USING THERMOECONOMICS AS A TOOL FOR THE ADEQUATE SELECTION OF DISTILLATION PLANT SCHEME IN AN AUTONOMUS DISTILLERY FOR RATIONAL ENERGY USE

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Abstract. *Nowadays different kinds of technologies are available for the ethanol industries such as: diffuser, electrical drives, multiple stages turbines, in the milling process, falling films for the juice concentration, vacuum or multi-pressure distillation systems and molecular sieves for the ethanol concentration. All the previous technologies are available for minimizing energy consumption and maximizing the whole plant efficiency. However, what is the technology combination that allows the highest efficiency with a lower cost? The objective of this paper is to carry-out an integrated thermoeconomic analysis for an ethanol distillery and its cogeneration plant considering different distillation plant schemes with a cogeneration plant that operate with steam parameters of 6.5 MPa and 490 °C. The different technologies are compared with a distillery using simple stage turbines for mill driving, four effects evaporation, atmospheric distillation and cyclehexane ethanol dehydration. These alternatives are compared based on their using as a tool the exergetic efficiency, performance indicators and the average exergy and economic cost for involved energy flows (electricity and ethanol). The results obtained allow to define the alternative that results in the highest efficiency in the whole plant with a better exergetic and monetary cost.*

Keywords*: cogeneration; ethanol production; thermoeconomics*

1. INTRODUCTION

Ethanol production is an important source of income for Brazil. It is also a renewable alternative to fossil fuel. Brazil has the lower production cost of ethanol, as a consequence of good soils and climate for sugar cane cultivation, experience in large-scale production and modern technologies.

Ethanol production from sugarcane can be accomplished trough several combined routes by application of different technologies for cogeneration plant, mills, fermentation, distillation and dehydration process. Indeed, they constitute chains of processes that must be driven by a specific objective, such as minimizing power, steam consumption and losses, improving product quality or plant robustness, among others (Moura and Medeiros, 2007). However, the technology applied has an initial investment, which can result in a less competitive plant if that chain was not constructed under a strict sense of consistency and focused on real results.

The present study shows how the combination of thermodynamics indicators with thermoeconomics tools can help in the selection of the better distillation plant scheme in an autonomous distillery, through the determination of the cost of each product separately. The main objective is of this paper is to carry out an integral analysis of the cogeneration and distillation considering four modernization alternatives of a mill's cogeneration plant, distillation and dehydration systems seeking the better choice that allows the reduction of steam plant consumption, maximization of the electric power generation and the minimization of the cost of final products (Electricity and Ethanol). For the decision making process, the exergetic and monetary costs of the main products are considered as well as thermodynamic indicators, calculated through the first and second law.

2. GENERAL ASPECTS

Sustainability for a distillation plant implies maximizing overall efficiency and optimizing the production of a range of products and by-products from the sugarcane feedstock. There is a wide range of ways in which this objective can be achieved. One alternative for improve the overall efficiency is the reduction of energy consumptions by process integration (particularly heat integration) and the other is trough the introduction and use of more efficient equipments to reduce losses. This last alternative requires the generation and assessment of many process flow sheets for finding those ones with improved performance indicators.

In an autonomous distillery the main energy-consuming sections are: milling, evaporation and distillation. The dehydration system consumes a smaller amount of thermal energy in comparison to the sections above.

In the *milling section* one way to reduce the energy consumption is to replace the simple stages steam turbines used to drive the mills by multiple stages steam turbines, electrical motors or by the utilization of the diffuser technology. For steam-driver roller mills a low whole efficiency of 24-26% is typical. For electrically driven mills this efficiency is in the range of 40-45%. Another important aspect is to minimize the mechanical energy consumption in the process.

For the ethanol processing stages, various solutions are available to reduce energy consumption. Among them one can find (Olivéiro e Ribeiro, 2006): (i) Multi-effect juice concentration systems with low steam consumption; (ii) Use of a more efficient distillation system, with lower steam consumption per liter of ethanol produced; (iii) Use of secondary steam from evaporation for use in distillation.

A main possibility of energy reduction in distillation is to employ staged pressure systems. These systems are based on the principle of operating the individual columns at different pressure level in order to achieve a temperature difference between the columns. As a result the overhead vapor of the columns can be used to heat one another.

Increasing the ethanol content of the incoming alcoholic mash from 10 to 12% saves more than 15% of steam. But this is of course dependent on the conditions of the fermentation process.

2.1 Performance assessment criteria based on the first and second law of thermodynamics for the integral evaluation

Different performance indicators can be used for the evaluation of the cogeneration plant. Among them are the *Energy utilization factor (EUF), Fuel energy economy rate* (FEER) and the *Exergy efficiency* Horlock (1987) and Lora *et al*. (2008). The EUF indicator leads to a "confused result" because the electricity and the thermal energy have different qualities, and this indicator doesn´t consider this difference. Lora *et al*. (2006) proposed the Energy productivity function for compared different cogeneration plant schemes of a factory producing sugar and ethanol. Escobar *et al*. (2008) used the specific index of gross electricity generation and the specific index of surplus electricity generation among other for the evaluation of different distillery plants operating with steam parameter in the range of 2 up to 10 MPa

The indicators proposed for the comparison of the analyzed scenarios presented in the Tab. 1 are de specific index of surplus electricity generation per ton of cane crushed and the global exergetic efficiency.

Global exergetic efficiency: this indicator is obtained by dividing the sum of the exergy of the hydrated and anhydrous ethanol and the surplus electricity, by the exergy contained in the sugarcane (Eq. 1).

$$\eta_g = \frac{E_{HE} + E_{AE} + E_{el.ex}}{E_c} \tag{1}$$

Where:
E_{HE} = Exergy content of hydrated ethanol (kW)
E_{AE}= Exergy content of Anhydrous ethanol (kW)
$E_{el.ex}$= Surplus of electricity (kW)
Ec = Sugarcane exergy (kW)

The sugarcane exergy content is calculated by the Eq. 2

$$E_C = E_B + E_{B:C} \tag{2}$$

Where:

E_B = Bagasse exergy content (kW)
$E_{B:C}$ = Sugarcane juice exergy content (kW)

Similarly to energy content of sugarcane, the exergy content is essentially comprised in the bagasse, juice and crop residues (straw). Therefore it is important making a distinction between "clean cane", which is that the cane that is traditionally transported from field and processed in a mill into juice and bagasse, and "whole cane" that includes crop residues. This study was conducted considering the definition of "*clean cane*".

3. CASES OF STUDY

Table 1 presents all the technological alternatives considered for each scenario, named C1, C2, C3, C4 and C5.

Table 1. Considered scenarios

Equipments and parameters	**C1**	**C2**	**C3**	**C4**	**C5**
Boiler: 6.5 MPa (abs) @ 490°C	X	X	X	X	X
Electric Generators					
CEST Condensing/Extraction	X	X	X	X	X
Mill					
Simple stage turbine (ST)	X				
Multiple stage turbine (MST)		X			
Electric Motors (M)			X		
Diffuser – Multiple Stage turbine (DMST)				X	
Diffuser – Electrical drives (DE)					X
Evaporation					
Falling films (FF)	X	X	X	X	X
Distillation					
Atmospheric (DA)	X	X	X	X	X
Multipressure (DM)	X	X	X	X	X
Dehydration					
Cyclohexane (CH)	X	X	X	X	X
Molecular sieves (MS)	X	X	X	X	X

The scenario C1 will be considered the reference (base case) for the evaluation of efficiency increase in the whole plant, for the schematic modifications proposed in the scenarios C2-C5

The methodology presented in the Fig. 1 was utilized in the evaluation of all the scenarios.

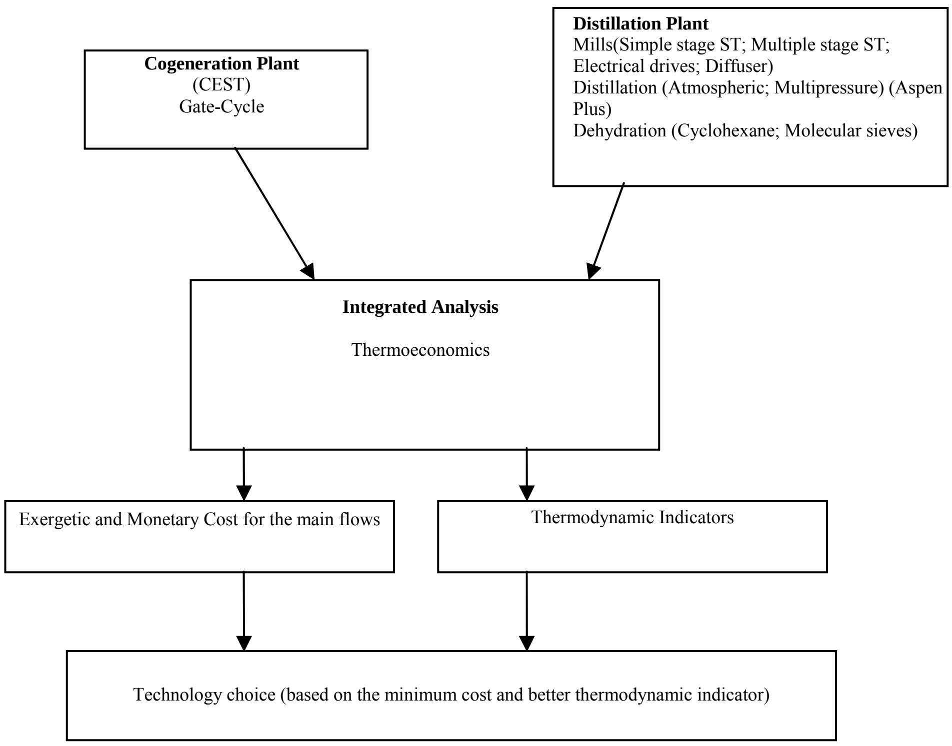

Figure 1. Flowchart for the technology selection

PLANT DESCRIPTION

Figure 2 represents the physical structure of the autonomous distillery with all the subsystems, which consists of a condensing/extraction steam turbine (CEST) cogeneration plant coupled to a distillation system. Mills are driven by simple stage steam turbines, the evaporation system is a four effects one, and the plant also has continuous fermentation, atmospheric distillation and dehydration system based on cyclohexane. The steam is generated in two boilers (B1and B2) at steam parameters of 490 °C and 6.5 MPa.

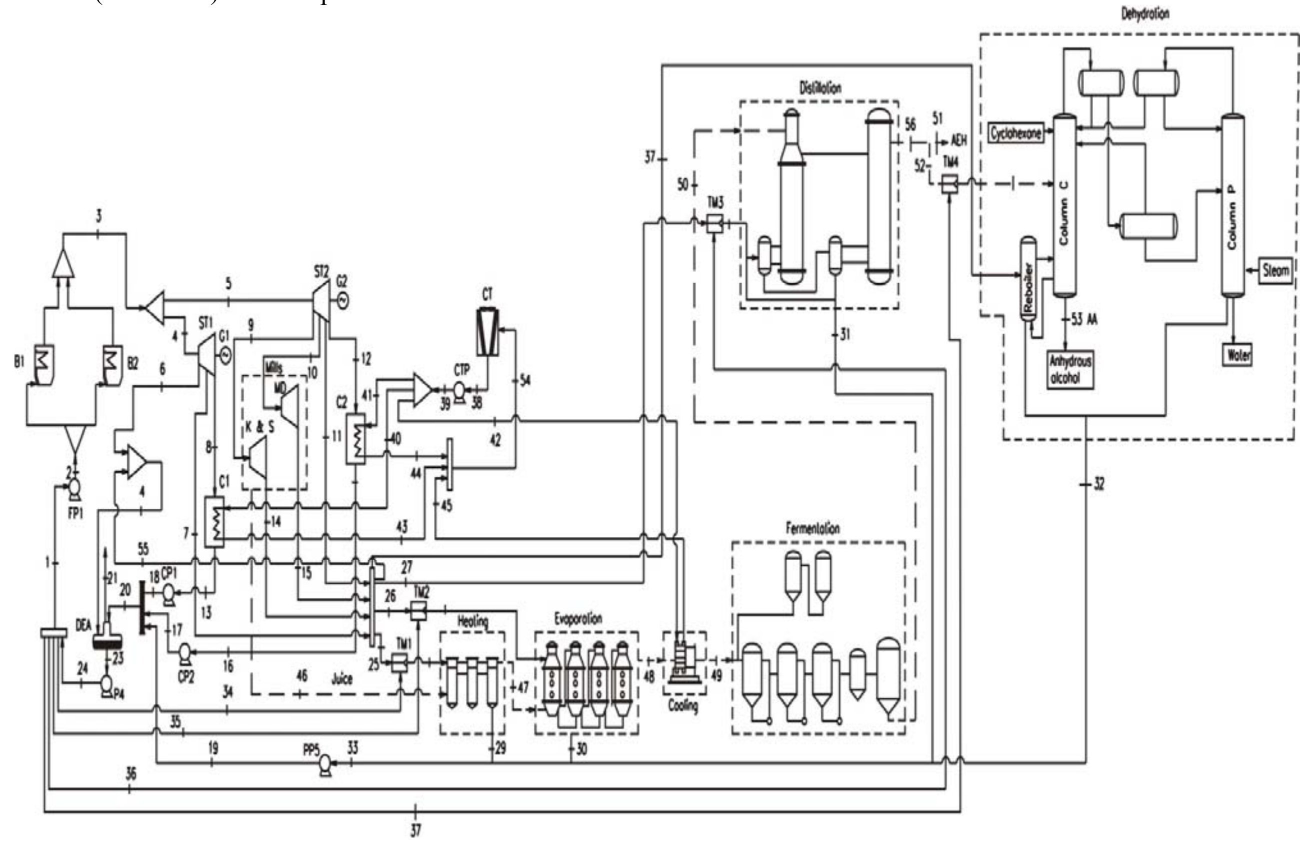

Figure 2. Physical structure for the scenarios C1 and C2

Aiming at establishing a common reference scenario for the study cases of Tab. 1, their evaluation was accomplished considering constant the parameters described in Tab. 2

Table 2. Main parameters considered in the cogeneration plant

Production and energy data for Cogeneration and Mill Systems	**Scenario C1**	**Scenario C2**	**Scenario C3**	**Scenario C4**	**Scenario C5**
Cane milling capacity [tc/h]	380	380	380	380	380
Cane harvest duration [d]	185	185	185	185	185
Steam production [ton/h]	250	250	250	250	250
LHV of bagasse[kJ/kg]	7562	7562	7562	7562	7562
Bagasse moisture [%]	50	50	50	50	50
Condensation pressure CEST 1 [kPa]	10-20	10-20	10-20	10-20	10-20
Condensation pressure CEST 2 [kPa]	12	12	12	12	12
Boiler efficiency [%]	88	88	88	88	88
Boiler feed water temperature [°C]	103	103	103	103	103
Cane milling system					
Inlet steam pressure [kPa abs]	2200	2200	---	2200	---
Inlet steam temperature[ºC]	320-315	320-315	---	320-315	---
Exhaust steam pressure [kPa abs]	170	170	---	170	---
Mechanical energy demanded [kW]	7045	7045	7626	3119	3374
Isentropic efficiency [%] /Motor efficiency [%]	40	78	95	78	95

Others commons characteristic are:

- Hydrated ethanol production capacity: 365 m^3/d.
- Anhydrous ethanol production capacity: 364 m^3/d.

Considering the first and second law indicators described previously, Fig. 3 presents, for each considered scenario, the specific index of surplus electricity generation as a function of the plant specific steam consumption.

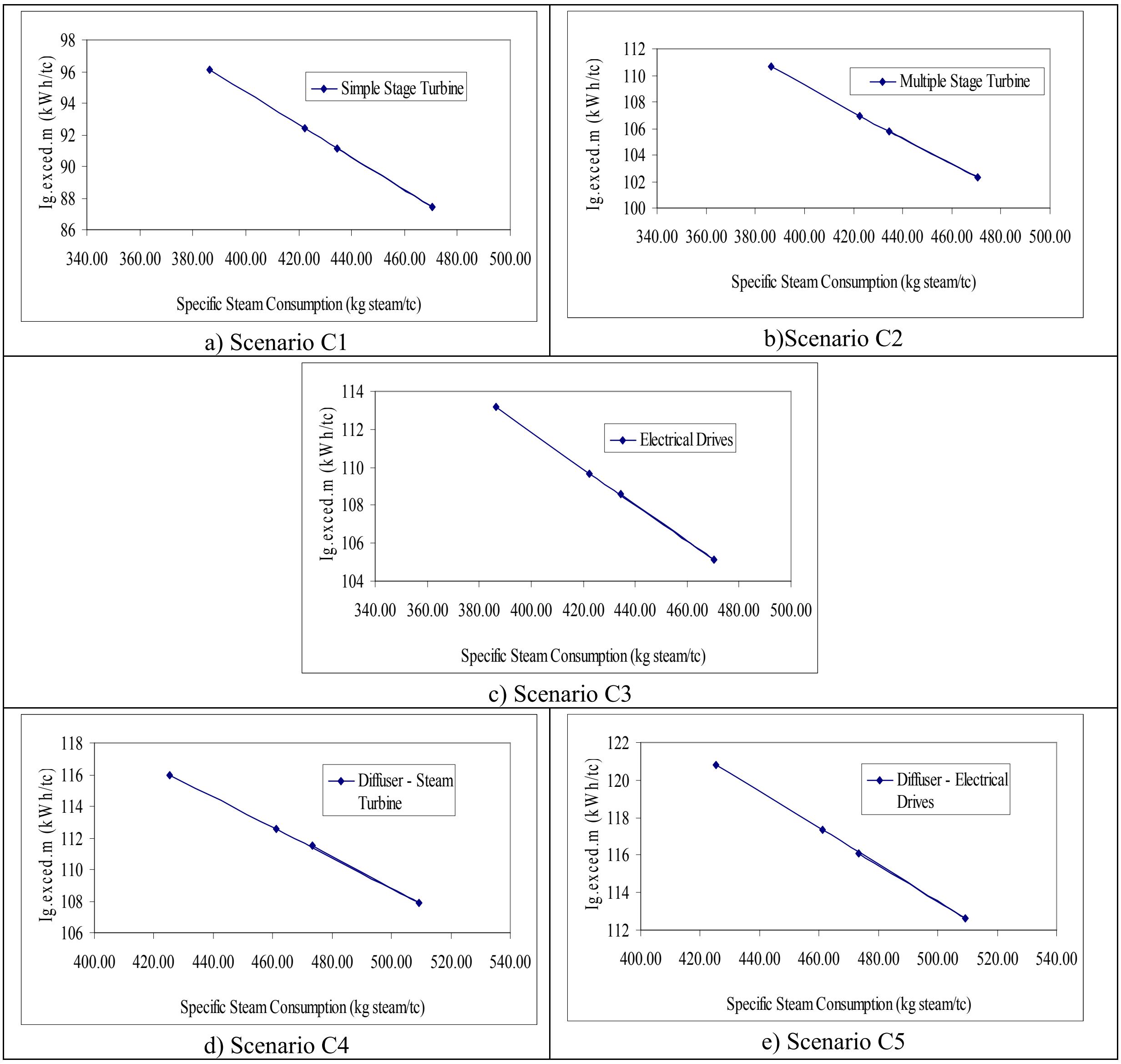

Figure 3. Index of surplus electricity per ton of crushed cane for the evaluated scenarios (C1-C5)

Figure 3 shows that the specific index of surplus electricity generation for the whole plant depends of mill technology selection for sugarcane preparation and juice extraction, as well as, of the technology choice in the distillation and dehydration stages.

On the other hand, the Tab. 3 shows the global exergetic efficiencies obtained for each scenario. The combined analysis of Fig. 3 and Tab 3, allows realizing the following comments:

The implementation of multiple stages steam turbines for the sugarcane preparation and juice extraction to replace simple stage turbines in the mills (Scenario C2 – MST- DA - CH) leads an increase of 17 % in the available electric power for export. This represents an increase of 2.5 % in the global exergetic efficiency of the plant. This is a consequence of the steam consumption reduction in the mills that allows to expand more steam in the main turbines and consequently to generate more electricity. For the same scenario increases of 26.6 % and 3.9 % are obtained in the electricity surplus for export and global exergetic efficiency respectively, when the distillation and dehydration technologies are changed simultaneously

Table 3. Global exergetic efficiencies for the evaluated scenarios (In Percentage)

Scenario	**C1**	**C2**	**C3**	**C4**	**C5**
DA-CH	37.39	38.33	38.50	38.68	38.98
DA-MS	37.62	38.55	38.74	38.90	39.20
DM-CH	37.70	38.62	38.79	38.97	39.28
DM-MS	37.93	38.85	39.01	39.19	39.49

For the scenario C3, the implementation of electrification in the cane preparation and juice extraction stages replacing the simple stage turbines together with a change in the distillation technology (Scenario C3-DM-CH) leads to an increase of 25.5 % in the available electric power for export, that represent an increase of 3.7 % in the global exergetic efficiency of the plant. When the distillation and dehydration technologies are changed simultaneously increases of 29.5 % and 4.3 % are obtained in the electricity surplus for export and global exergetic efficiency of the plant, respectively.

The implementation of diffuser technology allows to eliminate three tandems in the scenarios (C4 and C5) because the juice extraction is realized by lixiviation, and therefore mechanical drivers are only necessary for cane preparation and bagasse humidity control before it combustion in the boilers. In this sense (scenarios C4 and C5 - DA-CH) leads and increase of 23.48% and 28.9 % of the available electric power for export in the plant. When only the dehydration or distillation technology are changed (scenarios C4, C5 - DA-MS and C4, C5-DM-CH) the increases are 27.5 %, 32.9 % and 28.8 %, 34.3%, respectively.

4. THERMOECONOMIC MODELING

The thermoeconomic model is a set of cost equations describing all the process of cost formation in the plant, it describes the distribution of the resources in the plant through the components to obtain the final products. To obtain the set of equations, this paper considers the mathematical formalism used by Santos *et al*., (2006) and Frangopoulos (1994).

Figure 4 represents the productive structure of the plant, which graphically depicts its cost formation process. The external resource is the sugarcane (C) and the main products are the electrical net power (PNP), hydrated (AEH) and Anhydrous Ethanol (AA) volumetric flows.

The rectangles in Figure 4 are the actual productive units that represent the plant components. The rhombuses and the circles are fictitious productive units called junctions and bifurcation, respectively. The inlet and outlet arrows are productive unit fuels (or resources) and products, respectively. When a productive unit has more than one type of fuel it necessarily incorporates a small junction (e.g., F, D+TM3). The productive flows are all exergy flows representing: electrical power (P), mechanical power (W) or exergy of sugarcane (C), bagasse (B), juice (B:C) and water/steam ($E_{j:k}$ and $E_{j:k'}$). The exergy variation flows are defined based on physical flows, as Equation 3a and Equation 3b shows:

$$E_{j:k} = m_j.[(h_j - h_k) - T_0.(s_j - s_k)] \tag{3a}$$

$$E_{j:k'} = m_k.[(h_j - h_k) - T_0.(s_j - s_k)] \tag{3b}$$

The sugarcane juice exergy was calculated considering a methodology proposed by Nebra and Fernández (2005) and fermented wine, hydrated and anhydrous ethanol exergies were calculated considered the methodology proposed by Modesto et al. (2005). The mathematical model used for fuel exergy allocation is obtained by formulating the cost equation balance in all the actual and fictitious productive units, as shows in Equation (4), where *c* is the exergetic unit cost of each productive flow (unknown variable) and *Y* generically represents each respective productive flow, which can be, electrical or mechanical power (*P, W*), sugarcane exergy (*Ec*) or water, steam and juice exergy ($E_{j:k}$ and $E_{j:k'}$). Equation 5, allows calculate the monetary unit cost of the internal flows and final products, the term Z represents the cost of the equipments due to their capital, operation and maintenance.

$$\sum c.Y = 0 \tag{4}$$

$$\sum c.Y = Z \tag{5}$$

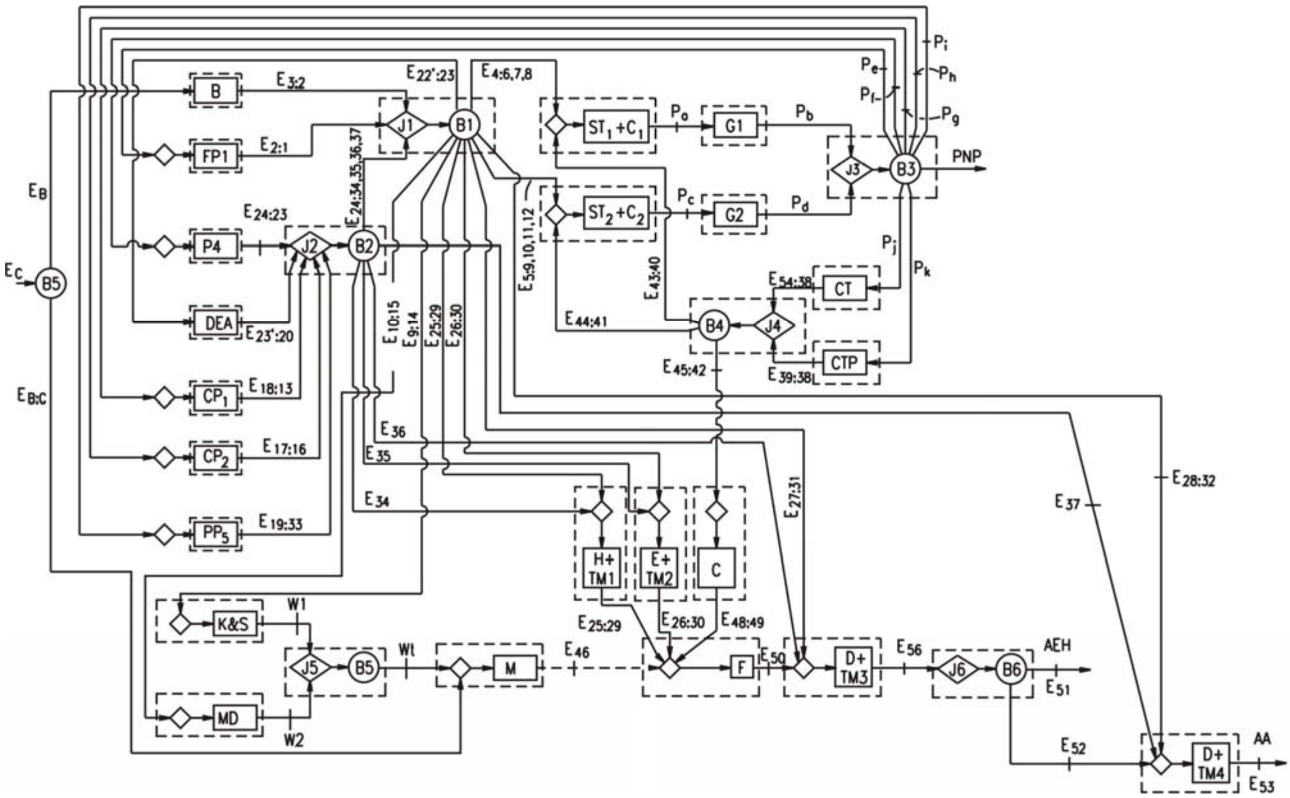

Figure 4. Productive structure for the scenarios C1 and C2

In the formulation of the cost equation balance, the inlet flows are considered negative (-) and the outlet flows are considered positive (+). The number of productive flows is greater than the number of productive units, and consequently, the number of unknown variables (exergetic unit cost) is greater than the number of equation. Therefore, it is necessary to establish auxiliary cost equations that attribute the same exergetic unit cost to all of the productive flows leaving the same bifurcations (equality equations). The Tab. 4 shows the mathematical model for the scenarios C1 and C2.

Table 4. Thermoeconomic model for the scenarios C1 and C2

Name	Productive Unit	Physical Unit	Equation
Bifurcation	B5	----	$c_B.E_B + c_{B:C}.E_{B:C} - c_c.E_c = C_c$ (6)
Boilers	B	B1, B2	$c_{3:2}.E_{3:2} - c_B.E_B = \dot{Z}_B$ (7)
Feed pumps	FP1	FP1	$c_{2:1}.E_{2:1} - c_P.E_{Pe} = \dot{Z}_{FP1}$ (8)
Deaerator pump	P4	P4	$c_{24:23}.E_{24:23} - c_P.E_{Pf} = \dot{Z}_{P4}$ (9)
Deaerator	DEA	DEA	$c_{23':20}.E_{23':20} - c_{22':23}.E_{22':23} = \dot{Z}_{DEA}$ (10)
Condenser pump	CP2	CP2	$c_{18:13}.E_{18:13} - c_P.E_{Pg} = \dot{Z}_{CP2}$ (11)
Condenser pump	CP3	CP3	$c_{17:16}.E_{17:16} - c_P.E_{Ph} = \dot{Z}_{CP3}$ (12)
Process pump	PP5	PP	$c_{19:33}.E_{19:33} - c_P.E_{Pi} = \dot{Z}_{PP5}$ (13)
Junction + Bifurcation	J1-B1	----	$c_{10:15}.E_{10:15} + c_{9:14}.E_{9:14} + c_{25:29}.E_{25:29} + c_{26:30}.E_{26:30} + c_{27:21}.E_{27:31} +$ $c_{5:9,10,11,12}.E_{5:9,10,11,12} + c_{4:6,7,8}.E_{4:6,7,8} + c_{22':23}.E_{22':23} -$ $c_{3:2}.E_{3:2} - c_{2:1}.E_{2:1} - c_{24:34,35,36,37}.E_{24:34,35,36,37} = 0$ (14)
Junction +	J2-B2	----	$c_{34}.E_{34} + c_{35}.E_{35} + c_{36}.E_{36} + c_{37}.E_{37} - c_{24:23}.E_{24:23} - c_{23':20}.E_{23':20} -$

Bifurcation			$c_{18:13}.E_{18:13} - c_{17:16}.E_{17:16} - c_{19:33}.E_{19:33} = 0$ (15)
knives and shredders	K & S	K & S	$c_{W1}.E_{W1} - c_{9:14}.E_{9:14} = \dot{Z}_{P+D}$ (16)
Mill drivers	MD	MD	$c_{W2}.E_{W2} - c_{10:15}.E_{10:15} = \dot{Z}_{Mills}$ (17)
Mills	M	P+D and MD	$c_{56}.E_{56} - c_{B:C}.E_{B:C} - c_{Wt}.E_{Wt} = 0$ (18)
Junction + Bifurcation	J4-B4	----	$c_{43:40}.E_{43:40} + c_{44:41}.E_{44:41} + c_{45:42}.E_{45:42} - c_{54:38}.E_{54:38} - c_{39:38}.E_{39:38} = 0$ (19)
Cooling tower	CT	CT	$c_{54:38}.E_{54:38} - c_P.E_{Pj} = \dot{Z}_{CT}$ (20)
Cooling tower pump	CTP	CTP	$c_{39:38}.E_{39:38} - c_P.E_{Pk} = \dot{Z}_{CTP}$ (21)
Steam turbine 1 and condenser 1	ST1+C1	ST1+C1	$c_{Pa}.E_{Pa} - c_{4:6,7,8}.E_{4:6,7,8} - c_{43:40}.E_{43:40} = Z_{ST_1+C_1}$ (22)
Steam turbine 2 and condenser 2	ST2+C2	ST2+C2	$c_{Pc}.E_{Pc} - c_{5:9,10,11,12}.E_{5:9,10,11,12} - c_{44:41}.E_{44:10} = Z_{ST_2+C_2}$ (23)
Electric generator 1	G1	G1	$c_{Pb}.E_{Pb} - c_{Pa}.E_{Pa} = \dot{Z}_{G1}$ (24)
Electric generator 2	G2	G2	$c_{Pd}.E_{Pd} - c_{Pc}.E_{Pc} = \dot{Z}_{G2}$ (25)
Heating and Temp. control 1	H+TM1	H+TM1	$c_{25:29}.E_{25:29} - c_{34}.E_{34} - c_{25:29}.E_{25:29} = \dot{Z}_{H+TM1}$ (26)
Evaporation and Temp. control 2	E+TM2	E+TM2	$c_{26:30}.E_{26:30} - c_{35}.E_{35} - c_{26:30}.E_{26:30} = \dot{Z}_{E+TM2}$ (27)
Cooling	C	C	$c_{48:49}.E_{48:49} - c_{45:42}.E_{45:42} = \dot{Z}_C$ (28)
Fermentation	F	F	$c_{50}.E_{50} - c_{56}.E_{56} - c_{25:29}.E_{25:29} - c_{26:30}.E_{26:30} - c_{48:49}.E_{48:49} = \dot{Z}_F$ (29)
Distillation and Temp. control 3	D+TM3	D+TM3	$c_{56}.E_{56} - c_{36}.E_{36} - c_{27:31}.E_{27:31} = \dot{Z}_{D+TM3}$ (30)
Junction + Bifurcation	J5-B5	----	$c_{Wt}.E_{Wt} - c_{W1}.E_{W1} - c_{W2}.E_{W2} = 0$ (31)
Junction + Bifurcation	J3-B3	----	$c_P.(E_{Pe} + E_{Pf} + E_{Pg} + E_{Ph} + E_{Pi} + E_{Pj} + E_{Pk}) - c_{Pb}.E_{Pb} - c_{Pc}.E_{Pc} = 0$ (32)
Junction + Bifurcation	J6-B6	----	$c_{51}.E_{51(AEH)} - c_{52}.E_{52} = 0$ (33)
Dedrydration and Temp. control 4	D+TM4	D+TM4	$c_{53(AA)}.E_{53(AA)} - c_{52}.E_{52} - c_{37}.E_{37} - c_{28:32}.E_{28:32} = \dot{Z}_{D+TM4}$ (34)

The solution of the set of cost equations (the mathematical model) presented in Tab. 4 furnishes the monetary unit cost of each productive flow and final products. In order to calculate the exergetic unit cost it is necessary to neglect the cost of the equipments (Z) and consider the exergetic unit cost of sugarcane equal to one.

Figure 5 show the exergetic unit cost for thermal, electricity and mechanical energy considering the five different technologies analyzed (simple and multiple stage steam turbine, electrical drivers and diffuser combined with multiple stage steam turbine or electrical drives). Similarly Fig 6, shows the exergetic unit cost for hydrated and anhydrous ethanol.

The Figure 5 shows the same exergetic cost for the generated steam, because the boilers are the same for all the evaluated scenarios and therefore their value is equal to 3.57 kW/kW. It also shows that the exergetic cost for the generated electricity is almost equal for all the scenarios. This is a consequence of considering the steam turbine and the condenser as a one real unit in the productive structure with the same condensing pressure for all the scenarios (12 kPa). As a consequence the electricity exergetic costs are 4.20, 4.20, 4.21, 4.16, and 4.17 (kW/kW). Finally, it is possible to obtain a reduction of 36.1 % in the mechanical energy produced in the mills by the substitution of simple stage steam turbine by a multiple stage one. Reductions of 43.9 % are obtained by the implementation of electrical drives. However, as the two variants considered in the diffuser system are based in multiple stage steam turbine and electrical drives their exergetic cost are equal in the scenarios C2-C4 and C3-C5.

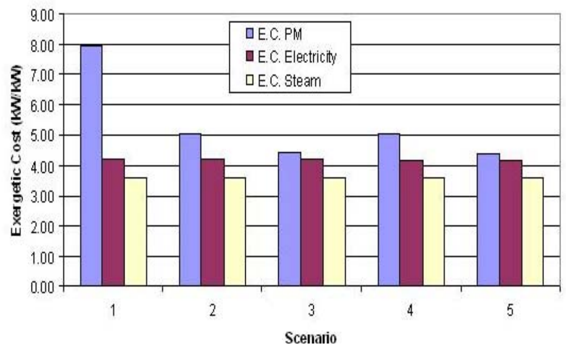

Figure 5. Exergetic unit cost for the main products of cogeneration plant and mills

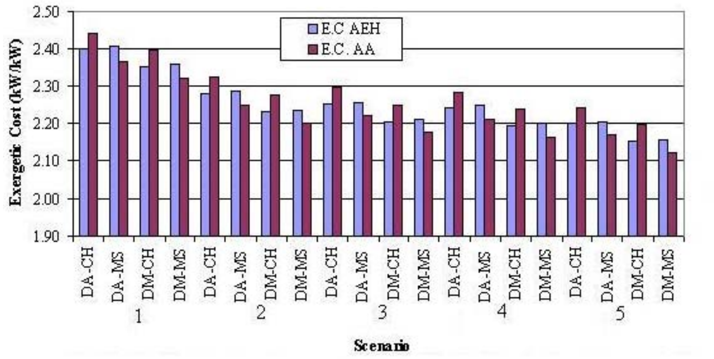

Figure 6. Exergetic unit cost for the main products for the different distillation plant schemes considered

The lowest exergetic cost for hydrated and anhydrous ethanol is obtained when is introduced in the mills a diffuser system based on electrical drives together with a multipressure distillation for hydrated ethanol production and molecular sieves for dehydration (C5-DM-MS). The introduction of a multipressure distillation , instead of, atmospheric distillation reduce the exergetic cost of hydrated ethanol in 2.20 % and the introduction of molecular sieves, instead of, cyclohexane dehydration allows reduce in 3.63 % the exergetic cost of anhydrous ethanol. To complement the analysis, Fig 7 and Fig 8 show the monetary unit costs obtained for the electricity, mechanical power, process heat, hydrated and anhydrous ethanol. An annual interest rate of 15% and an amortization period of 10 years were considered.

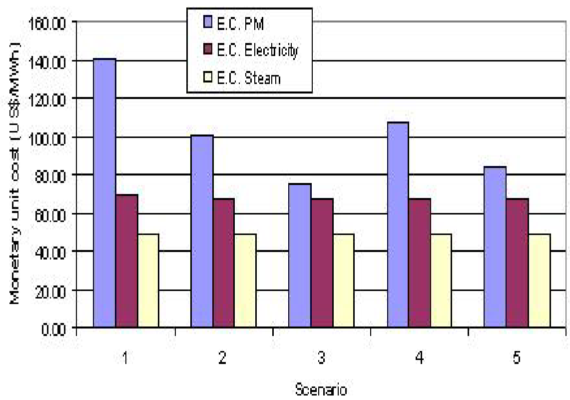

Figure 7. Monetary unit cost for thermal, electricity and mechanical energy for the evaluated scenarios

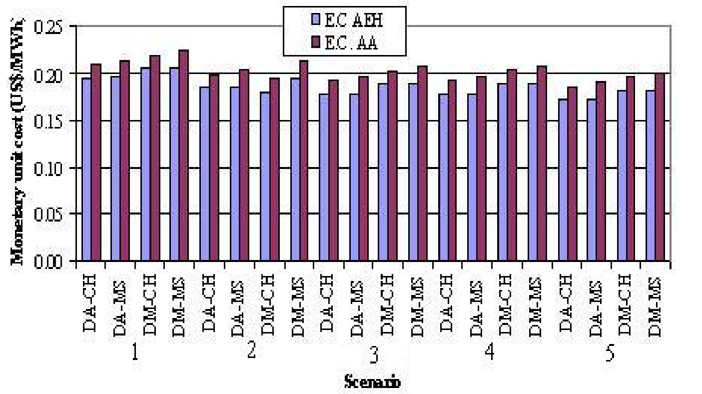

Figure 8. Monetary unit cost for hydrated and anhydrous ethanol

For all the evaluated scenarios the thermal energy cost was 49.18 US$/MWh. The electricity cost has a low decrease (≈0.4 %) for the scenarios C3 and C5 in relation to the scenarios C1, C2 and C3. As a consequence of the high quantity of exergy destroyed in the simple stage steam turbines for the mills, the scenario C1 present the most expensive cost of mechanical energy with a value of 141.56 US$/MWh. It was obtained a reduction of 28.34 % and 46.60 % of this cost by the implementation of multiple stages turbines (scenario C2) and mechanical drives (scenario C3). When the diffuser system is considered (scenarios C4 and C5) the cost of mechanical energy increase in 6.00 % and 12.15 % with relation to scenarios C2 and C3, this is a consequence of the higher cost of this technological alternative in comparison with the traditional mills.

Finally, the monetary costs of hydrated and anhydrous ethanol are mainly influenced by the technology choice in the mills, distillation and dehydration system. The change of an atmospheric distillation system by a multipressure one leads an increase of 6.13 % in the monetary cost of hydrated ethanol. On the other hand, when the dehydration system uses a molecular sieve technology, instead of, cyclohexane system, the increase in the cost of anhydrous ethanol is 7.95 %. Therefore, it is possible to show that the technology that allows to obtain a lower exergetic cost for hydrated and anhydrous ethanol not always represent the lowest monetary cost.

5. CONCLUSIONS

As a result from thermoeconomic analysis, the alternatives for autonomous distillery modernization and overall plant performance increasing should be considered in the following sequence:

1. The substitution of the actual mill drive system based on simple stage turbines by a diffuser system based on electrical drives or as a second alternative, considers only the implementation of electrical drives in the mill.
2. The implementation of multipressure and molecular sieves systems leads and increase of 6.13 % and 7.93 % in the cost of hydrated and anhydrous ethanol. So, it is possible to maintain the actual systems of atmospheric distillation and cyclohexane dehydration, but the quantity of exported electric power will be 7.18% smaller.
3. If the plant goal is to obtain an additional increase in the electricity surplus the distillation system must be changed before the dehydration for the reason that it has a higher steam consumption.
4. Finally if economics aspects are not a limit in the plant modernization, the dehydration system must be changed simultaneously with the distillation system.

Therefore, the first considered change in the plant must be the scenarios C5 DM-CH, or C3 DM-CH. Others alternatives when economics barriers are not a problem are the scenarios C5 DM-MS or C3 DM-MS. Or it is also possible, as a third alternative, to consider the scenarios C5 DA-CH or C3 DA-CH.

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8. RESPONSIBILITY NOTICE