ISSN 2176-5480

22nd International Congress of Mechanical Engineering (COBEM 2013)
November 3-7, 2013, Ribeirão Preto, SP, Brazil

THERMODYNAMIC ANALYSIS OF A SUGARCANE MILL WITH EXTRACTION PROCESS BY DIFFUSION, DEPENDING ON THE MIX OF PRODUCTION AND THE FRACTION OF STRAW USED AS A SUPLEMENTARY FUEL TO BAGASSE

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Abstract. *In the present work, a thermoeconomic analysis of a sugarcane mill that, further of bagasse, uses straw as a fuel in the steam generating unit was carried out. It was considered the variation of most relevant process parameters, such as the straw-bagasse relationship and the sugar-alcohol production mix, to survey the energy and exergy flows of a typical power plant. For evaluation purposes of economic performance, an exergoeconomic analysis was performed taking into account the cost of all products and byproducts generated, including the cost of surplus electricity for commercialization. The numerical procedure was implemented through the software EES (Engineering Equation Solver) and the results obtained were then compared with those provided for a conventional plant without straw burning.*

Keywords: *Cogeneration, Bagasse, Straw, Sugarcane.*

1. INTRODUCTION AND OBJECTIVES

The cultivation of the sugarcane in Brazil comes from the XVI Century and has always been one of the main economic activities of the country. In mid of decade 70, with the implementation of the Alcohol National Program (PROÁLCOOL) this activity becomes strategic in the scenery of economic policy and of automotive fuels.

Through this initiative, great incentives and heavy investments was allocated for development of technologies to the sugarcane industrial park and to the planting of sugarcane. However, with the lack of rainfall occurred in the year 2001, was identified the fragility of the Brazilian energy matrix, due to the strong dependence of the hydropower. Given this scenario, were created the Thermoelectric Priority Program (PPT) and the Incentive Program for Alternative Sources of Energy (PROINFA) that aimed, respectively, the deployment of thermoelectric plants and cogeneration plants, allowing the hiring of energy produced by renewable alternative sources.

Thus, the sugarcane sector started to invest and to develop heavily technologies for the generation of surplus electricity through the burning of sugarcane residues. Since then, this whole thread acquires an unimaginable dimension until recently, both in the national and global scenarios of energy policy and of sustainability.

From a technical point of view, the bagasse constitutes the conventional source of energy in cogeneration processes of the sugarcane mills. Nevertheless, in view of the growing market of energy and mandatory social demands for an energy policy that values the minimization of environmental impact, the sugarcane straw gains a paramount importance due to stopping the burned. Essentially, the straw consists of everything that is removed from the sugarcane before the juice extraction process, either by milling or diffusion process. This includes not only dry leaves but also green leaves and pointers (the tip of the plant). In each ton of harvested cane are produced on average 140 kg of straw (Xavier *et al.*, 2009). This byproduct has an energy potential high. The value of its lower heat value (*LHV*) is about 15 MJ/kg and, therefore, it can be used as an extra source of fuel for the generation of surplus electricity.

The main objective of this work, is conduct a thermoeconomic analysis of a sugarcane mill, which uses straw as supplementary source of fuel by computing the exergoeconomic costs for the processing of its main products: sugar, ethanol and electricity, according to the content of straw in the sugarcane and the mix of sugar-alcohol production.

2. PROBLEM DESCRIPTION

For the present study, the raw material will be considered from the integral cut system, for purposes of costs minimization (Michelazzo and Braunbeck, 2008). For the juice extraction, it will be considered a unit of preparation and dry cleaning, where it is separated the straw from the sugarcane, followed by an extraction unit by diffusion. This proposal aims to increase the sugar extraction rate and decrease the water and energy consumption.

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For the remaining process steps, it will be considered conventional units for the treatment of juice, evaporation and sugar production, fermentation, distillation, and water treatment. In this context, the industrial park will be divided into the following sectors:

- Unit of Reception, Preparation and Dry Cleaning of Sugarcane;
- Unit of Broth Extraction by Diffusion;
- Unit of Broth Treatment;
- Unit of Sugar Production;
- Unit of Fermentation and Distillation;
- Unit of Water Treatment;
- Unit of Steam and Power Generation.

For the characterization of a given unit, it is established a control volume to quantify the amortization of invested capital, the costs associated with maintenance and operation, (Z), as well as all involved flows (work, heat, mass and cash flows associated with the inputs and outputs) that cross the unit, as can be seen in Fig. 1.

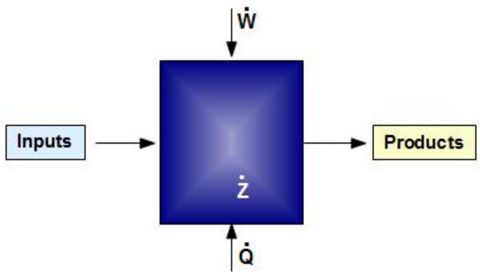

Figure 1. Representation of various flows in a given unit.

To meet the demands of heat to process of a given unit, it will be established from a line of steam that enters in the domain as an input. Thus, the equipment of a given unit will be always considered as adiabatic. Naturally, after the utilization of the steam in the process, the condensed will results as product. Thus, from the thermal demand of each unit, it must to be established not only the steam demand, but also the demand for cooling water of the industrial park.

A simplified view of the thermal power plant, in which are identified the connections between all the units described previously, is shown in Fig. 2.

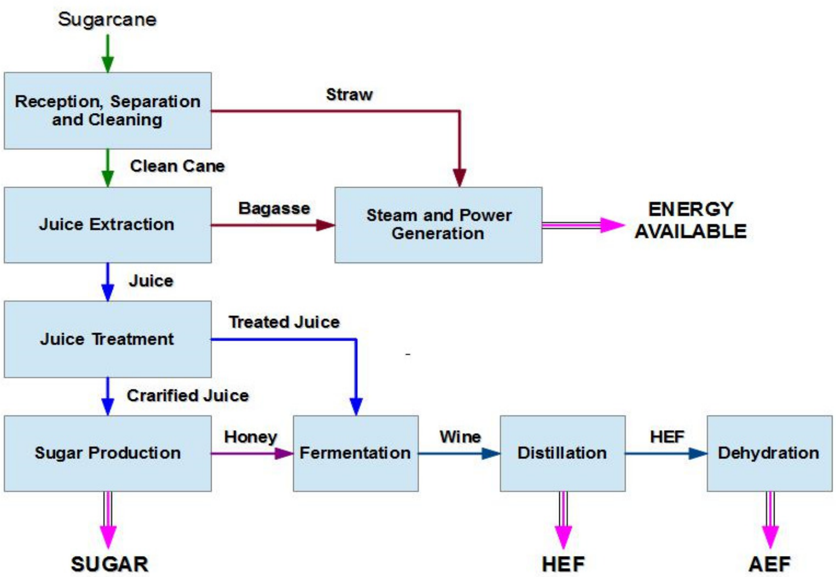

Figure 2. Scheme of the flows of cane, juice, bagasse and straw for the production of sugar, hydrous (AEHC) and anhydrous (EACA) ethanol and electricity available for sale.

For the thermodynamic analysis of the steam generation unit will be considered the plant displayed in Fig. 3.

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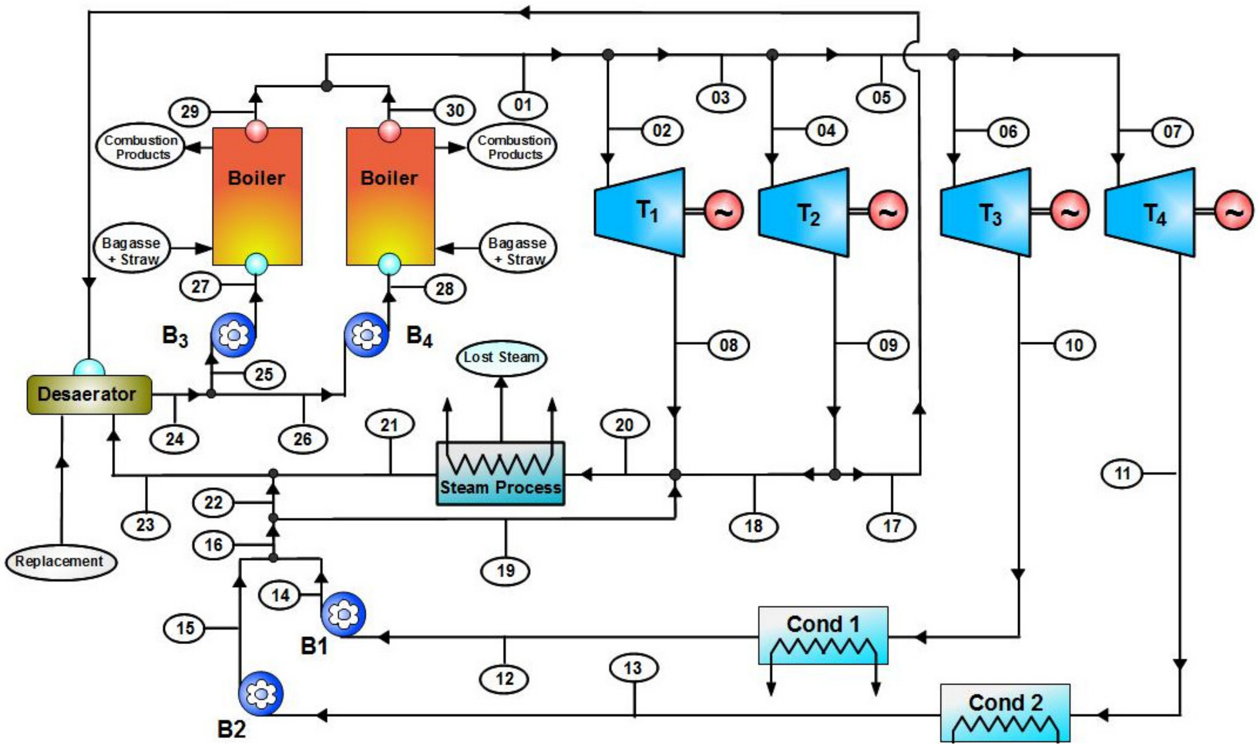

Figure 3. Thermal power plant of a sugarcane mill that burns bagasse and straw.

3. THEORETICAL FOUNDATIONS

3.1 Mass and Energy Balance

The continuity equation in steady state for a given control volume is given by (Van Wylen *et al.*, 1995):

$$\sum \dot{m}_s - \sum \dot{m}_e = 0 \tag{1}$$

where $\dot{m}_e$ and $\dot{m}_s$ are the mass flows input and output of a given control volume.

Neglecting the changes in the kinetic and potential energies, the first law of thermodynamics in a given control volume can be written as follows (Van Wylen *et al.*, 1995):

$$\dot{Q}_{v.c.} - \dot{W}_{v.c.} + \sum \dot{m}_i.h_i - \sum \dot{m}_o.h_o = 0 \tag{2}$$

where h_i e h_o are the specific enthalpy at the inlet and outlet of the control volume; $\dot{Q}_{v.c.}$ the thermal power and $\dot{W}_{v.c.}$ the work transfer rate in the control volume.

With respect to the second law of thermodynamics, the analysis is restricted, here, only to check for their compatibility, according to (Van Wylen *et al.*, 1995):

$$\dot{S}_{ger.v.c.} + \sum \left(\frac{\dot{Q}_{v.c.j}}{T_j} \right) + \sum \dot{m}_i.s_i - \sum \dot{m}_o.s_o = 0 \tag{3}$$

where s_i and s_o are the specific entropy at the inlet and outlet of the control volume; T_j is the surface temperature of the control volume and $\dot{S}_{ger.v.c.}$ is the entropy generation in the control volume.

For analysis purposes thermoeconomic were evaluated exergy flows entering and leaving each control volume. The physical exergy relative to the reference state given by the ambient temperature and pressure is given by:

$$b = (h - h_0) - T_0(s - s_0) \tag{4}$$

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The processing of sugar and alcohol involves numerous complex mixtures. Thus, the chemical exergy was not computed because of the difficulty of their calculation. However, the error made by this procedure is small considering that the thermoeconomic analysis is based on the principle of conservation of costs, essentially.

3.2 Isentropic Efficiencies and Performance Index

The isentropic efficiencies for turbines, pumps and boilers are given, respectively, by:

$$\eta_{turb} = \frac{\dot{W}_{v.c.}}{\dot{m} \cdot \Delta h_{iso}} \tag{5}$$

$$\eta_{pump} = \frac{\dot{m} \cdot \Delta h_{iso}}{\dot{W}_{v.c.}} \tag{6}$$

$$\eta_{boiler} = \frac{\dot{m} \cdot \Delta h_{water}}{\dot{m}_{fuel} . LHV_{fuel}} \tag{7}$$

where Δh_{iso} is the difference between the enthalpy of inlet and outlet of the control volume, for isentropic process; $\dot{m}$ the mass flow of water or steam into the control volume; $\dot{m}_{fuel}$ is the mass flow of fuel in the boilers and LHV_{fuel} is the fuel Lower Heat Value.

To analyze the performance of the plant will be considered the Energy Utilization Factor (*FUE*), which relates the thermal and mechanical energy harnessed in the cycle with the energy of the fuel:

$$FUE = \frac{\dot{W}_{net} + \dot{Q}_{useful}}{\dot{m}_{fuel} \cdot LHV_{fuel}} \tag{8}$$

where $\dot{W}_{net}$ represents the shaft net power and $\dot{Q}_{useful}$ the process thermal load of the plant.

3.3 Exergoeconomic Costs

For a given control volume, from the mass flow with associated rates of exergy transfer ($\dot{B}_i$ and $\dot{B}_o$), power ($\dot{W}$), and exergy transfer rate associated with heat transfer ($\dot{B}_Q$), are established the following exergoeconomic costs (Lozano and Valero, 1993):

$$\dot{C}_i = c_i.\dot{B}_i = c_i(\dot{m}_i.b_i); \qquad \dot{C}_o = c_o.\dot{B}_o = c_o(\dot{m}_o.b_o); \qquad \dot{C}_w = c_w.\dot{W}; \qquad \dot{C}_Q = c_Q.\dot{B}_Q \tag{9}$$

where c_i, c_o, c_w and c_Q denote the average costs per unit of exergy in Reais per Gigajoule (R$/GJ). The exergoeconomic cost analysis involves the balance of costs usually formulated for each component separately. A balance of cost applied to the *n*-th component of the system shows that the sum of costs rates associated with all exergy flows output is equal to the sum of costs rates of all exergy flows input plus the appropriate price due to capital investment $\dot{Z}_{IC}$ and operating and maintenance costs $\dot{Z}_{OM}$. The sum of the last two terms is denoted by $\dot{Z}_n$. Consequently, for a component that receives heat and generates power results the following equation:

$$\sum_o \dot{C}_{o_n} + \dot{C}_{w_n} = \dot{C}_{Q_n} + \sum_i \dot{C}_{i_n} + \dot{Z}_n \tag{10}$$

This equation simply indicates that the total cost of exergy output flows is equal to the total expenditure to get them: the cost of exergy input flows plus the capital and other costs. Inserting the expressions of cost rate, Eq. (9), in Eq. (10) results:

$$\sum_o (c_o.\dot{B}_o)_n + c_{w_n}.\dot{W}_n = c_{Q_n}.\dot{B}_{Q_n} + \sum_i (c_i.\dot{B}_i)_n + \dot{Z}_n \tag{11}$$

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The exergy rates related to the flows crossing the control volume ($\dot{B}_i$ and $\dot{B}_o$), as well associated to the heat and the work ($\dot{B}_Q$ and $\dot{W}$), of the *n*-th component are calculated in an exergy analysis. The last term ($\dot{Z}_n$) is obtained by calculating the capital investment associated with on *n*-th component and then computing the values partitioned of these costs per unit of system operating time. Thus, making use of Lozano and Valero (1993) propositions and of Eq. (11) were determined the costs of flows involved in the analysis of the industrial park.

3.4 Estimation of the Invested Capital in Equipments

To estimate the cost of the equipment of the plant proposed for analysis, it was necessary an extrapolation from known equipment prices. Conversion costs in relation to the capacity or size of the equipment can be made comparing the same equipment but with different size or capacity in accordance with the following correlation (Bejan *et al.*, 1996):

$$C_y = C_x \left(\frac{S_y}{S_x} \right)^{\alpha} \tag{12}$$

where, C_y is the cost to be calculated for the equipment "*y*"; C_x is the cost know for the equipment "*x*"; S_y is the variable conversion (capacity) of the equipment "*y*", S_x is the variable conversion (capacity) of the equipment "*x*" and α is the scale factor depending on the type of equipment (Bejan *et al.*, 1996).

3.5. Estimating of the Costs of Amortization, Maintenance and Operation

To simplify the analysis, it was considered that all the investment was made in the year zero. To calculate the amortization was considered a lifetime (*N*) of 20 years, being despised the sales values of the equipment at the end of its useful life. For the calculation of financial costs was considered a typical interest rate (*j*) of 12% per year. Thus, the amortization index (I_m) is given by:

$$I_m = \left[\frac{j(1+j)^N}{(1+j)^N - 1} \right] \tag{13}$$

In relation to the maintenance and operation expenses were considered the values recommended by Bejan *et al.* (1996), approximately 5 % of the amortization cost of the equipments in analysis.

4. RESULTS AND DISCUSSION

For the analysis of the proposed work, all numerical results were obtained computationally using the EES - Engineering Equation Solver (Klein and Alvarado, 1995).

Initially, it was established a standard problem that represents a medium size plant. The main parameters for this standard case are shown in Tables 1 to 4.

To perform the thermodynamic analysis of the steam generation and power plant were considered process parameters presented in Tab. 5.

According to the nomenclature established in Fig. 3, the thermodynamic results that were obtained for the standard case are shown in Tab. 6.

Table 1. Process data in the plant (baseline case).

Parameter	**Value**
Sugarcane processed (t)	2,000,000
Process period (days)	220
Hours effective extraction (h)	5,184
Juice extraction (t/h)	284
Mix Sugarcane/Alcohol (%)	50
Mix Ethanol Hydrous/Anhydrous (%)	63

Table 2. Sugarcane data.

Parameter	**Value**
Fiber in the sugarcane (%)	12.3
POL - Polarization (%)	16.4
Brix (%)	18.5
RS - Reducing sugars (%)	1.5
Straw humidity (%)	35
Fiber LHV (kJ/kg)	15,180

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Table 3. Efficiency of equipment.

Equipment	Efficiency (%)
Boiler	85
Electric motors	95
Generators	95
Backpressure turbine	85
Condensing turbine	80
Condensate pump	75
Boiler pump	60

Table 4. Power indicators.

Unit/Equipment	Power
Separation/Clean (MJ/t of sugarcane)	0.69
Juice extraction (MJ/t of sugarcane)	5.0
Juice treatment (MJ/t of sugarcane)	3.0
Sugar production (MJ/t of sugar)	200
Distillery (MJ/m³ of ethanol)	150
Boiler (MJ/t of fuel)	60
Water treatment (MJ/m³ of water consumed)	0.078

Table 5. Data relating to the steam generation unit.

Parameter	Value
Steam pressure (MPa)	6.7
Steam temperature at the boiler outlet (°C)	530
Saturation temperature of the steam in the condenser (°C)	50
Saturation temperature of the steam in the process (°C)	130

Table 6. Operating parameters for the standard case.

Points	$\dot{m}$ (kg/s)	*P* (bar)	*T* (°C)	*h* (kJ/kg)	*s* (kJ/kg K)	*b* (kJ/kg)
1	87.1	67	530	3,486	6,913	3,218
2	28.4	67	530	3,486	6,913	3,218
3	58.8	67	530	3,486	6,913	3,218
4	28.4	67	530	3,486	6,913	3,218
5	30.4	67	530	3,486	6,913	3,218
6 - 7	15.2	67	530	3,486	6,913	3,218
8 - 9	28.4	2.7	165.7	2,796	7,207	2,520
10 - 11	15.2	0.123	50	2,470	7,699	2,182
12 - 13	15,2	0.123	49	205	0.690	92
14 -15	15.2	2.7	49	205.3	0.690	92.4
16	30.4	2.7	49	205.3	0.690	92.4
17	1.74	2.7	165.7	2,796	7,207	2,520
18	26.6	2.7	165.7	2,796	7,207	2,520
19	1.65	2.7	49.02	205.3	0.690	92.4
20	56.7	2.7	130	2,720.4	7,027	2,449
21	53.9	2.7	129	541.8	1,623	406
22	28.7	2.7	49	205.3	0.690	92.4
23	82.6	2.7	101.4	424.7	1,321	296
24	87.1	2.7	110.1	461.8	1,419	330.6
25 - 26	43.6	2.7	110.1	461.8	1,419	330.6
27 - 28	43.6	67	110.82	471.5	1,427	340.1
29 - 30	43.6	67	530	3,486	6,913	3,218

To determine the equipment values were considered the costs and benchmark data of Passolongo (2010) and the exponent α, used in Equation (12), obtained from Bejan *et al.* (1996), resulting the data present in Tab. 7.

Through the analysis of exergoeconomic costs were determined in Tab. 8 the prices of the sugar, hydrous and anhydrous ethanol, electricity generated; amount of electricity available for sale and the amount of water consumed by the plant, according to the process data presented in Tab. 1, for a straw fraction of 10 % in the sugarcane and production of 53.6 MW of electricity, being necessary the capture of 1.12 m³ of water per ton of sugarcane in this condition.

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Table 7. Costs and benchmarks for calculating the value of the equipment.

Equipment	Reference Cost (R$)	Reference Parameter	Exponent α
Boiler	27,000,000.00	$\dot{Q}$ = 215,000 (kW)	0.78
Backpressure turbine	3,000,000.00	$\dot{W}$ = 12,000 (kW)	0.50
Condensing turbine	1,000,000.00	$\dot{W}$ = 3,000 (kW)	0.90
Condensing pump	100,000.00	$\dot{W}$ = 2.5 (kW)	0.48
Boiler pump	1,800,000.00	$\dot{W}$ = 500 (kW)	0.48
Deaerator	2,000,000.00	$\dot{m}$ = 45 (kg/s)	0.60
Condenser	800,000.00	$\dot{Q}$ = 16,500 (kW)	0.66
Separation and clean unity	6,000,000.00	M_{crop} = 440,000 (t)	0.60
Juice extraction unity	8,000,000.00	M_{crop} = 250,000 (t)	0.40
Juice treatment	10,000,000.00	M_{crop} = 1,000,000 (t)	0.60
Sugar production unity	20,000,000.00	M_{crop} = 1,000,000 (t)	0.60
Distillery	20,000,000.00	M_{crop} = 1,000,000 (t)	0.60
Water treatment water	8,000,000.00	M_{crop} = 2,000,000 (t)	0.60

Table 8. Thermoeconomic result for the default case.

Parameter	Specific Cost
Sugar	R$ 0.48/kg
Hydrous ethanol	R$ 0.57/liter
Anhydrous ethanol	R$ 0.75/liter
Electricity	R$ 116.21/MWh
Treated water	R$ 0.18/m³

The cost of sugarcane destined for juice extraction unit was calculated in terms of the total costs of inputs in the separation unit and the portion related to the mass fraction of sugar cane (culm) in relation to the total weight of raw material purchased (culm + straw). The cost of straw destined to the boiler and its exergoeconomic cost were obtained through the conservation costs equation. For consistency, it was assigned to the bagasse the same exergoeconomic cost obtained for the straw. Thus, it was possible to establish the total cost for the juice and its exergoeconomic cost. This procedure allowed the evaluation of the entire chain of products generated in the various units established for analysis of the industrial park. Regarding the thermoeconomic analysis of the unit steam generation and power, it is important to note that the cost of electricity generated was obtained from the costs conservation equation in the condensing turbines, when is assigned a null value to the low-pressure steam exiting turbine.

As byproducts produced in the plant are obtained filter cake and vinasse that are used as fertilizers in agriculture and therefore have commercial value. The value found for the filter cake was R$ 24.00/t and to the vinasse R$ 1.70/m³. It is worth noting that Silva (2009) refers to the price of R$ 50.00/t for the sale of the filter cake and that the prices charged for the sale of vinasse are of the order of R$ 3.00/m^3 to R$ 6.00/m³.

The influence of the straw fraction burned on the amount of electricity produced and in the costs of production of sugar, alcohol and electricity is shown in Tab. 9, for a sugar-alcohol production mix of 50 %.

Table 9. Influence of the straw fraction burned in the amount of electricity produced and in the costs of production of sugar, alcohol and electricity, for a sugar-alcohol production mix of 50 %.

Parameter	Straw fraction burned			
	4 %	6 %	8 %	10 %
Electricity available (MW)	38.5	43.5	48.5	53.6
Electricity cost (R$/MWh)	107.43	111.68	114.34	116.21
Sugar cost (R$/kg)	0.48	0.48	0.48	0.48
Hydrous ethanol cost (R$/liter)	0.58	0.58	0.57	0.57
Anhydrous ethanol cost (R$/liter)	0.75	0.75	0.75	0.75

Figures 4 and 5 present, respectively, the evolution of the availability of electricity and the cost of production of sugar and alcohol as a function of the straw fraction burned, for a sugar-alcohol production mix of 50 %.

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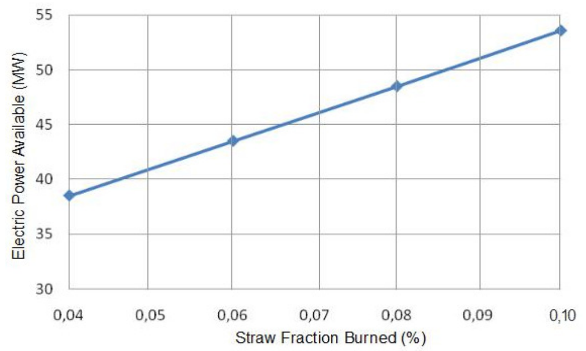

Figure 4. Availability of electricity as function of the straw fraction burned, for a sugar-alcohol mix of 50 %.

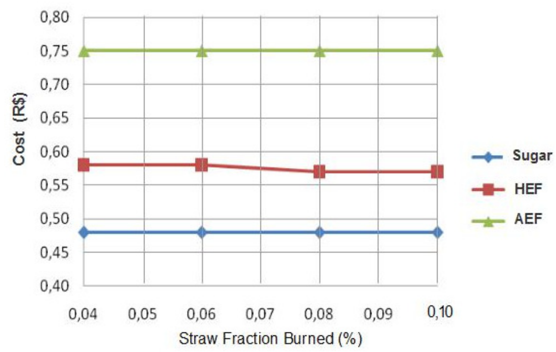

Figure 5. Sugar and alcohol costs as function of the straw fraction burned, for a sugar-alcohol mix of 50 %.

As was expected, it is verified in Fig. 4 that the rate of power generation increases strongly with increasing content of straw burned in boilers. However, it is interesting to see the evolution of the average cost of power generated: the higher the rate of burning fuel in the boilers, the greater the flow of steam in the condensing turbines. Since these devices have higher costs in relation to the backpressure turbines imply, then, an increase in the costs of energy generation. By the other side, in Fig. 5 is observed that the costs of producing sugar and ethanol are stable.

The influence of the sugar-alcohol mix on the amount of electricity produced and in the costs of production of sugar, alcohol and electricity is shown in Tab. 10, for a straw fraction burned of 10 %.

Table 10. Influence of the sugar-alcohol mix in the amount of electricity produced and in the costs of production of sugar, alcohol and electricity, for a straw fraction burned of 10 %.

Parameter	**Sugar-alcohol Mix**			
	20 %	**40 %**	**60 %**	**80 %**
Electricity available (MW)	57.7	54.9	52.2	49.4
Electricity cost (R$/MWh)	124.85	119.04	113,44	108.20
Sugar cost (R$/kg)	0.60	0.50	0.47	0.44
Hydrous ethanol cost (R$/liter)	0.57	0.57	0.58	0.59
Anhydrous ethanol cost (R$/liter)	0.74	0.74	0.75	0.76

Figures 6 and 7 present the evolution of the availability of electricity and the cost of production of sugar and alcohol as a function of the mix of sugar-alcohol production. It is interesting to note that the curve of commercially available power decreases with the increase of the mix, since the specific consumption of steam in sugar production is high. For the same reason, it is worth noting that the process steam and electricity costs decreases with increasing the mix, because in this case there will be a greater demand of steam in the backpressure turbines which show an cost evolution less pronounced when compared the condensing turbines.

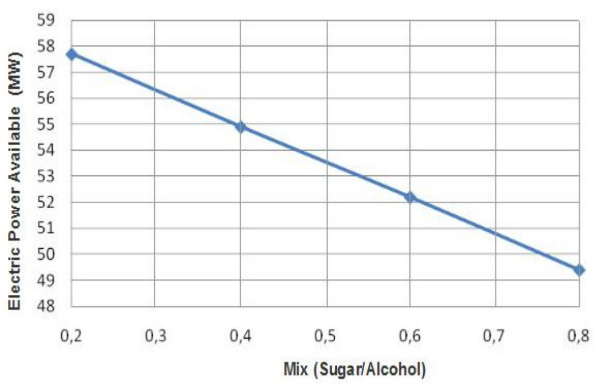

Figure 6. Availability of electricity as a function of the sugar-alcohol mix, for a straw fraction burned of 10 %.

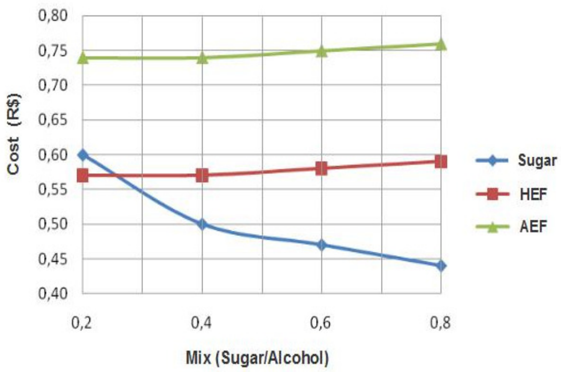

Figure 7. Sugar and alcohol costs as a function of the sugar-alcohol mix, for a straw fraction burned of 10 %.

ISSN 2176-5480

Until now, all the results present are related to the baseline case in which was considered a amount of 2,000,000 t of sugarcane processed per crop. The influence of the amount of sugarcane processed in the crop on amount of electricity produced and in the costs of production of sugar, alcohol and electricity, for a sugar-alcohol mix of 50 % and a fraction of straw burned of 10% is shown in Tab. 11.

Table 11. Influence of the amount of sugarcane processed in the crop on amount of electricity produced and in the costs of production of sugar, alcohol and electricity, for a sugar-alcohol mix of 50 % and a fraction of straw burned of 10%.

Parameter	Sugarcane processed in the crop (t)			
	1,000,000	2,000,000	3,000,000	4,000,000
Electricity available (MW)	26.8	53.6	80,3	49.4
Electricity cost (R$/MWh)	127.65	116.21	110.76	107.33
Sugar cost (R$/kg)	0.53	0.48	0.46	0.45
Hydrous ethanol cost (R$/liter)	0.62	0.57	0.55	0.54
Anhydrous ethanol cost (R$/liter)	0.81	0.75	0.72	0.70

Making an analysis of the costs as function of the amount of sugarcane processed to a mix of 50% and a fraction of straw of 10% there is a reduction in the cost of products for milled above the considered in baseline case and a increase for milled below the baseline case, as expected.

It is important to note that the proposal plant to steam generation has been designed to avoid stoppages in the industrial park caused by failures or maintenance equipment. Therefore, when it is necessary to stop an equipment the flows may be diverted for a similar equipment and thus ensure the continuity of the process. However, if were replaced the equipment that are duplicated by a single of power doubled, the costs of investment, operation and maintenance will decrease, since the cost calculation chain, given by Equation (12), is nonlinear. In this case, a new thermoeconomic analysis was performed and interestingly it was observed little changes in the cost of the sugar, hydrous and anhydrous ethanol, since the equipment of these units are not changed. But the cost of electricity decreases significantly, from R$ 116.21/MWh to R$ 95.45/MWh, considering the baseline case of 2,000,000 tons of sugarcane processed per crop.

5. FINAL COMMENTS AND CONCLUSIONS

In this paper it was performed a thermodynamic analysis of a steam generation and power plant that operates with sugarcane burning straw as supplementary source of fuel as well as a thermoeconomic analysis of the mill plant, calculating the costs for processing its main products (sugar, ethanol and electricity) as function on the content of the straw in the cane and also of the mix sugar-ethanol production. For the power and steam generation plant were considered typical thermodynamic parameters, perfectly feasible today.

With the use of straw, there was an increase of up to 50% on thermal load in the boiler. How the burning of bagasse only meets all the needs of process steam of the mill, this additional thermal load was used to produce steam necessary to generate surplus electricity.

For this reason, it was considered a plant with two backpressure turbines to provide process steam demanded by the industrial park and also with two condensing turbines of high efficiency to increase the generation of surplus electricity to commercialization. The option by two boilers, two backpressure turbines and two condensing turbines, result in a slightly larger investment, but ensure a huge security on industrial operation during the crop.

For the straw separation and the preparation of the sugarcane to the juice extraction was considered a unit of dry cleaning. This system has a higher initial investment but decreases the process costs in view of eliminating of the water and of lost sugar in the traditional system of the cane washing. For juice extraction was considered a diffusion extraction unit, which enables a significant reduction in the extraction process costs and also a reduction of the sugar content in the bagasse. With respect to the juice treatment unit, evaporation unity and crystallization unity, it was considered process parameters and equipment typical of current plants. With respect to the distillation unit, it was considered the use of molecular sieve to anhydrous ethanol extraction.

Regarding thermoeconomic analysis, it was considered the Theory of Cost Exergoeconomic. For the success of this proposition it was decisive to proper allocation of exergoeconomic costs of the total reduced sugar, straw and energy generated by the turbines. The costs of the other products were obtained using common sense and through the principle of costs conservation.

The specific costs of sugar, ethanol and electricity were checked by varying the straw fraction present in sugarcane and also of the sugar-alcohol mix. It was observed that the specific costs obtained for hydrous and anhydrous ethanol varied little for all cases analyzed.

Regarding the sugar production it was observed that the cost decreases significantly as the greater the mix for your production. Regarding the generation of electricity, it was observed that by increasing the fraction of straw present in

ISSN 2176-5480

cane sugar increases the generation of surplus for sale substantially. However, the cost of electricity has a behavior opposite to that found for sugar: the higher the generation, the higher their specific cost. This fact is related to the increase in the investment and operating costs of the condensing turbines.

In general, the specific costs obtained for the sugar, hydrous and anhydrous ethanol and electric power for all cases analyzed are significant and reasonable. But it is important to emphasize that the proposed methodology provides a technical procedure and safe for the assessment of costs. This procedure associated with the market opportunities may represent a powerful tool in developing strategies and economic decision-making.

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7. RESPONSIBILITY NOTICE

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