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A COMPUTATIONAL METHOD FOR THERMO-EXERGETIC ANALYSIS OF THE SUGAR MILL PROCESS.

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Abstract. *This publication presents a computational method for thermo-exergetic analysis of the process of production in sugar mills. This study is motivated by the deficiency of thermo-exergy studies on that process and environmental impacts. The Brazilian thermo-exergetics matrix is based in fossil fuels and economical analysis led us to the solutions in cogeneration from agricultural residues surpluses. This sector can provide solutions that complement the energy matrix by reduction industrial demand, leading to energy independence or even the generation of electricity surpluses (rational energy use and optimizations). This methodology applies the conservation and thermodynamics laws to effectiveness and available work losses in flows and each chemical component (water and sucrose). The thermodynamic results determined economically viable alternatives for investments decisions. The computational routine maps the inlet and outlet variables for each control volume: enthalpies and entropies, availabilities, mass flows, specific consumptions, irreversibilities and effectiveness. From the results was possibility to identify that in subsystem 1 the pre-evaporator is the least effective equipment with effectiveness ≈ 47% and 97,4MW of irreversibility. In subsystem 2 the group air heater and sugar drier has effectiveness ≈ 25% and 1,37MW of irreversibility while the second centrifuge has effectiveness ≈ 23% and 115,6MW of irreversibility.*

1. Introduction

In any industrial section, indexes or parameters of productive process are accepted, that seek to directions and to give subsidies to technical decisions, even if they can induce errors of analysis. The generation and rational use of energy inputs are the essential importance for the sugar industry, because this survival in the market. The establishment of conservation programs and administration of energy requests the involvement of professionals' teams, information centralization and the give details of the productive process so that whether can establish aims, new procedures and more efficient accompany to methods.

The establishment of the aims and organization of conservation projects of energy should have an analysis technical-economical detailed of vary options followed by the establishment of the priorities that will permit the implantation of the measurements. Accompany and evaluation of these actions takes place with the use of reports of consumption of energy and data of production. The continuous improvement should search for with the option of new products, modifications in the processes, and improvement in the monitoring techniques of the variables or personnel's training, between others.

In effective form can reduced the demand of energy with the adequate use of the available energy. In this aspect, the energetic and exergetic analysis based on the conservation of the mass laws and the 1st and 2nd Laws of Thermodynamics, quantifies and locates of the losses, as escape of process mass, energies not used or work available wasted, that denote inefficient use of resources and generation of pollutant sources. According to Bayramogïlu and Tekin (2001), the exergetic losses in steam power unit of sugar plant detain 77% of the exergetic losses of the all plant, they also described with success it analysis of the thermodynamic efficiency of the thermal-chemical processes in plant of sugar production and with that it can be evaluated the irreversibilities among the all components of the plant, revealing those that more contributes to your inefficiency.

For economical and environmental reasons, a constant need of restructuring exists in the sugar industry due to the tendency of increasing the production rate with the use of progresses in technologies and the preoccupation/exigencies of environmental protection.

Relative studies the improvement of the efficiencies of energy systems for plants in sugarcane industries have been developed during the retaking of the growth in this sector. Austmeyer et all (1995) studied the viability of the use of evaporators plates in sugar industries where have description of various designs of evaporators plates, besides they obtain results of heat transfer. Belloti and Moreau (1996) simulated the processes of sugar production with a cogeneration plant annexed, where the authors concluded the possibilities to attain 235 kg steam consumed by ton of cane and 723 kW by ton of fiber with 40 bar of pressure in the boiler. Camargo et all (1990) make equations the productive process of an industrial plant of the section, with plant of sugar enclosed to a distillery of alcohol, also making studies of some options of improvements of the process. Duarte (2002) applied the methodology of the analysis energetic and exergetic for a typical plant of production of sugar locating and quantifying them efficiency and irreversibilities for each control volume, considering and evaluating the global efficiency of the plant.

In the present work takes place one analysis qualitative and quantitative to a Brazilian typical plant, by Camargo (1990), being used the Law of Conservation of Mass and of Chemical Species together with to 1st and 2nd Laws of the Classic Thermodynamics, where the establishment the relation was aimed at between inputs and products for each one of the sub-processes of the production line.

2. Description of the Productive Process

For better comprehension of the industrial circuit, in the figure 1, have an outline of the industrial process. The hypotheses considered for it analysis of the productive flow they were the following ones: doesn't losses for attrition and doesn't losses among equipments. To proceed they are commented quickly on some characteristics of each one the productive process phases.

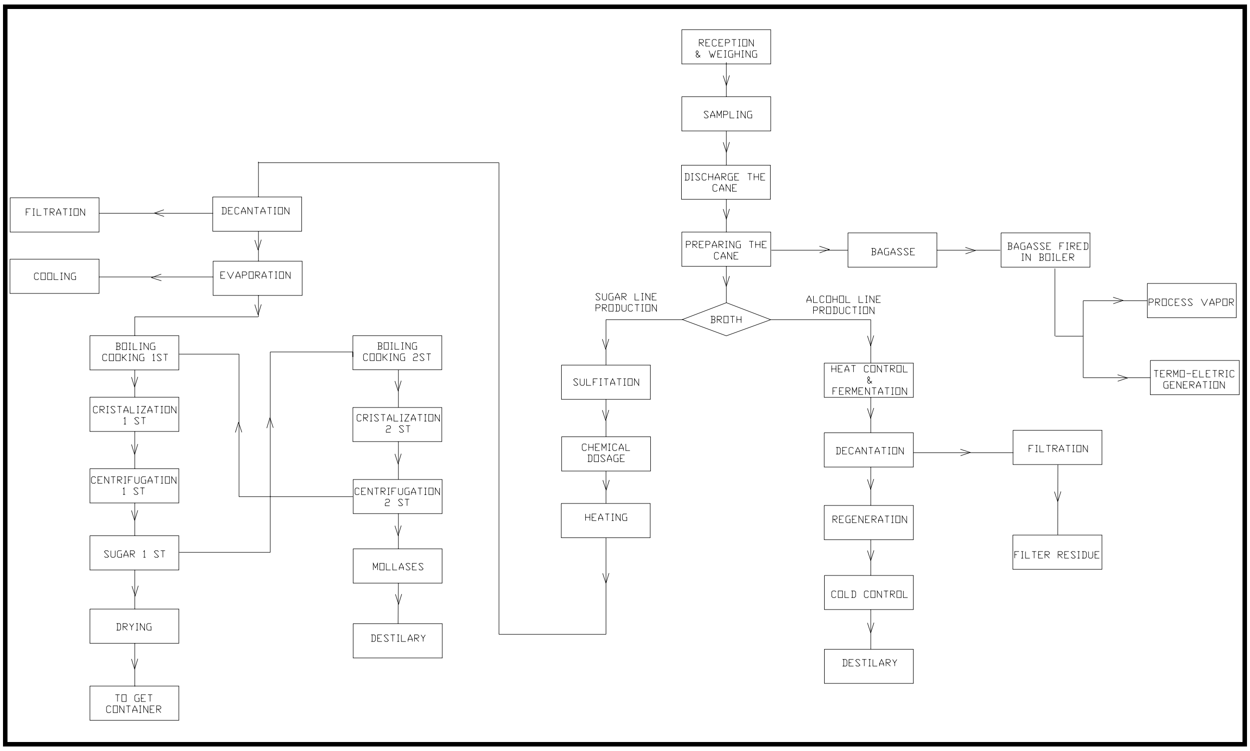

Figure 1 – Process Description of the Sugar Cane Industrial Production

RECEPTION OF SUGARCANE: They are part of this process: the weighing, the sampling, the discharge and the storage of the cane. The weighing should be executed strictly, once it is done, through her, the agricultural and industrial control of the unit. The incorrect weighing provokes mistakes in the balance and global revenues of the industry. After the weighing, raw material samples are sent to the laboratory, where they are certain the of sugar and fiber percentile, and through those analyses occurs the payment of the cane for the sucrose percentile.

WASHING THE SUGARCANE: as the shipment of the cane is accomplished, most of the time mechanically, is taken sludge to the plant (it sands, clay, straw and stone) during the transport, being these fence 4% in dry days and 15% in humid days that it results in waste of the equipments for erosion, increasing the time of decantation, taking the an increase of the loss of inversion sugar and besides increasing the volume of ashes in the combustion chamber of the kettles that burn pulp. To reduce those inconveniences the cane should be washed before being processed. However, sucrose losses and also retention of water in the cane (hydration) might happen.

PREPARATION THE SUGARCANE: in the intention of disaggregating the fibers of the cane, to facilitate the extraction of the broth, since the cane can offer larger or smaller resistance the recovery of the sucrose in function of the proportion among the hard parts (calm) and soft (fibers). The preparation of the cane is also important to increase the capacity of the mills for the increase of the density of the feeding mass, turning her compacts and homogeneous.

PROCESS OF GRINDING: the mill is a constituted smashing unit of “suits”, each one formed by three or four cylinders. Each cylinder has a function the extracts the maximum possible the broth. In the first suit the objective is to reach an extraction from 50 to 70%, with that the pulp is led to the other suits for complement the extraction. A technique to increase the sucrose extraction is to add water to the cane, process known as “soak”, being extracted larger amount of broth.

TREATMENT OF THE BROTH: the destined broth the production of the sugar is drizzled and pumped for the sulfitation tower, followed by the alkalization with “lime water”, and to the finish is warm between 100°C and 105°C occurs like this the sedimentation and the decantation. To proceed is ordered for the evaporation section.

EVAPORATOR: the objective is a water retreat of the mixed broth. It should raise the saccharose concentration for about 60° to 70° but without presenting crystallized sucrose. In practice some conveniences does with that stoops down the concentration of the syrup, such as, facility in the obtaining of “cooking feet”; better conditions for the boiling cooking operation; necessity of dissolution of any crystals. The evaporation system more used in the Brazil is the effect multiples in parallel currents (the broth and vapor are fed in the pre-evaporator, proceeding parallel through the first until the last effect). In general, the circuit is composed by five similar equipments being the first is denominated pre-evaporator, which contain the double of area in relation of the others.

BOILING COOKING and CENTRIFUGING: the syrup from the evaporation sector contains 60% of saccharose, 7% of sludge and 33% of water. Because high viscosity the syrup cannot be more concentrated in common evaporators, needing to use boiling cooking with effect of the vacuous, tends the final product of this stage the “mass of first”. While “mass of first” taking to centrifuges, obtained 2 products: syrup residual or “poor honey” and the crystallized part of “sugar of first”. The “poor honey” will go to one according to boiling cooking and after centrifuges leave the “honey of second” that is going to the distillery and the one that is crystallized and common called “sugar of second”. This procedure can repeat you vary times until the exhausting the honey. In Brazil is more used the two stages.

DRYING: the “sugar of first” originating from of the “centrifuges of first”, with about 2% of humidity should have this next value of 0,1% (0,04% is international specifications), effect this gotten in the dryer of sugar, usually of the rotated type. This equipment works with a drying air that is warm in a heater of air, that admits atmospheric air and it heats up in an indirect heater with the use of escape vapor. This warm air is induced on the mass of sugar and the humid gases are led for a hurricane for a recovery of the sugar dragged by the air.

3. Definition of the Control Volumes

After technical visits in vary units of sugar production and being taken starting from a statistical work of the typical configurations of the Brazilian industrial units, proposed by Camargo (1990), were defined the following control volumes for energetic and exergetic analysis, as shown in the figures 2 and 3, showed below.

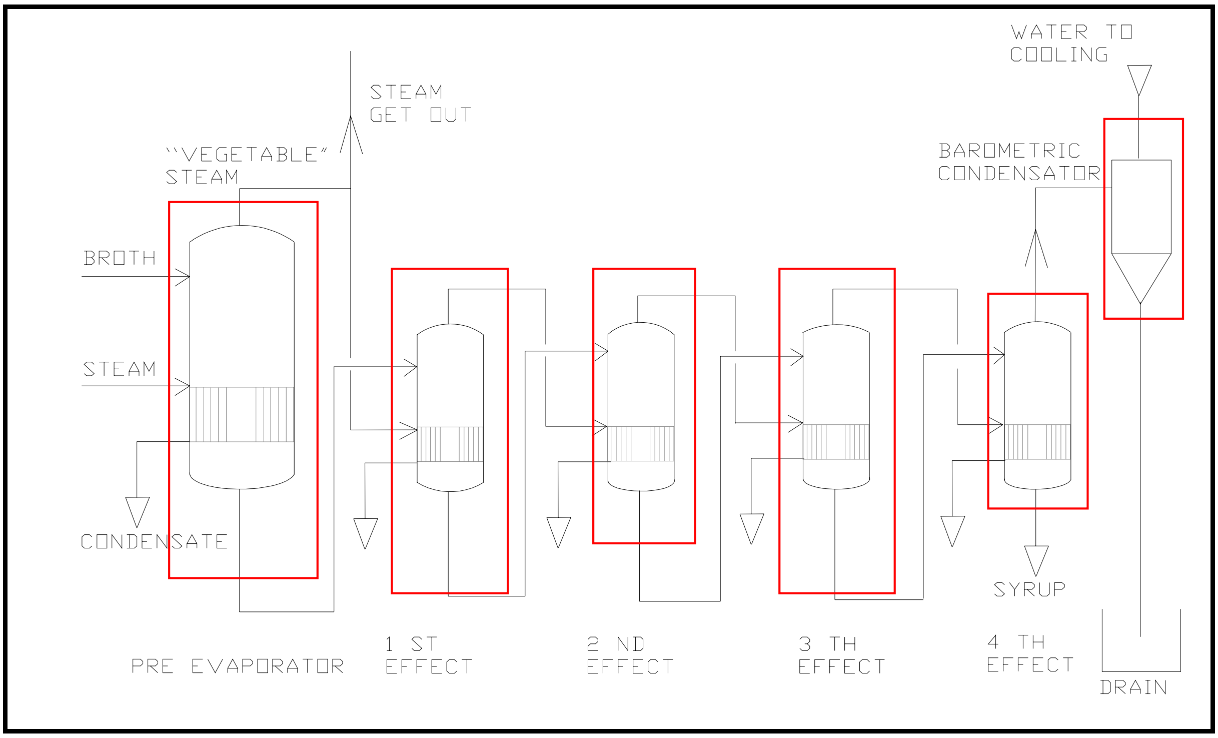

Figure 2 – Control Volumes for evaporation section.

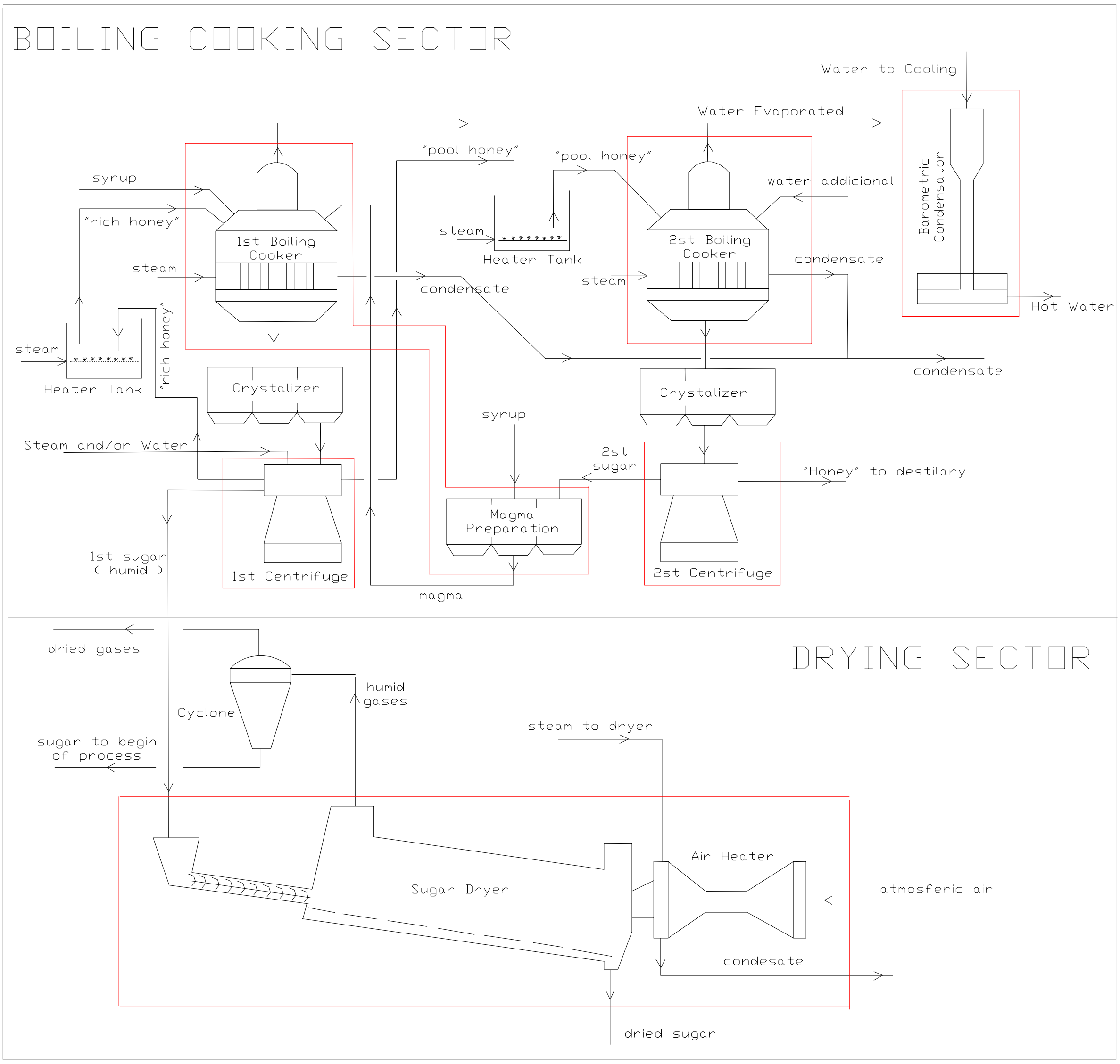

Figure 3 – Control Volumes for cooking boiling and drying section.

4. Mass and Energetic-exergetic Balances

In the formulation the chemical mass/species balance was firstly applied the Mass Law Conservation and that was ratified by Camargo (1990). Decided to study taking for base not only flow but the components of this flow also became separated like this the flows in your basic components, water and sugar. Later, with the software MathCad® grew a routine that the energetic/exergetic balance with is applied 1st and 2nd Laws the Thermodynamics. With those data can be obtained the values of energy, effectiveness and irreversibility thermodynamics in each one of the control volumes proposed. For such a formulation becomes below necessary the use of some defined properties:

COEFFICIENT STECHIOMETRIC: Mass relationship (in moles) of a reagent in a mixture or chemical reaction. See equation (1)

$$C_e = \frac{m * CON}{M} \tag{1}$$

where: C_e = Coefficient Stechiometric;
m = Total Mass;
CON = Concentration;
M = Mass molar.

SPECIFIC HEAT: The equation described below proposes the specific heat in terms of the concentration of sugar or sucrose and doesn't consider the effect of the temperature of the mixed broth, according to Hugot [04]. See equation (2)

$$C_p = 4{,}187 * (1 - 0{,}6 * CON) \tag{2}$$

where: C_p = Specific Heat;
CON = Concentration.

CONSERVATION OF MASS:

$$\sum \dot{m}_i - \sum \dot{m}_j = 0 \tag{3}$$

where: m = Mass flow;
i,j = Refer input and output of each control volume.

FIRST LAW OF THE THERMODYNAMICS:

$$\sum \dot{Q} - \sum \dot{W} = -\Delta E_\sigma + \sum_j m_j * h_{o_j} - \sum_i \dot{m}_i * h_{o_i} \tag{4}$$

where: h_0 = total enthalpy specifies of the material crossing the border
ΔE_σ = variation of internal energy inside of the control surface σ
∑Q, ∑W = rates liquidate respectively of heat and work

SECOND LAW OF THE THERMODYNAMICS:

$$w_{u(max)} = -\Delta\Phi_\sigma + \sum (h_{o_i} - T_0 * S_i) * \dot{m}_i \tag{6}$$

where: S= entropy specifies of the matter entering or leaving
$\Delta\Phi \equiv E + p_0 V - T_0 S$ (This function determines maximum work in VC).
The subscript "0" is referent to the atmospheric conditions.

ENERGY AVAILABILITY: is defined as realizable maximum work in a process between any state and the stables state in relation to the middle, that is, the work free from "losses". For a system the availability is:

$$\Delta\Lambda = W_{máx} = -\Delta E + T_0\Delta S - p_0\Delta V = -\Delta(E + T_0 S - p_0 V) = -\Delta\Phi \qquad (7)$$

Where: Λ= availability
p_0 = pressure of the middle
V = volume of the control volume
W_{max} = Maximum work;
ΔE = Variation of energy;
ΔS = entropy Variation;
T_0 = Temperature of the middle (usually supposed constant)

For a control volume it is added to the term $-\Delta\Phi$ the reversible work of the currents entering and leaving.

$$\Delta\Lambda = -\Delta\Phi + \sum_i h_{0i} T_0 S_i \dot{m}_i \qquad (8)$$

Where: h_o = total specific Enthalpy = h +1/2C^2 +gZ
T_o = temperature in relation to the one of reference
S_i = specific entropy
M_i = mass flux

Note: *i* refers to the one current of all (m → + mass entering; m → - mass leaving)

ENERGY EFFECTIVENESS: the energy effectiveness of the process in one of each control volume is defined starting from to 2nd Law of the Thermodynamics. It is the reason among the maximum work leaving the control volume and the maximum work entering in the control volume.

$$\xi = \frac{A_s + \sum W_s + \sum Q_s * \frac{T_s - T_o}{T_s}}{A_e + \sum W_e + \sum Q_e * \frac{T_e - T_o}{T_e}} \qquad (9)$$

The effectiveness of certain equipment is defined as the reason among the maximum work obtained in the process and the work worn-out maximum.

$$\xi_{equipamento} = \frac{\Delta\Lambda_{produtos} + \sum W_s + \sum Q_s * \frac{T_s - T_o}{T_s}}{\Delta\Lambda_{insumos} + \sum W_e + \sum Q_e * \frac{T_e - T_o}{T_e}} \qquad (10)$$

Where: A or Λ = availability
W = potency

Q = heat
ξ = Efficiency.

IRREVERSIBILITY: is defined, as losses cannot recuperate in system.

$$IRR = A_{entrada} - A_{saída} + \sum_j W_j + \sum_k Q_k \cdot \frac{T_k - T_0}{T_k} \quad (11)$$

Where: IRR é a irreversibility

5. Results and discussions

The table 1 shows the irreversibilities values and effectiveness for each sub process. A preliminary analysis identifies the pre-evaporator as presenting the lowest effectiveness and higher irreversibility, followed for the evaporator of the 4th effect. The high values of irreversibility can be the difference between the condensed vapor and the vapor to be evaporated of the sugary solution, denoted that in the pre-evaporator this different is of 17 C and 4th effect is of 21 C, while us other evaporators is around 5 C.

The section corresponding to the boiling cooking and drying introduced them you centrifuge with low thermal acting, as show the table 2. Was detected as less efficient you centrifuge them, mainly the one of 2a and the group heater +dryer. In an analysis more discerning can be affirmed that the heating group + sugar dryer is the least efficient because have a very smaller irreversibility not making possible a lot of solutions concerning the operation point for reduction of this inefficiency.

Table 1 - Effectiveness and irreversibilities of the subsystem of the Evaporation.

Evaporation	Effectiveness [%]	Irreversibility [MW]
Pre-evaporator	47,38	97,4
1st effect	85,24	23,6
2nd effect	82,62	27,7
3th effect	78,40	34,3
4th effect	70,73	46,4
Barometric Condensator	82,23	06,1

Table 2 - Effectiveness e irreversibilities of Boiling Cooking and Drying subsystems

Boiling Cooking e Drying	**Effectiveness [%]**	**Irreversibility [MW]**
Boiling Cooking 1st + magma coach + heating tank	53,73	130,70
Centrifuge of 1st	37,55	116,20
Boiling Cooking 2nd + heating tank	88,62	19,28
Centrifuge de 2nd	23,08	11,52
Air Heater + sugar dryer	25,58	1,37

6. Conclusions

Through a mass balance and energy was verified (or was determined when necessary) the flows of each current. It was quantified the losses and mass revenues was calculated and energy that allow evaluations of the productive process and the orientation of the efficiencies projects. The analysis showed that the evaporation sections the pre-evaporator possesses the smallest effectiveness exergetic and with high losses; while in the cooking section and drying you centrifuge they present them low effectiveness but your operation point can be corrected because possesses discharges irreversibility while the group heater + sugar dryer possesses low irreversibility not giving chance to corrections operational, like this needing to be redesigned with individual equipment.

This proposed methodology is applied in other subsystems of industrial plants or combined subsystems, but process data is necessary for the analysis.

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