATCH

The problem of sequencing tasks (Anglo-Saxon translation of scheduling, the expression programming operations is also used) can be considered as complementary to the design problem: the equipment and their capabilities are set and it is about determining the order in which the various batches of the different products use the resources of the plant as well as the time intervals in which such use so happen that a certain performance or cost function is optimized.

The sequencing of tasks is always required when it is a matter of produce multiple products sharing production time. The problem is defined by the structure of the production network, processing times required for each product in each operation, the presence or absence of intermediate storage, the cost associated with changing products, cleaning time, and other costs of penalties, and as well as delivery dates assigned to each product.

The problem of sequencing tasks (batch) responds in short-term to: units that are required for products and the order in which various products must be produced and when each phase must be processed, but excludes important production factors including: supplies of raw material and inventories, inventories of intermediate and final products, launch time of production, ignores limitation on resources and availability of labor, inventory levels and production losses, also ignores the foresight in implementing sequencing tasks to obtain an optimal production plan.

These problems can be solved by mathematical programming so the models that usually describe them consist of several elements such as; shared resources, within these are time and equipment, tasks in charge of the manufacture of products in the available equipment in amounts specified by the demand for specific dates of delivery, performance criteria that are determined by optimization of an objective function, and the most common restrictions such as the time it takes to process a task on an equipment T_{ij}, order of products manufacturing, utilities, labor, storage policies and equipment capacity, [4]

3. DESCRIPTION OF SUGAR PRODUCTION PROCESS

It consists of 2 well distinctive phases: In the first liquor is obtained, and sugar in the second.

3.1. Beet Room

Reception: Beet arrives uncrowned in vehicles, it is weighed and samples are taken to determine the level of impurities and sugar content.

Storage: Vehicles dumped the load to the discharge hoppers. By using conveyor belts, the load is brought into the storage silos where it has air from environment for its conservation.

Transportation: The load goes from the silos to the plant, it is carried out by water along a channel provided with separating stones equipment.

Wash: Is performed in washing rooms, different technologies (vibrating screens, rotary drum) are used, the water is treated and reused. Tare of dust in the beet to the entrance is 3% and 0.5% when it comes off. See Figure 1.

Chopping of the beet: Once washed, they pass over to the feed hopper of roots-cutting in order to divide them into strips called cossettes of triangular sections and have a thickness of 2 to 3 mm.

Diffusion: Is the extraction of sugar beet by the action of hot water in countercurrent in continuous diffusers within which the cossettes goes through inclined augers. At the opposite end of the diffuser the exhausted cossettes called pulp are passed thru a press, then they pass through the dryer to dry the pulp. In here juice with about 16° Brix and a purity of 85% is obtained.

Pressing, drying and granulating the pulp: The pressing is done to recover the hot water with high sugar content that is in the pulp that comes out of the diffuser, this water returns to the process of diffusion and the pulp passes to the drying process.

Evaporation: Its aim is to increase the dry material of 15 °Brix to 60 or 70 °Brix, this way water is evaporated from juice, this is done in a multi-effect system in several evaporators, where 1 kg of steam removes 4 kg of water contained in the juice, the outgoing juice of the evaporation is called syrup with a 65 ºBrix and 91-93% purity. [7], [8].

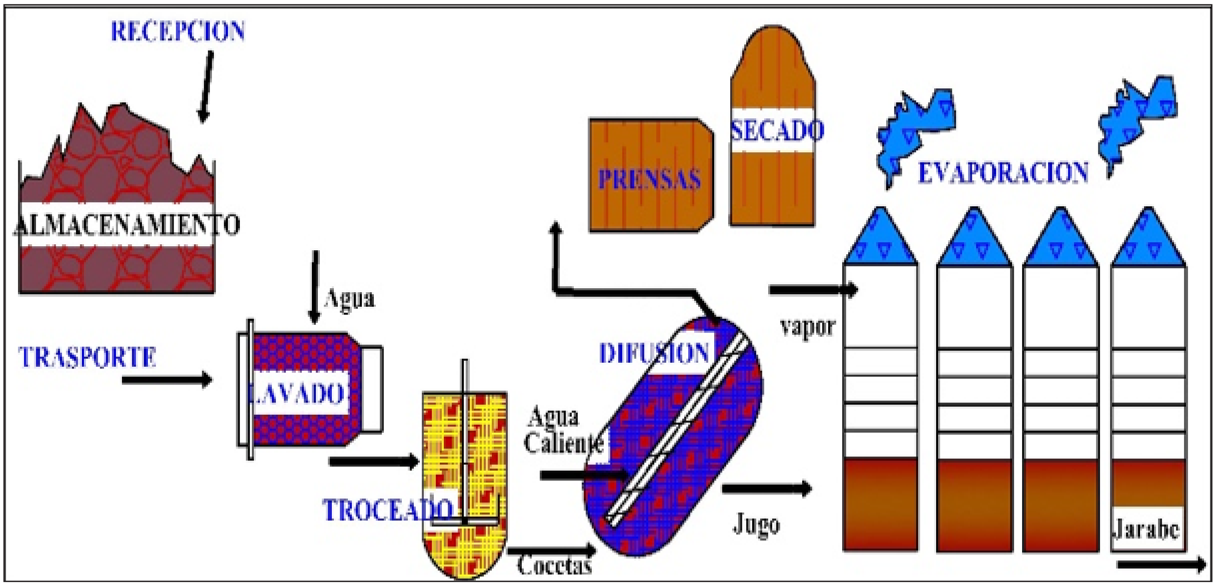

Figure 1: Beet room.

3.2. Sugar Room

Crystallization is carried out in the sugar room and consists of; 1st, 2nd and 3rd Distillations, the blenders, centrifuges, the foundry, deposits and necessary pipelines. Steps are:

1st. Cristalization (Distillation process 1st): It is performed in discontinuous distillations, semi batch, by the cooking process wherein the syrup is concentrated to achieve a controlled saturated solution, at this point a sugar crystals about 5 microns are seeded and should accretion to 500 microns, the syrup passes to be called massecuite and the solution, mother honey.

Malaxator: The massecuite is discharged into kneaders and crystallization continues by cooling. The kneaders retains massecuite´s homogeneity (Slurry) through agitators, these deposits are "Buffers" that store provisionally.

Centrifugation of the 1st product: This process occurs in continuous centrifuge, which separates the crystals from the solution (mother enfolds honey), by spinning forces this operation is done in 2 stages: the first stage poor honey is obtained which is the liquid that comes out of centrifugal by centripetal forces, the second crystals are subjected to a washing process with hot water or steam under pressure, this liquid is called rich honey and returns to the 1st crystallization, the remainder is the commercial sugar with purity 99.99% and 1.00% °Brix.

Drying and conditioning sugar: The sugar of the first crystallization is called white sugar, this is subjected to a drying process, cooling and subsequent sifting for conditioning before storing in the sugar silo for packaging and subsequent marketing.

2nd. Cristalization (Tachas/2nd. Distillation): It is a batch or continuous process and distillations are fed with the mixture of premium poor honey and second category rich honey, the final product is the second massecuite is downloaded to Kneaders of second category.

Centrifugation of the 2nd. product. By the process of spinning, you get sugar, rich honey and second category poor honey to be sent directly to the 3rd crystallization process.

3rd. cristalization (Tachas/3rd. Distillation). Fed with second category poor honey and third category rich honey. In these distillation third category massecuite is obtained, its crystallization proceeds in the horizontal and vertical blenders to obtain by cooling a better mass depletion.

Centrifugation of the 3rd. product: Centrifugation of the massecuite of 3rd category results in sugar of 3rd category with purity of 94.1% and a Brix of 97.83, rich honey of 3rd category with purity of 0.84% and a Brix of 0.67 these return to the 3rd crystallization and a non-crystallizable solution known as molasses having 80 °Brix and purity of 58 to 60%, [8], [9], [10].

In Figure 2, the equipment and process lines of our case study are detailed, also three parallel distillations of first, second and third categories.

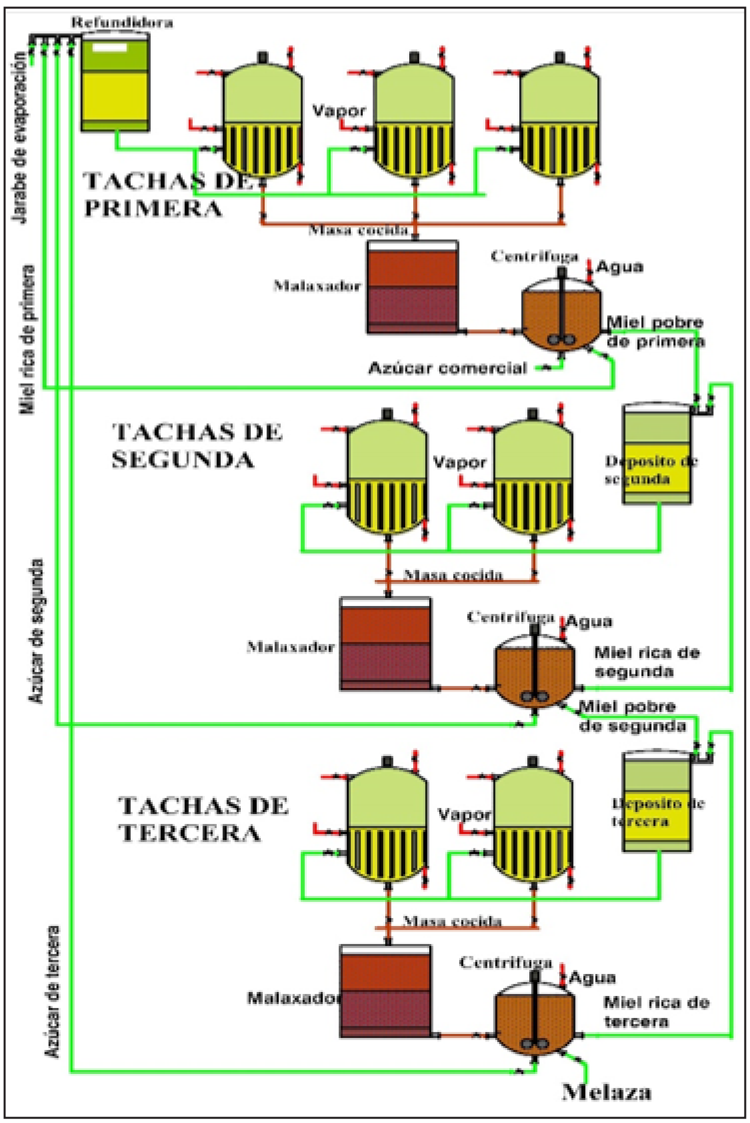

Figure 2: Sugar Room

4. PROBLEM STATEMENT

The foundry and the two deposits of syrup are limited storage, subject to capacity constraints and to lower and upper limits of operation, which requires that the deposits should not remain empty, but neither should overflow. This balance should be achieved through the start of distillation and regulation of syrup input that the deposits are receiving. Other important aspects are the values of purity and Brix, it is known that by entering two or more volume flows to a tank with different Brix and purity, the outflow will have Brix and purity directly proportional to the balance of inflows.

Distillations keep a limited storage and are without storage equipment on phases, when ending the cooking phase distillation must be downloaded. Once they loaded distillation and massecuite has reached the saturation point it is necessary to maintain a steady flow of liquor to continue crystallization. At this stage it is important to maintain the levels of syrup deposits and blenders, you can not start all distillations at the same time because the foundry or vice versa would stay empty, or download them all at the same time because the malaxator would be overflown or contrary. So there should be some restrictions for boot, loading and unloading of distillations. The amount of steam needed in the distillation to bring the liquor at saturation (mayor brix grades), is related to Brix input, the higher Brix in the liquor entering in distillation, the lower vapor is needed, in the cooking phase, purity decreases slightly this occurs by the concentration of certain impurities. And finally ensure the material balance, all the liquor that comes in should equal water leaving as vapor and the massecuite that is discharged, where the sugar it contains should be equal to sugar liquor initially entered.

The three blenders are buffer deposits, so you can say it is a limited stage storage, its dynamics depends on distillations downloads, these can not be empty or can be overflown, for that end, capacity limits and operation must be declared. The three centrifuges are continuous type, what comes in equals what comes out, it must ensure the balance in the flow of sugar, poor and rich honey to keep Brix values and purity. They constantly receive massecuite of kneaders and steam for cleaning crystals.

To solve the aspects of sequencing problems mentioned before, constraints and equations must be defined and apply the concepts of STN in discrete time, and MINLP optimization.

4.1. Process Sequence

The foundry is continually receiving evaporation syrup, rich honey of first category, sugar of second and third categories. It is responsible for feeding the first distillations throughout the cooking process, distillations start depending on the volume of the tank. When cooking is complete, the distillation is discharged to the malaxator, this one temporarily holds the massecuite and continuously sends a flow to the continuous centrifuges of first category, the centrifuge separates the rich honey that returns to the intermediate tank, the commercial sugar that is sold and poor honey sent to the second category distillations; n this deposit is mixed with the rich honey of second category, to get the liquor that feeds the distillations of second category and get the second category massecuite, sequencing at this stage is slower and depends on the volume of the second category deposit.

The malaxator receives the cooked mass form the downloads of the distillations of second category and in order to maintain the capacity limits, sends a steady flow of product to the continuous centrifuges of second category. Out of the centrifuges is obtained second category rich honey, also second category sugar that returns to the intermediate deposit of the first category distillations and second category poor honey that is sent to the third category distillations.

The third category deposit receives the second category poor honey and rich honey of third category and supplies liquor to the third category distillations, for the third category massecuite, the sequence is the slowest of all at this stage, but yet start is necessary for the deposit is not overflown. The third category massecuite is discharged to the malaxator which at the same time is sending product to centrifuges not to overflow. The third category centrifuge separates the rich honey returning to the third category deposit, the third category sugar that is sent to intermediate storage and molasses that contains all impurities and impossible using sugars using this method of crystallization, Figure 2.

To represent the sequence of distillations the Gantt chart is used.

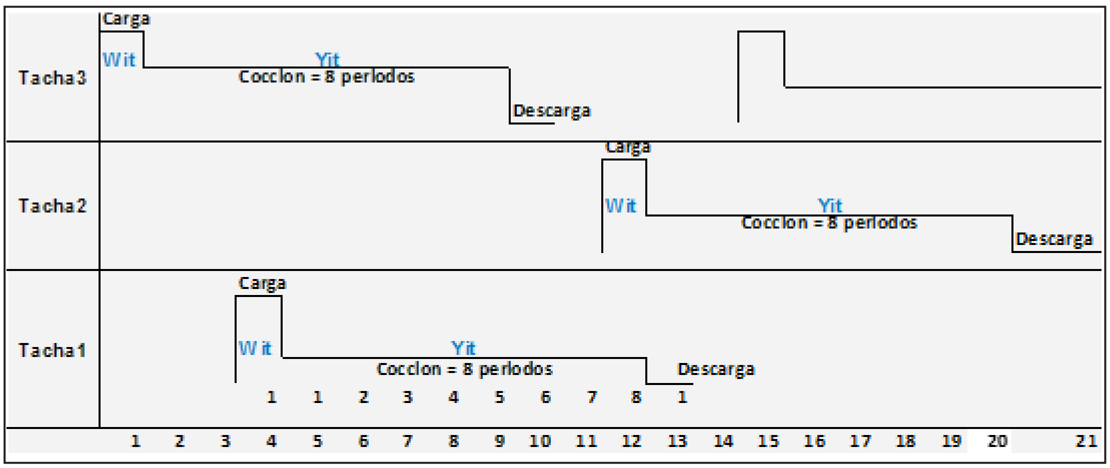

Figure 3: Gantt diagram for sequencing.

Charging time for distillations is 15 minutes (1 period), 120 minutes cooking time or process (8 periods) and 15 minutes to download (1 period). If a distillation is in charge can not be in cooking and if it is in cooking it is not being loaded, for sequencing binary variables are defined to set the loading and unloading. See Figure 3.

5. MATHEMATICAL FORMULATION

The mathematical model is set and it is solved using MINLP, [5], [6].

5.1. Nomenclature

Table 1: Principal variable of the problem

BINARY VARIABLES	
i	Set of distillations (Tacha 1,2,3)
t	Set of periods (1t…50t)
u	Set of distillations (Tacha1,2,3), "Alias"
p	Set of periods (1t…50t), "Alias"

Tp_i	Periods of process (8t) of the distillations i, where 1 period is equal to 15 minutes
W_{it}, W_{ip}	1 if distillation i is loaded, in period t, 0 is not
Y_{it}, Y_{ip}	1 if distillation i is cooking, in period t, 0 is not
Fe	Inflow of Syrup
VD_t	Foundry volume in each period t
$Qcarga_{it}$	Load flow to the distillations i in period t
$Qdesc_{it}$	Download flow of the distillations i in period t
VT_{it}	Distillation volume in each period t
QM	Discharge flow of the malaxator
$QCAzu$	Comercial sugar flow

5.2. Ecuations and Restrictions

5.2.1. Definition of the objective function

We maximize the benefit that is determined by the production of commercial sugar, second category sugar, third category sugar and molasses, and the amount of syrup processed from the evaporation phase, minus the operation costs of the distillations whose operations cost is basically by the amount of steam used in each sequence and the operating cost of centrifuges, where there is an operating cost in each period, so the three distillations totaling 150 work periods, and is defined as follows:

$$\begin{aligned} Max \textstyle\sum_p & QCazu * QCAzuVal + \\ & \textstyle\sum_p S\_QCazu * S\_QCAzuVal + \\ & \textstyle\sum_p T\_QCazu * T\_QCAzuVal + \\ & \textstyle\sum_p T\_QCme * T\_QCmeVal \quad + \textstyle\sum_p Fe * FeVal \\ & -150 * CosCen - Vaporusado * CosVap \\ & -S\_Vaporusado * CosVap \\ & -T\_Vaporusado * CosVap \end{aligned} \qquad (1)$$

Subjected to the next restrictions.

5.2.2. Assignment and start of Distillations.

Within a range of 9 periods you can only start one distillation (2).

$$\sum_p W_{ip} \leq 1 \text{ , } p \geq (max\ (1, t - Tp_i - 1)), \quad p \leq t \quad , \forall i, t \epsilon p \qquad (2)$$

If you started a distillations in a period t, it will be in cooking 8-period of processes (TP_i) later.

$$\sum_p Y_{ip} \geq min\ [(T_{pi}\ , 50\text{-}t) * W_{it}], p \geq (t+1)\ t \quad ,p \leq t\ , \quad \forall i, t \epsilon p \qquad (3)$$

5.2.3. Restrictions on the sequence of tasks.

A Distillation can not be in loading and cooking at the same time.

$$Y_{it} \leq 1 - W_{it} \quad , \quad \forall i, \qquad (4)$$

If you load a distillation at time t, then at the previous time is not in cooking.

$$Y_{it-1} \leq 1 - W_{it} \quad , \quad t \geq 2, \quad \forall i\ , \ t \qquad (5)$$

If you load a distillation over a period of time t, when the cooking phase finish it will be in download.

$$Y\ (i, t + (Tpi + 1)) \leq 1 - W_{it} \quad , t \leq (50 - Tp_i)\ , \forall i\ , \ t \qquad (6)$$

5.2.4. Restrictions for cooking.

To ensure that cooking periods are fully accomplished in each sequence, it must be defined if distillation is in cooking in any period, it should have started earlier Tp periods max.

$$\sum_p W_{ip} \geq Y_{it}, \quad p \geq (max\ (1\ , t - Tp_i) \quad , \quad p \leq t\ , \ \ i, t \epsilon p\ , \qquad (7)$$

Flows are defined for the crystallization process, if it is in boot it is the $Qc1$ flow of 320 kg / period and if in cooking is the $Qc2$ flow of 60 kg / period, and are assigned to the sequence through the binary variables.

$$Qc1 * W_{it} + Qc2 * Y_{it} \leq Qcarga_{it}\ , \forall i, t \qquad (8)$$

$$Qcarga_{it} \leq Qc1 * W_{it} + Qc2 * Y_{it}, \forall i, t \qquad (9)$$

5.2.5. Restrictions for downloads.

The download is made after cooking time. (Figure 3),

$$Qd * W_{it} \leq Qdesc\,(i, t + Tp_i + 1)$$
$$, t \leq (50 - Tp_i - 1), \forall i,\ t \qquad (10)$$
$$Qdesc\,(i, t + Tp_i + 1) \leq Qd * W_{it}$$
$$, \quad t \leq (50 - Tp_i - 1), \quad \forall i, t \qquad (11)$$

If distillation charges in period 1 (initial charge), you can only download up to period 9 (Figure 3).

$$Qdesc_{it} = 0 \ , \quad t \leq 9 \ , \quad \forall it \qquad (12)$$

5.2.6. Restrictions for the foundry

Shown in equation (13) the material balance and of equations (14) - (15) capacity restrictions.

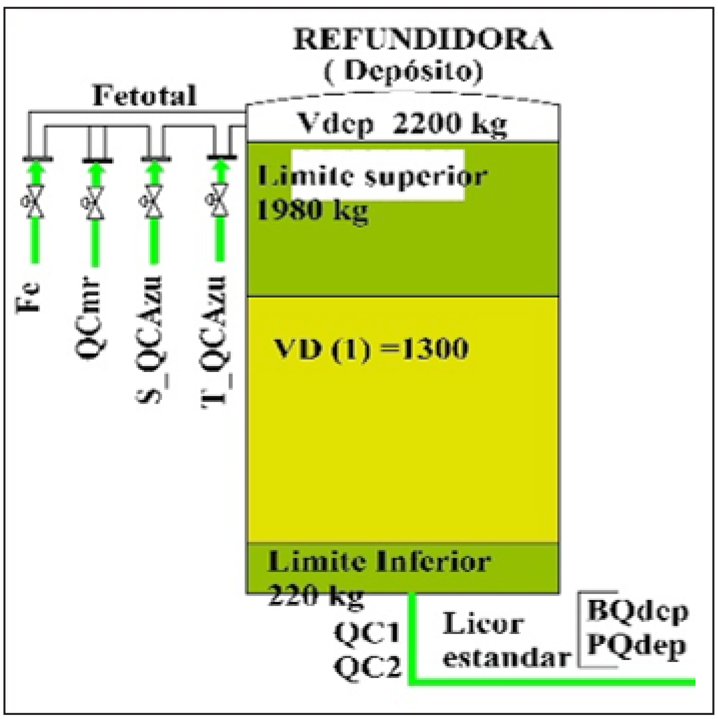

Figure 4. Variables in the founder.

$$VD_t = VD_{t-1} + Fe + QCmr + S\_QcAzu +$$
$$T\_QcAzu - \sum_u Qcarga_{ut} \ , \ t \geq 2, \quad \forall t \qquad (13)$$
$$0.1 * Vdep \leq VD_t \ , \quad \forall t \qquad (14)$$
$$0.9 * Vdep \geq VD_t \ , \quad \forall t \qquad (15)$$
$$VD_1 = 1300 \qquad (16)$$

5.2.7. Balances at Brix and Purity

$$FeTotal = Fe + QCmr + S\_QCAzu + T\_QCAzu \qquad (17)$$

$$BQdepos = \frac{Fe*BFe + QCmr*BCmr + S\_QCAzu * S\_BCAzu + T\_QCAzu * T\_BCAzu}{FeTotal} \qquad (18)$$

$$PQdepos = \frac{Fe*PFe + QCmr*PCmr + S\_QCAzu * S\_PCAzu + T\_QCAzu * T\_PCAzu}{FeTotal} \qquad (19)$$

5.2.8. Material balance for distillations

The sugar content entering the distillations is known for multiplying the input stream multiplied by its °Brix and purity (20), which is not sugar is water more other substances in the liquor inlet (21), which enters of sugar to the distillations is what must come out at the moment of its download(22), the same with what is not sugar, water and impurities (23).

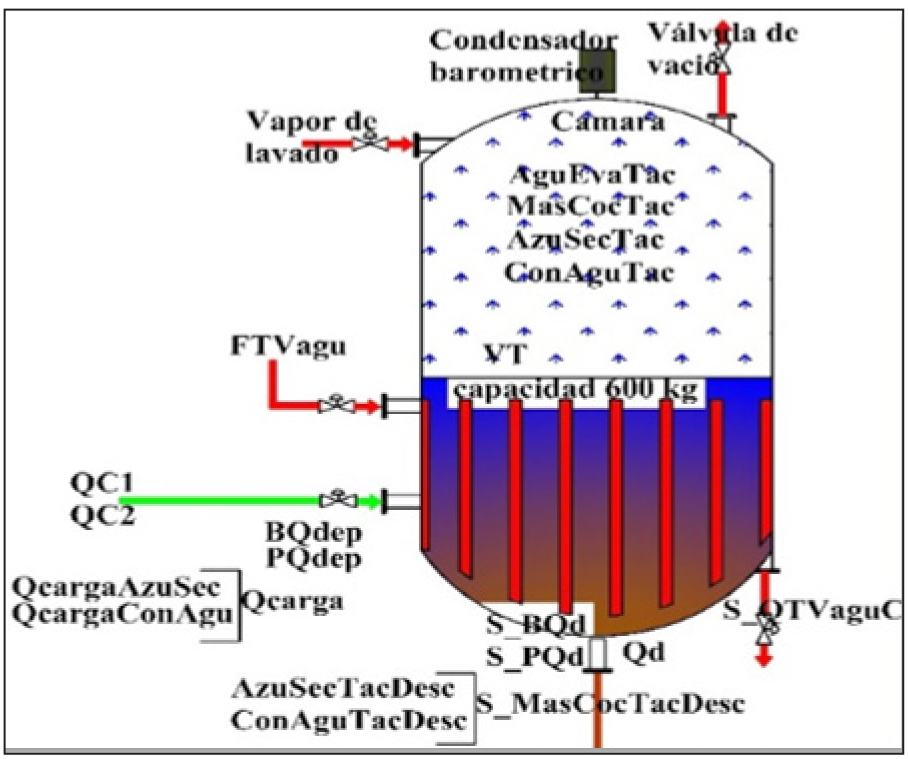

Figure 5: Variables in the distillations

$$QcargaAzuSec_{it} = Qcarga_{it} * BQdep * PQdep \ , \forall i,\ t \qquad (20)$$

$$QcargaConAgu_{it} = Qcarga_{it} \ - QcargaAzuSec_{it}, \forall i,\ t \qquad (21)$$

$$BQdep*PQdep*Qd*W_{it} = QdescAzuSec(i,t+Tp_i+1),\ t \leq (50-Tp_i-1),\ \forall i,\ t \qquad (22)$$

$$(1 - (BQdep * PQdep)) * Qd * W_{it} = QdesConAgu(i, t + Tpi + 1),$$
$$t \leq (50 - Tp_i - 1), \quad \forall i,t \qquad (23)$$

To calculate the steam Hc Antoine equation is applied, where the heat of change of state (25) and Hv is the enthalpy of steam (26), with this value the evaporation constant is calculated that determines how much steam is needed to evaporate 1 kg of water (24). It is determined how much steam is needed in each period (27) and total used (28) - (29), and the resulting condensed water outflow (30).

$$Ctevap = \frac{Hv}{Hc} \qquad (24)$$

Where:

$$Hc = 5.9893 \times 10^2 + Tsat\{-6.19 \times 10^{-1} + Tsat[6.82x10^{-4} + Tsat * (-4.86 x10^{-6})]\} * 4.184 \qquad (25)$$

$$Hv=4.18 * Temp + Hc \qquad (26)$$

$$FTVagu_{it} = AguEvaTac_{it} * Ctevap, \quad \forall i, t \qquad (27)$$

$$FTVaguAcum_t = \sum_u FTVagu_{ut} + FTVagu_{t-1}, \quad \forall t \qquad (28)$$

$$Vaporusado = FTVaguAcum_{50} \qquad (29)$$

$$QTaguC = FTVagu_{it}, \quad \forall i, t \qquad (30)$$

What goes in must be equal to everything that comes out, which is divided into a portion of water that is evaporated (31), the massecuite in the distiller (32) composed of sugar (33) plus water and impurities (34) and the dynamics of the volume in the distiller in each period when increasing massecuite (35).

$$AguEvaTac_{it} = MasCocTac_{it} - \frac{AguSecTac_{it}}{BQd * PQd}, \forall i,t \qquad (31)$$

$$MasCocTac_{it} = Qcarga_{it} - AguEvaTac_{it}, \quad \forall i, t \qquad (32)$$

$$AzuSecTac_{it} = QcargaAzuSec_{it}, \quad \forall i, t \qquad (33)$$

$$ConAguTac_{it} = MasCocTac_{it} - AzuSecTac_{it}, \quad \forall i, t \qquad (34)$$

$$VT_{it} = MasCocTac_{it} + VTi_{t-1} - MasCocTacDesc_{it}, \forall i, t \qquad (35)$$

The amount of water evaporated during the entire cooking (36), as well as the total discharged cooked mass (37), which is composed of water in the baked mass (39) and sugar (38), this amount of sugar which is discharged must be equal to all the sugar that was loaded in the distillation.

$$AguEvaTacDesc_{it} = MasCocTacDesc_{it} - \frac{AguSecTacDesc_{it}}{BQd * PQd}, \forall i,t \quad (36)$$

$$MasCocTacDesc_{it} = Qcarga_{it} - AguEvaTacDesc_{it}, \quad \forall i, t \quad (37)$$

$$AzuSecTacDesc_{it} = QcargaAzuSec_{it} \quad \forall i, t \quad (38)$$

$$ConAguTacDesc_{it} = MasCocTacDesc_{it} - AzuSecTacDesc_{it} \quad \forall i, t \quad (39)$$

Restrictions of the malaxator

Shown in equation (40) the material balance and in equations (41) - (43) capacity constraints.

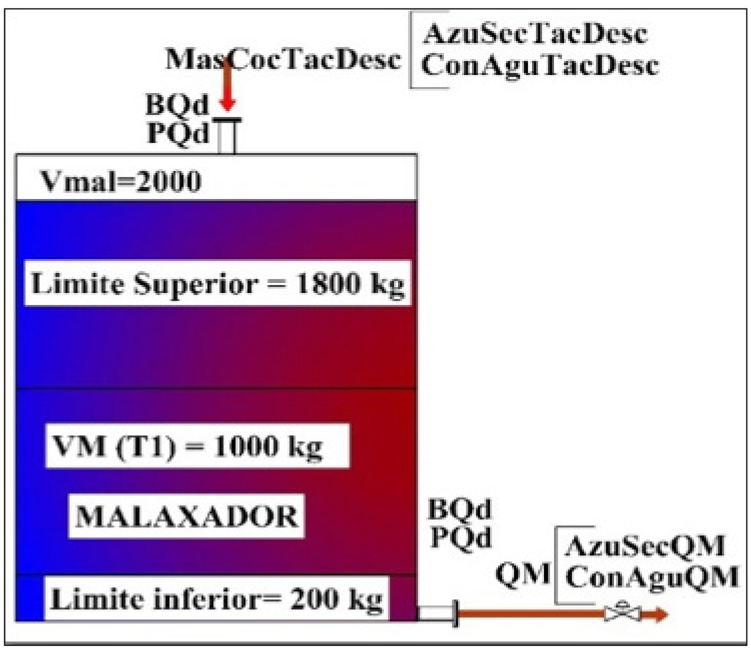

Figure 6: Variables in the malaxator

$$VM_t = VM_{t-1} - QM + \sum u \; MasCocTacDes_{ut}, \quad \forall t \quad (40)$$

$$0.1 * Vmal \leq VM_t, \quad \forall t \quad (41)$$

$$0.9 * Vmal \geq VM_t, \quad \forall t \quad (42)$$

$$VM_1 = 1000 \quad (43)$$

Balances of sugar and water in the discharge flow

The malaxator has a QM constant download of 100 kg/period that contains sugar (44) and water (45), this balance is described this way:

$$AzuSecQM = QM * BQd * PQd \quad (44)$$

$$ConAguQM = QM - AzuSecQM \quad (45)$$

Balances of material in the centrifuge.

The centrifuge of first category is frequent, separates the cooked dough from the malaxador in: Poor honey, rich honey and commercial sugar, with different Brix degrees and purity. Therefore, the balance is:

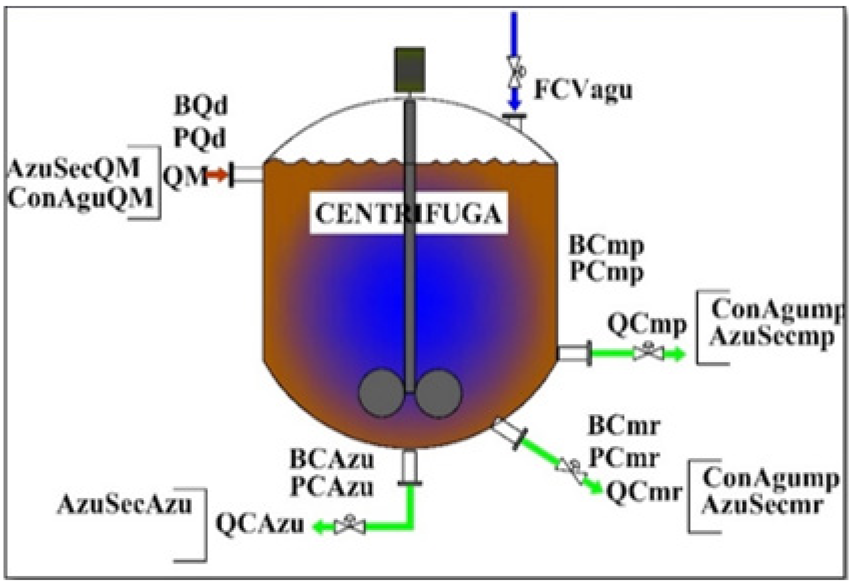

Figure 7: Variables in the Centrifuge

$$ConAgump = QCmp - AzuSecmp \quad (46)$$

$$Azusecmp = QCmp * BCmp * PCmp \quad (47)$$

$$FCVagu = QM * PORagu \quad (48)$$

$$QCmr = PORmr + FCVagu \quad (49)$$

$$AzuSecmr = AzuSecQM – AzuSecmp - AzuSecAzu \quad (50)$$

$$BCmr = \frac{AzuSecmr}{(PORmr + FCVagu) * PCmr} \quad (51)$$

$$QCAzu + QCmp + QCmr = QM + FCVagu \quad (52)$$

$$AzuSecAzu = QCAzu * BCAzu * PCAzu \quad (53)$$

All these equations and constraints correspond to the first distillations, also apply to the second and third distillations.

6. RESULTS

It has been obtained to process 105,384 kg/t of syrup and a production of 62 kg/t of white sugar, 18 kg/t of second category sugar, 7.3 kg/t of third category sugar, 10.20 kg/t molasses, for a economic profit of 3067.49 euros throughout the sequencing.

In Figure 9, 22 periods of 50 are shown, the optimal sequencing of the three distillations of first category, two of distillations of second category, and two of third category, in starting in green, cooking in blue and download in red. For first category distillations cooking takes 8 periods (2 hours), the ones of second category 20 (5 hours) and the ones of third 32 (8 hours).

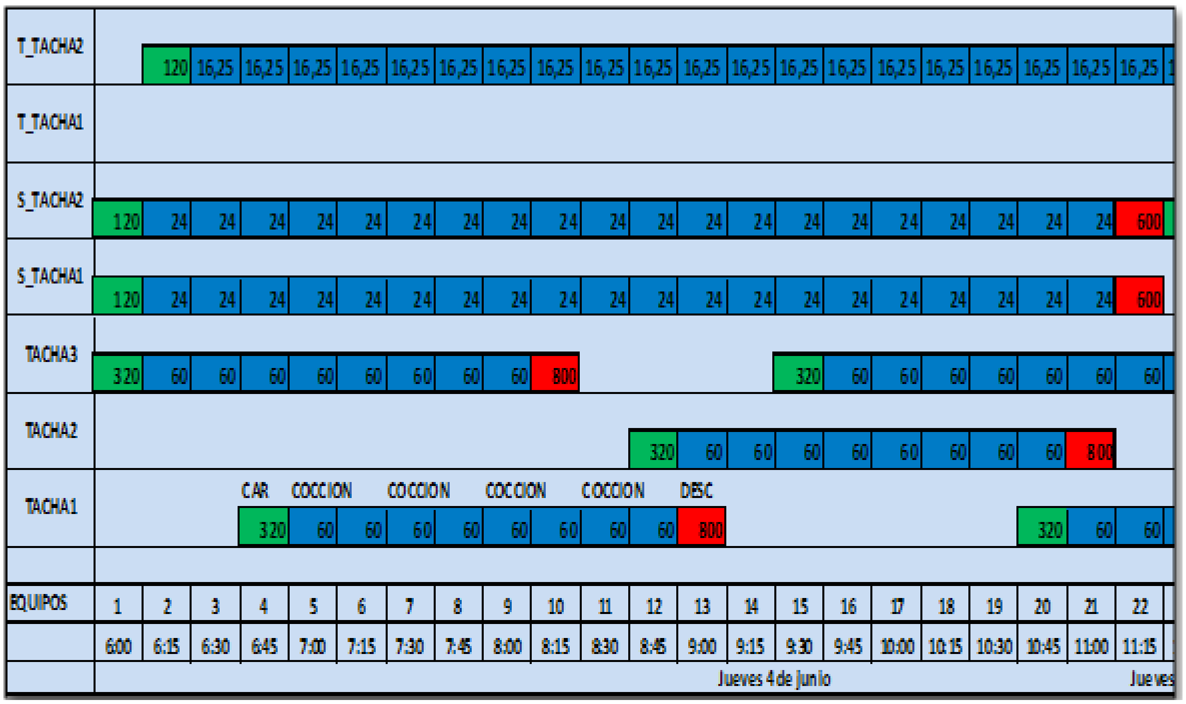

Figure 8: Optimal sequencing for 22 periods

In Figure 9, continuous line you can see the dynamics in the intermediate storage, and compliance with capacity constraints when it reaches 1980 kg maximum capacity, start two distillations to prevent overflow.

In blue line is the behavior of malaxator, also it shows that when this reaches the point of being left empty, the lower limit value of 200 kg a distillation is immediately discharged and returns to its operating point. At the bottom the sequencing of the three distillations of first category (1st in Blue, 2nd red. 3rd green) can be seen, the sequencing period is 13 hours (50 periods of 15 minutes)

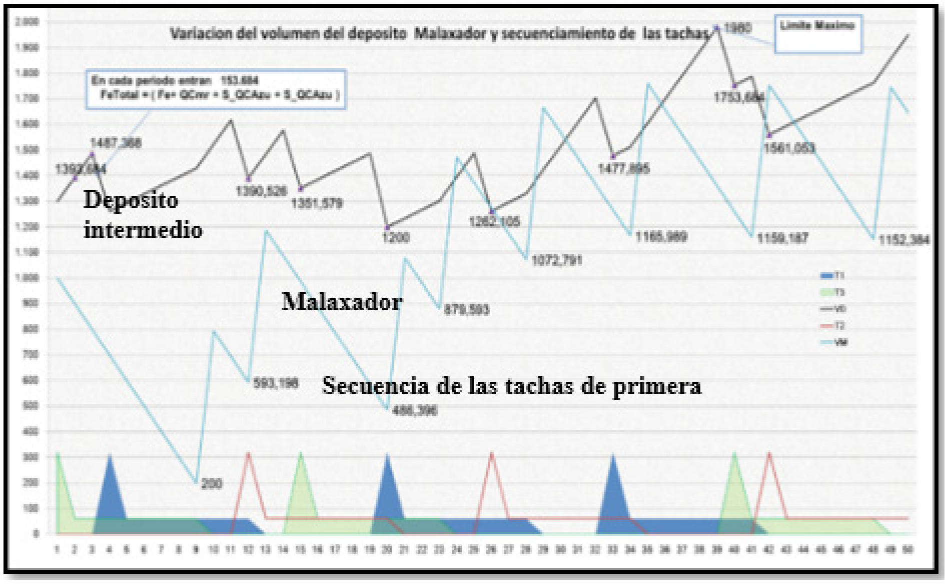

Figure 9: Results for first categories distillations

In Figure 10, are the results of the second category distillations, dynamic of reservoir volume and malaxator are softer, this because the sequences are slower, the inflow to both distillations during the loading phase and cooking is also lower (1st in blue, red 2nd)

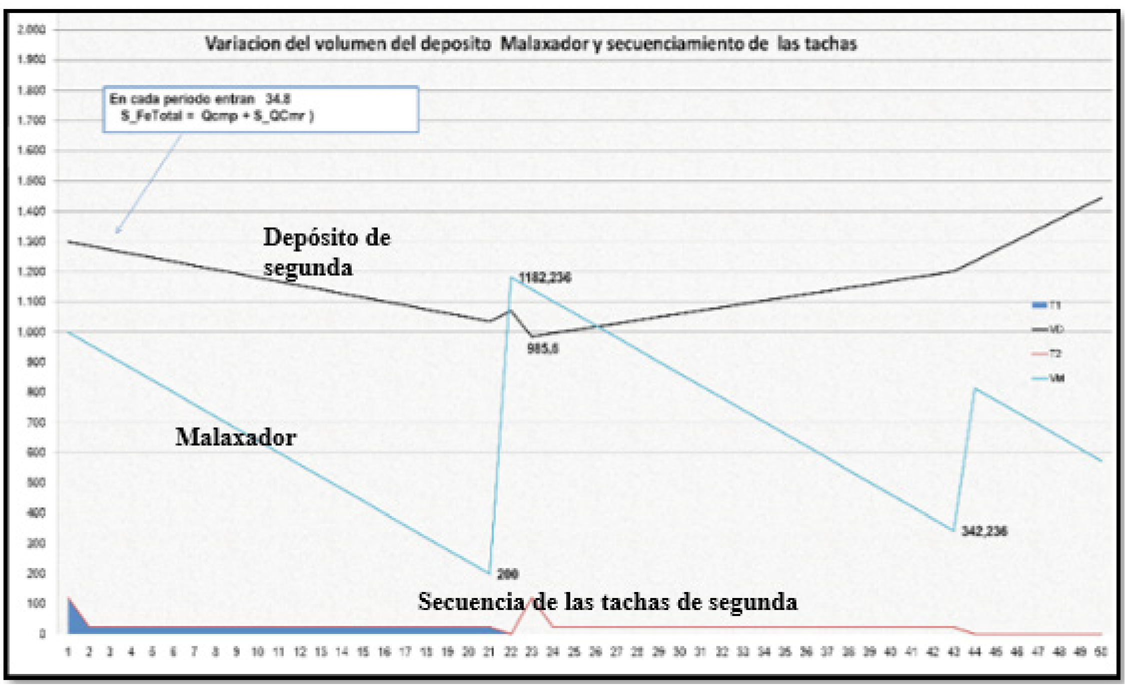

Figure 10: Results of second category distillations

In figure11, are the results of the third category distillations, and the dynamics of the reservoir volume and the malaxator, the sequences are slower at this phase, the inflow to both distillations during the loading step and cooking is very little. (1st in blue, red 2nd)

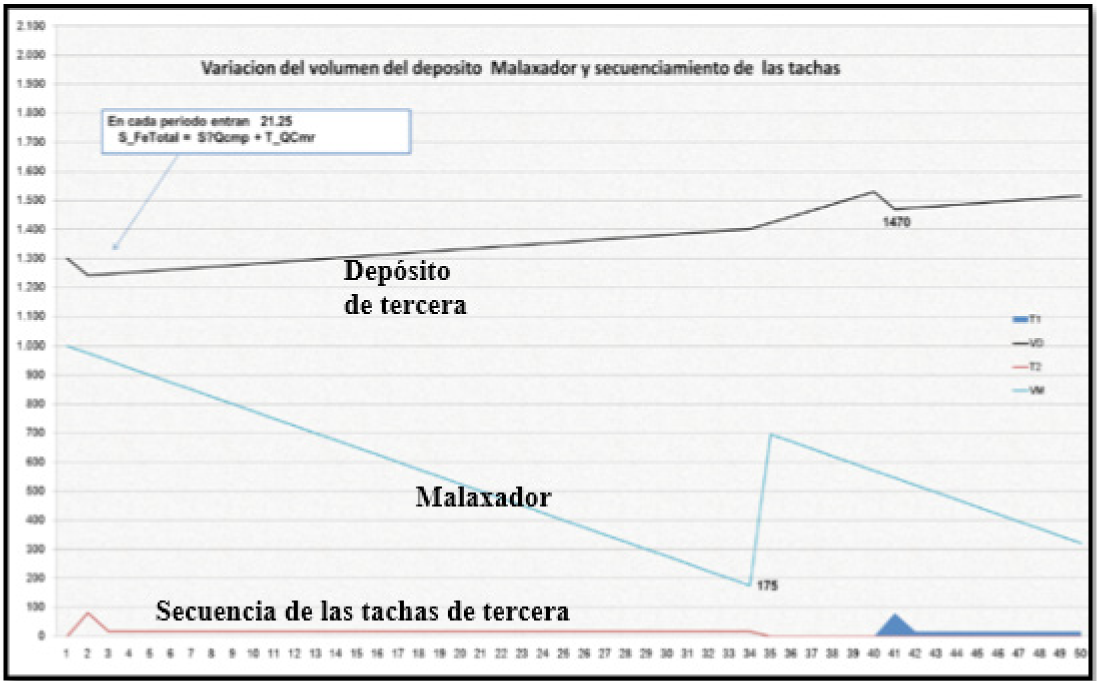

Figure 11: Third category distillation results

7. CONCLUSIONS

It has identified the optimal sequencing of the distillations of the crystallization room, through resolution of the mathematical model using mixed integer nonlinear programming (MINLP).

The cost function has been optimized and a local optimum has been found.

8. REFERENCES

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