Proceedings of the 11th Brazilian Congress of Thermal Sciences and Engineering -- ENCIT 2006
Braz. Soc. of Mechanical Sciences and Engineering -- ABCM, Curitiba, Brazil, Dec. 5-8, 2006

Paper CIT06-0661

ETHANOL PRODUCTION FROM SUGAR CANE: ASSESS OF POSSILITIES OF DECREASE OF THERMAL ENERGY CONSUMPTION THROUGH EXERGETIC COST ANALYSIS

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ABSTRACT: The sugar and ethanol production is one of the most important economical activities in Brazil, mainly due its high efficiency and competitiveness. The ethanol production is done by several steps: juice extraction, treatment, fermentation and distillation. The juice extraction and treatment is a common operation of both industries sugar and alcohol. The process begins with the sugar cane juice extraction, usually done by devices namely mills, where the cane is compressed between big cylinders for the separation of the juice from the bagasse. Recently, another juice extraction system named diffuser was introduced in some sugar and alcohol factories. On diffusers, after sugar cane preparation stage, done with knives and shredders, it passes through a bed, where the juice is separated from bagasse by the addition of imbibition water and steam, in a lixiviation process. This study evaluates two possibilities of decrease the thermal energy consumption through exergetic cost analysis. The first case, a traditional ethanol production plant is assessed, determining the unitary exergetic cost of ethanol and electrical energy, in the following case, second and third, two proposals were assessed: use of the diffuser as a extraction system and use of pinch technology to perform a energetic integration between distillation and extraction (diffuser) systems. The results of exergetic efficiency, irreversibility generation and unitary exergetic cost of products of the three cases are analyzed and compared. The results shows the validate of the use of diffuser and pinch technology on the decrease of the thermal energy consumption in the ethanol production plant.

Keywords: sugar cane juice, extraction system, exergetic cost analysis

NOMENCLATURE

$\dot{m}$: mass flow	[kg/s]
Brix: proportion of solids in juice cane	[%]
e: exergy	[kJ/kg]
E: total exergy	[kW]
h: enthalpy	[kJ/kg]
I: irreversibility	[kW]
k: unitary exergetic cost	
LHW: Lower Heating Value	[kJ/kg]
Q: heat rate	[kW]
s: entropy	[kJ/kg-K]
tc: ton of cane	[ton]
W: work	[kW]
x: percentage of fibre	[%]

Greek Letters

η : efficiency

Subscripts

ch: chemical
DT: direct turbine
in: inlet
o: reference
out: outlet
st: steam turbine

1. INTRODUCTION

The sugar cane plants are constituted by three basic arrangements. There are that produce exclusively sugar or ethanol and those that produce sugar and ethanol simultaneously. For all of them, the industrial process begins with the preparation of the cane and the extraction of the juice, which will be used in the sequence as the principal raw material of the final product.

The preparation systems consist of feed tables for wholestick cane discharge, carrier rollers, leveller knives, set of knives and shredder. Heavy duty knives can be necessary, depending on the kind of extraction system. The extraction systems usually adopted in sugar cane plants are milling and/or diffuser. The first one is largely used in Brazilian sugar cane sector, being a technology well known by the factory operators. Its principle is the use of mechanical work of the mills to extract the juice by compression. Mills are generally connected to drive turbines that consume medium pressure vapour (20 bar) as driving force.

The diffuser is another option for juice extraction and has been rarely used in Brazil. The first plant that installed this device was Galo Bravo in Ribeirão Preto (São Paulo State) in 1985. Some problems with the new technology were detected at that period and the diffusers were not adopted by many other plants in spite of their advantages. The condition of the bagasse in the output of the diffuser was a serious problem, presenting impurities and high moisture levels, being difficult its combustion into the boilers. This problem occurred due the fact that those equipments were imported and projected for beet sugar factories [1].

The principle of the diffuser is the application of imbibition water in the cane for the extraction of the juice through a lixiviation process. The water and the juice re-circulated in the equipment are heated with low pressure steam (2 bar or lower). There are also dewatering mills at the exit that are used as pre-dryers, reducing the moisture of the bagasse to 50% approximately and extracting the remaining juice for re-circulation. Today, there are only 10 diffusers installed in 324 Brazilian sugar cane plants in operation [1]. The problems in the past inhibited the application of these pieces of equipment but new experiences showed they present many advantages when compared with milling.

Firstly the extraction efficiency of the diffuser is 2 to 3% higher than the milling, reaching 99% in the nominal load, when the milling maximum possible efficiency is 97% [2]. This high efficiency level in the diffuser can be obtained only with the adequate preparation of the cane, being necessary heavy duty knives reaching open cells values between 90 and 92% [1].

Moreover the maintenance costs with a diffuser are 70% lower than milling and the operation can be done with 3 operators, while milling needs 8 or 9 of them [2]. Comparing milling and diffuser systems, it was observed that sand and dust in cane can seriously reduce percolation rates and extraction performance in a diffuser, what would be avoided with a correct cane preparation and storage [3]. The low values of suspended solids in mixed juice from the diffuser were considered satisfactory in a South African sugar plant that installed the equipment in 1994. The combination of diffuser and the sand and stones removal system installed in that factory contributed for that result. The equipment removed stones, gravels and sand with a variable-speed spiked roller that picked up cane from the feeder table before discharge into the main cane carrier [4].

The energy consumption of both extraction systems shows some important differences that influences the sugar cane plant energy balance. Mills require medium pressure steam into drive turbines for all the equipments, while diffuser uses low pressure steam for imbibition water heating that can be obtained with vapour bleed from first and/or second effects of evaporation station of the sugar production process, or from turbine extractions at low pressure in an ethanol production process.

Comparison of the energy consumption between milling and diffusers has been done by some authors [3], [5] and [6]. The change of traditional milling systems by diffusers should increase 3 to 6% the sugar production at very reasonable cost [5].

2. DESCRIPTION OF THE SYSTEM

In order to compare the performance between mills and diffusers, a simple cogeneration system has been proposed and simulated. The system uses cane bagasse as fuel and produces electricity and steam to process. The cogeneration and juice extraction systems are shown in figure 1.

The set is composed by a boiler, a steam turbine, a deaerator, a juice extraction system (mill or diffuser), two pumps, fermentation plant, heat exchanges that heats the wine (ethanol water mixtures) from fermentation plant to finally distillation system. The thermodynamic data of this system are shown in Table A1 in Appendix A. The sugar cane is introduced in the extraction system, flow (13); with the imbibition water, flow (14); the bagasse produced, flow (15), in the juice extraction system is used as fuel in the boiler (I) and the juice, flow (16), is available to be used in the sugar or ethanol production. In the cogeneration system, the bagasse produced in the juice extraction system is used in the boiler as fuel, producing steam with temperature of 480°C and a pressure of 80 bar. The steam from boiler is expanded in a steam turbine with extractions at a pressure of 22 bar, the steam is used to generate mechanical energy for extraction systems and at of 2,5 bar it is used to deaerator and extraction system (in the case of use of diffuser). The flows [4] and [12] supply the thermal demand of heater of imbibition water and wine and the distillation system. The all flows condensed are joined and returned to the cogeneration system by the flow [6], pressurized in the electric pump 1 (VII), passed through the deaerator (VI), are pressurized in the electric pump 2 (V) and go back to the boiler, closing the cycle.

In this simulation the following hypothesis are assumed:

The cane mass flow was calculated as the sum of bagasse and juice flow as shown in Eq. (1):

$$\dot{m}_{cane} = (1-x)\,\dot{m}_{juice} + (x)\,\dot{m}_{bagasse} \qquad [1]$$

Where: "x" is a percentage of fibre in the cane, adopted as 14%, Stucci (2005).

The bagasse that leaves the extraction system was considered with 50% of moisture.

The juice enters in the extraction system with a Brix value of 18,5 % and leave with a value of 13,5 % and a purity of 83,5%.

The mass flow of imbibition water consumption per tc was estimated by [7], for the mill and [8] for the diffuser.

Mechanical work consumption adopted for the mill and the diffuser were obtained from [9], [8] and [10], respectively.

Three situations were simulated. In first case, the traditional ethanol production plant using mill as an extraction systems. In second case, the extraction system using mill is replaced by another system using a diffuser. And third and last case, the mechanical turbine is replaced by an electrical engineers and the technology pinch is used to integrated the hot flows of distillation system to heater the cold flows from extraction and fermentation system, decreasing the thermal consumption of the ethanol processes. The figure 1 shows the cases I and II, the figure 2 the case III and the Table 1 (showed in Appendix A), the thermodynamics data of three cases considered

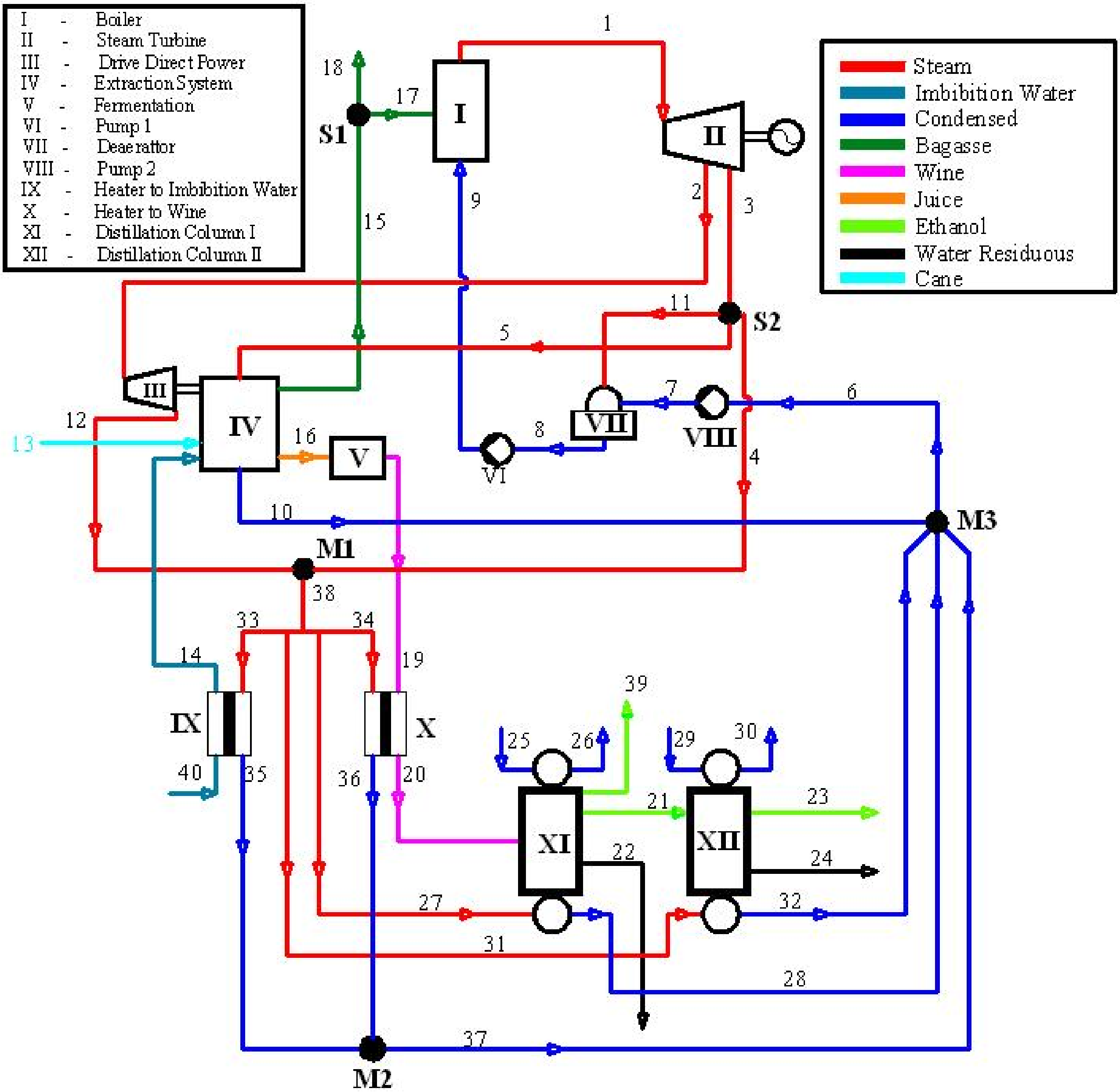

Figure 1 Sketch of Cogeneration, Extraction and Distillation Systems

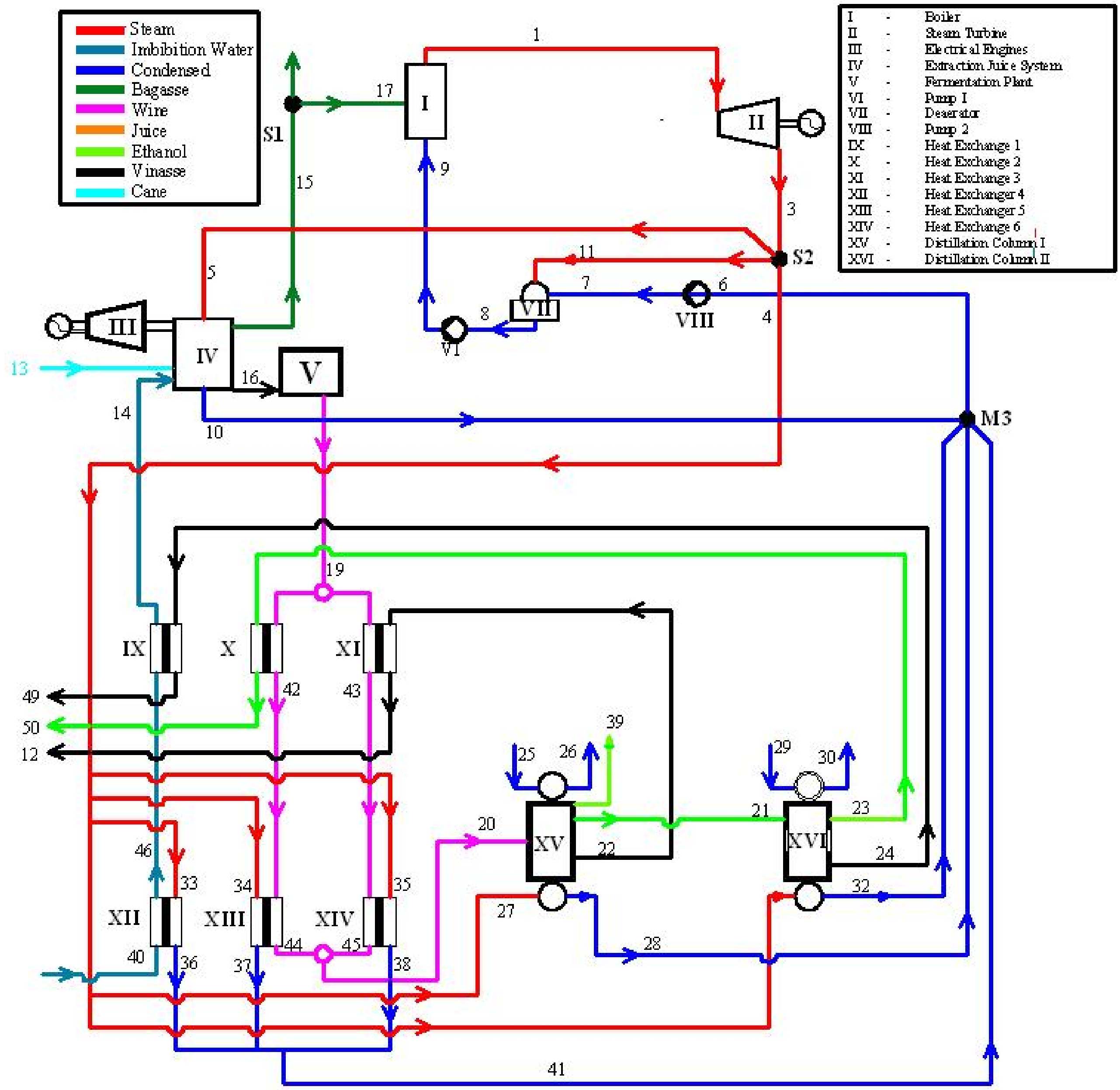

Figure 2 Sketch to cogeneration system integrated with extraction and distillation system through pinch technology

Table 2 Parameters adopted for extraction System

	I	II	III
Bagasse Fibre (%)	13		
Direct Drive Power (kWh/ tc)	20	10.85	
Consumption of Electric Energy (kWh/ tc)	14.83	14,15	
Imbibition water (kg/ tc)	235	360.8	
Juice Production (kg/ tc)	0.995	1.101	

3. THERMODYNAMIC ANALYSIS

The classic evaluation of thermal power plant performance is done through the energetic analysis based on the First Law of Thermodynamics. Such analysis permits, from an energetic point of view, a quantitative determination of the all plant performance and also of each one of its devices. Through the first law analysis it is not possible to determine the quality of energy used and where are located the points of exergy losses. In order to determine and quantify these exergy losses due to irreversibility's, the analysis by the Second Law of Thermodynamics must be used [11].

This type of analysis is essential when the system includes cogeneration. The Equations (2), (3) and (4) show mass, energy and exergy balance for a generic control volume, not considering the variation of kinetic and potential energy/exergy, respectively.

$$\sum \dot{m}_{in} - \sum \dot{m}_{out} = 0 \quad (2)$$

$$\dot{Q} - \dot{W} + \sum \dot{m}_{in} h_{in} - \sum \dot{m}_{out} h_{out} = 0 \quad (3)$$

$$\dot{Q}\left(1 - \frac{T}{T_o}\right) - \dot{W} + \sum \dot{m}_{in} e_{in} - \sum \dot{m}_{out} e_{out} = \dot{I} \quad (4)$$

The variable "e" represents the specific exergy of a flow and can be calculated with the following equations. For determination of steam and water exergies, the Equation 5 was used:

$$e = h_i - h_o - T_o(s_i - s_o) + e_{ch} \quad (5)$$

Where: hi = enthalpy of the flux at point “i”; h_o = enthalpy of reference; s_i= entropy of the flux at point “i” s_o = entropy of reference; e_{ch} = standard chemical exergy of water.

In order to determine the sugar cane bagasse exergy, a methodology proposed by [12] for wood was adopted, with the necessary changes in the composition of the fuel and its Low Heat Value (LHV). For bagasse at reference environment conditions, its total exergy is equal to its chemical exergy, being possible calculating it by the referred methodology. The following composition for the bagasse was assumed: 47% of Carbon, 6,5% of Hydrogen, 44% of Oxygen and 2,5% of Ash [13]. In flow (15) the bagasse was considered with 50% of humidity, to calculate the properties of flow (13), dried bagasse was considered following Equation [1].

The juice exergy was calculated following the methodology described in [14] and exergy of ethanol-water mixture, in [15]

3.1 First Law Analysis

In order to assess the juice extraction system, two simulations were performed using the EES® software, through the mass and energy balances in each component of the cogeneration, juice extraction and distillation systems. The energetic consumptions of the systems are shown in Table 3. Thus, it was possible to calculate the consumptions of the pumps, direct drive turbines and others. In order to do possible this simulation some values must be adopted, like as:

$\eta_{boiler} = 0.80$ Energetic efficiency of boiler
$\eta_{ST} = 0.812$ Isentropic efficiency of steam turbine
$\eta_{pumps} = 0.80$ Isentropic efficiency of pumps
$\eta_{DT} = 0.55$ Isentropic efficiency of drive turbines
$\eta_{ger} = 0{,}98$ Efficiency of electrical generator and electric engines

Table 3 Specific Energetic Consumptions

Power	**I**	**II**	**III**
Energy Generated (kWh/ tc)	29.48	64.25	66.08
Pumps (kWh/ tc)	1.06	1.85	1.21
Net Electrical Power (kWh/ tc)	24.30	47.83	48.36
Ethanol Production (liters/tc)	85.93	90.41	90.41
Cold Utilities (m^3/tc)	17.81	20.93	20.93
Thermal Energy (kWh/tc)	261.1	282,20	178.00
Available bagasse excess (%)	40.56	17.52	32.12

The hydrated ethanol production reaches 85.93litres/tc (Mills) and 90.41 litres/tc (Diffuser) consuming 261.1 kWh/tc (Mill), 282.20 kWh/tc (Diffuser) and 178 kWh/tc (Diffuser with energetic integration) this energy is supply from steam generated in the boiler through bagasse utilization as fuel. The surplus of electrical energy reaches 24.30 kWh/tc (Mill), 47.83 kWh/tc (Diffuser) and 48.36 kWh/tc (Diffuser with energetic integration) with cane bagasse surplus reaches 40.56% (Mill), 17.52% (Diffuser) and 32.12% (Diffuser with Energetic Integration).

The electrical energy surplus is directly proportional to the steam produced in the boiler. The greater steam consume in the diffuser system provides the possibility of increasing the electricity generated. But, the bagasse surplus decreases with the diffuser system. But, with an energetic integration using the pinch technology and the replacement of the mechanical turbine by electrical engines, the bagasse surplus reaches a value near of mill as an extraction system. The utilization of pinch technology to integrated the extraction and distillation system allows a decrease of thermal energy consumption of the 37%, thus, obtain a similar level of bagasse surplus.

Depending on the utilization of bagasse, it can be more advantageous the surplus increase to utilize the bagasse in another process (syngas production, ethanol production from hydrolysis of bagasse, or gasification). These other utilizations will be analyzed in futures studies.

The bagasse surplus is directly proportional to boiler efficiency. The increase of boiler First Law efficiency through the use of a bagasse dryer, the pre heating of air or feed water boiler, the increase of pressure and temperature of steam allows to increase bagasse surplus. Another possibility for increasing bagasse surplus is the utilization of cane varieties with more percentage of fibers.

For the same conditions, the juice extraction system based on diffuser has an electric net power generation 97% larger than the system based on mills. The direct drive power in mills is 84% larger than diffuser, the electrical consumption in pumps are similar. The energy consumption in the diffuser is 8.8% larger than mills; the bagasse excess in mills is 135% larger than in diffusers. But, with use of pinch technology, diffuser has energy consumption 31% lower than mill, with a bagasse surplus 20% lower.

In order to improve the diagnostic of the three cases considered, an exergetic analysis was performed for the determination of exergetic efficiency and irreversibility generated in both systems.

3.2 Second Law Analysis

The exergy equation balances (eq 4) was applied in each component of the plants to determine the irreversibility and efficiency of each control volume considered. In the special case of the extraction system the exergy balance equation is written for the diffuser (eq. 6) and the mill (eq 7) as follows:

$$\begin{aligned}&\dot{m}_{14}e_{14} + \dot{m}_{juice}e_{juice\_13} + \\ &\dot{m}_{bagasse}e_{bagasse\_13} + \dot{W}_{ele\_dif} + \\ &\dot{m}_5 e_5 - \dot{m}_{10}e_{10} - \dot{m}_{15}e_{15} - \dot{m}_{16}e_{16} = \dot{I}_{IV}\end{aligned} \tag{6}$$

$$\begin{aligned}&\dot{m}_{14}e_{14} + \dot{m}_{juice}e_{juice\_13} + \\ &\dot{m}_{bagasse}e_{bagasse\_13} + \dot{W}_{mill} \\ &-\dot{m}_{15}e_{15} - \dot{m}_{16}e_{16} = \dot{I}_{IV}\end{aligned} \tag{7}$$

Where:

W_{ele_dif} : electrical power consumption in the diffuser [kW]

W_{mill} : mechanical power consumption in the diffuser [kW].

The set of equations of exergy balance was solved using the EES® software, determining the irreversibility generated in each component of the system. The efficiency of each component was calculated according as suggested [11] and [12], considering Figure 1 and 2 and the exergetic efficiency of the global plant is written by:

$$\varepsilon = \frac{\dot{W}_{net} + \dot{m}_{23}e_{23} + \dot{m}_{18}e_{18}}{\dot{m}_{13}e_{13}} \tag{8}$$

The exergetic analysis is a powerful tool to assess several types of thermal systems. This analysis allows quantify and identify the components that most produce irreversibility in the system. The main difference between the two systems is the juice extraction device. The mill generates 96% more irreversibility than diffuser and has exergetic efficiency 6% lower. The juice extraction system is responsible by 13% (diffuser) and 30% (mill) of total irreversibility generated in the system. The cogeneration set and juice extraction system with diffuser produce 14% more irreversibility than the juice extraction with mill, this result is due mainly to the irreversibility generated in the boiler, because more steam quantity need to be produced with the use of diffuser (but, at the same time more cogeneration level is reached). The global efficiency of the plant using mill is larger than plant using diffuser. The eq (8) shows that the parameters which influence of this value are the net power and bagasse surplus. The influence of bagasse surplus is larger due of the high value of exergy of this, so, the system using mill has a greater efficiency mainly due the high surplus of bagasse for this system. However, the exergetic efficiency of the mill component is lower than diffuser in the extraction system. The value of global efficiency obtained with diffuser using energetic integration is similar when uses a mill as a extraction system. The values are shown in Table 4.

Table 4 Exergetic Efficiency and Irreversibility

	Exergetic Efficiency (%)			Irreversibility (kW)		
	I	II	III	I	II	III
I	27.87	27.91	27.87	1110.21	1533.64	1267.78
II	83.52	84.21	84.32	15.74	43.45	44.23
III	62.76	62.76	-	42.73	23.18	-
IV	88.02	93.67	93.81	672.81	345.20	346.63
VI	85.07	85.16	85.07	0.56	0.77	0.01
VII	99.96	99.96	99.96	0.07	0.11	0.08
VIII	84.91	84.91	84.91	0.01	0.02	0.64
IX	42.93	41.36	19.29	10.13	16.60	1.24
X	38.89	37.47	18.77	39.04	46.82	66.68
XI	93.42	93.39	80.50	258.4	289.16	9.94
XII	99.12	97.80	52.00	81.90	263.48	5.44
XIII	-	-	35.28	-	-	29.92
XIV	-	-	19.32	-	-	288.55
XV	-	-	93.35	-	-	263.48
XVI	-	-	97.80	-	-	4.76
Total	55.36	48.12	54.92	2231.6	2562.43	2329.38

3.3 Theory of Exergetic Cost

The methodology used to perform the exergetic cost analysis is the Theory of Exergetic Cost proposed in [16]. This methodology can be used to determine the exergetic and monetary cost of each one of the flows that compose the system. In [17] it was presented the determination of the exergetic and monetary costs of a cogeneration system in a sugar plant evaluating the influence of the price of the main fuel, cane bagasse, in steam production and electricity costs. In [8] it was used the exergoeconomic methodology to assess the exergetic cost of sugar in the production process.

The exergetic cost calculation is made through cost balance equations in each component, as shown by Eq. (9)

$$\sum k_{in} E_{in} - \sum k_{out} E_{out} = 0 \tag{9}$$

Where "k" defines the unitary exergetic cost and "E" the total flow exergy, the subscript "in" and "out" indicate the flows that enter and leave the control volume, respectively.

The application of Eq. (9) in all control volumes form a linear equations set, where the variable number is greater than the equation number. In order to obtain a set with a unique solution it is necessary to add some additional equations, to equalize the number of equations and variables. In [18] it was reported in a simple way the postulates of the methodology to define these additional equations.

In the special case of the extraction system the exergetic cost balance equation is written for the diffuser (eq. 10) and the mill (eq 11) as follows:

$$\begin{aligned} &\dot m_{14} e_{14} k_{14} + \dot m_{juice\_13} e_{juice\_13} k_{juice\_13} + \\ &\dot m_{bagasse\_13} e_{bagasse\_13} k_{bagasse\_13} + \\ &\dot W_{ele\_DF} k_P + \dot m_5 e_5 k_5 - \dot m_{10} e_{10} k_{10} - \\ &\dot m_{15} e_{15} k_{15} - \dot m_{16} e_{16} k_{16} = 0 \end{aligned} \tag{10}$$

$$\begin{aligned} &\dot m_{14} e_{14} k_{14} + \dot m_{juice\_13} e_{juice\_13} k_{juice\_13} + \\ &\dot m_{bagasse\_13} e_{bagasse\_13} k_{bagasse\_13} + \\ &\dot W_{mill} k_m - \dot m_{15} e_{15} k_{15} - \dot m_{16} e_{16} k_{16} = 0 \end{aligned} \tag{11}$$

The set of additional equations were following the considerations proposed by Lozano and Valero [16]. To the unitary exergetic costs of the inputs (juice and bagasse) a unitary value is assigned, and therefore:

$$k_{juice\_13} = k_{bagasse\_13} = k_{40} = 1 \quad (12)$$

All the irreversibility generation in the turbines must be carried out by the unitary exergetic cost of electric or mechanical power, and consequently the unitary exergetic costs of the steam entering and leaving these turbines are considered equal. Therefore, we have:

$$k_1 = k_2 = k_3 = k_{12} \quad (13)$$

In the splitters, where no irreversibility generation takes place, flows entering and leaving the valves have the same exergetic cost.

$$\begin{aligned} S1: &\quad k_3 = k_4 = k_5 = k_{11} \\ S2: &\quad k_{15} = k_{17} = k_{18} \end{aligned} \quad (14)$$

In the diffuser, the following considerations were made:

i) The unitary exergetic cost of the steam that enters, flow (5), is the same of the condensed that leaves, the flow (10), the diffuser;

$$k_5 = k_{10} \quad (15)$$

ii) The unitary exergetic cost of flow (15), bagasse, is the same that of the cane that enters in the diffuser and consequently all the irreversibility generation is carried by the unitary exergetic cost of the juice that leaves the diffuser, flow (16), the same hypothesis is adopted in mill. Thus:

$$k_{15} = k_{bagasse\_13} \quad (16)$$

With this set of equations above, the number of equations is equal to the number of variables. The system was solved using the EES® software [19] Thus, to calculate unitary exergetic cost for the original project becomes possible. The additional equations for the mills are similar to that adopted for the diffuser. Table 5 shows the values of the unitary exergetic cost for both systems.

The products of this cogeneration and juice extraction system are the electrical power (k_P), juice(k_{16}), mechanical power (k_m) and ethanol (k_{23}). The juice extraction system using mill has a value of (k_P) 3.21% lower, for juice cane cost (k_{16}), the value is 14.4% higher, mechanical power (k_m) has a similar value and for ethanol (k_{23}), the value is 9.2% higher than diffuser. Considering that the juice is a main product of the juice extraction system, the diffuser produces a juice sugar cane with more efficiency and exergetically cheaper than mill, and this juice cost spread to ethanol cost, decreasing the ethanol exergetic cost. When the energetic integration between extraction and distillation systems is used all values decreasing.

When compared with mill, the extraction system based on diffuser decreases the juice exergetic cost in 12.6%. This reduction of juice cost result in a decrease of exergetic ethanol production cost of 3.8%. In case III, the decrease of this costs are 14% and 8% respectively. The values of mechanical and electrical power and imbibition water remain unchanged due that the operation conditions (pressure and temperature) of cogeneration system remain the same. However, the most important information obtained from exergoeconomic analysis is the decreasing of the influence of the extraction system on the ethanol production cost, as shown in figure 3.

Table 5 Unitary exergetic cost of main flows of cogeneration, extraction and distillation systems

Flow	**I**	**II**	**III**
Steam from Boiler [1]	3.633	3.595	3.331
Cane – Juice [13]	1.000	1.000	1.000
Cane – Bagasse [13]	1.000	1.000	1.000
Bagasse to Boiler [17]	1.000	1.000	1.000
Juice [16]	1.457	1.272	1.253
Wine [20]	1.498	1.321	1.263
Ethanol [23]	1.882	1.812	1.727
Electrical Energy (k_P)	4.246	4.356	4.030
Mechanical Energy (k_m)	5.789	5.728	-

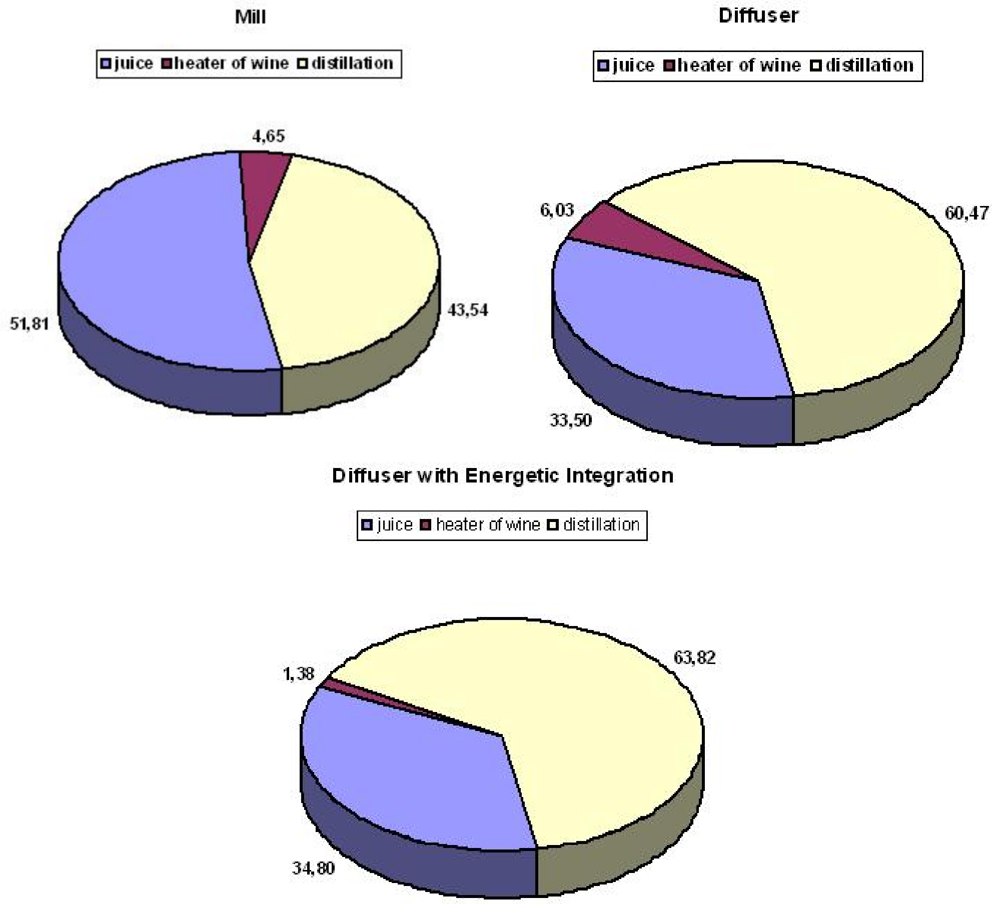

Figure 3 Participation (%) of each steps in composition of ethanol exergetic cost production. a) mill; b) diffuser and c) diffuser with energetic integration

In this figure, the process of formation of the unitary exergetic cost is shown proportionally to of the participation of each step of process: extraction, heater of wine and distillation.

The participation of extraction step start with 51.81% (Case I), decrease to 33.5% (Case II) and reaches 34.8%. In this step the main difference occurs due of replace of the extraction component mill by the diffuser. With use of the diffuser, the participation of extraction system decrease about 14%.

The step of wine heater has a lower participation of the composition of ethanol cost produce in Case III. In this case, the use of the pinch technology allows decrease the necessity of thermal energy in this step.

Finally, the distillation system has an increase of participation in the composition of ethanol cost. In the three cases studied, there are no modification in this system, thus the participation of this step in the ethanol cost tends to increase

The variation of values of unitary exergetic cost of ethanol is shown in figure 4 to diffuser and diffuser with energetic integration compared with mills. The diffuser decrease the unitary exergetic cost in 3.72% and 8.24% using energetic integration by pinch technology..

A complete exergoeconomic analysis of this integrated system must be performed in a future work, considering monetary costs of production of ethanol, like as, equipment, investment, operational and maintenance costs reaching a monetary value of ethanol production cost based on exergy concepts.

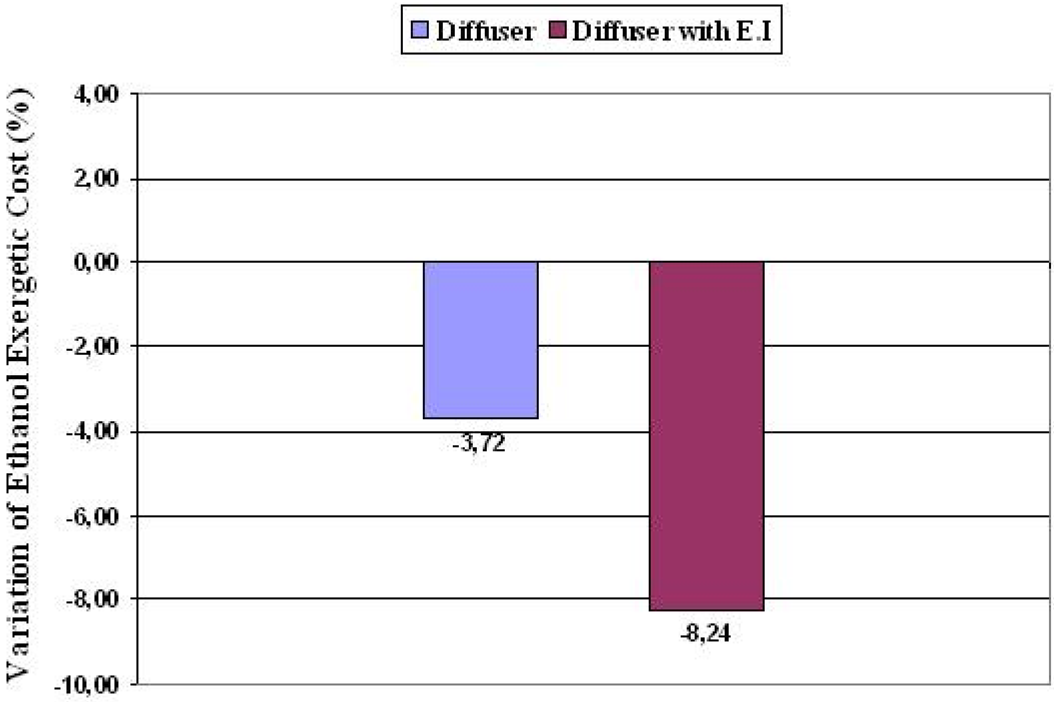

Figure 4 Variation of Unitary Exergetic Cost of Ethanol.

4. CONCLUSION

This study analyzed a cogeneration and distillation integrated system with a juice extraction scheme using a mill or a diffuser, and a diffuser with energetic integrated by pinch technology. The three cases were compared using the First and Second Thermodynamic Laws and Exergetic Cost Analysis. The mill has higher consumption of mechanical energy than diffuser, what decreases the electric energy generated by the steam turbine. In spite of its lower mechanical energy consumption, the diffuser needs more thermal energy, so, more steam needed to be produced in the boilers, consequently more electric energy is generated, but more fuel (bagasse) is also spent. However, the use of energetic integration allows the increase of extraction efficiency and keeps the similar level of bagasse surplus of the mills.

The comparison showed that mill generates more irreversibility than diffuser, once it needs much more mechanical energy, consuming steam at high pressure and temperature in direct drive turbines with low isentropic efficiencies, increasing the irreversibility generation. The diffuser, on the other hand, needs lower mechanical power and consume steam at low pressure and temperature for the lixiviation processes, reaching higher exergetic efficiency than the mill.

Due to its principle of work, that consume more steam at high pressure and temperature, mills presents a value of unitary exergetic cost of juice produced higher than the diffuser, representing higher consumption of the energy available in the plant and consequently higher costs for the production of the final product, ethanol.

A future Thermoeconomic Analysis comparing both juice extraction systems will show the differences considering the operational cost, including maintenance, and investment cost to obtain the monetary juice cost in each case, being an important analysis tool for the decision of which extraction system is the best to invest.

Acknowledgment

The authors would like to express their gratitude to Research Foundation of Sao Paulo State – FAPESP, and National Council of Scientific and Technological Development – CNPq for the financial resources to do this study.

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APPENDIX A

Table A.1 Thermodynamic data of the cogeneration, extraction and distillation system in three cases studied

	$\dot{m}(kg/s)$			$T(^{o}C)$			$P(bar)$			$e(kJ/kg)$		
	I	II	III	I	II	III	I	II	III	I	II	III
1	0,330	0,457	0,377	480	480	480	80	80	80	1896	1896	1896
2	0,291	0,158	-	317,8	317,8	-	22	22	-	1568	1568	-
3	0,038	0,299	0,377	132,4	132,4	127,4	2,5	2,5	2,5	1150	1150	1147
4	0,036	0,227	0,306	132,4	132,4	127,4	2,5	2,5	2,5	1150	1150	1147
5	-	0,068	0,068	-	132,4	127,4	-	2,5	1,05	-	1150	1150
6	0,328	0,453	0,374	121,8	121,8	121,8	2,1	2,1	2,1	582	582	81
7	0,328	0,453	0,374	121,8	121,8	121,8	4	4	4	582	582	582
8	0,330	0,457	0,377	121,8	127,4	125	2,5	2,5	2,5	586	588	588
9	0,330	0,457	0,377	125	128,7	126,3	88	88	88	595	598	598
10	-	0,068	0,068	-	121,8	121,8	-	2,1	2,1	-	582	27660
11	0,002	0,005	0,002	132,4	132,4	127,4	2,5	2,5	2,5	1150	1150	1147
12	0,291	0,158	0,901	172,6	172,6	40	2,5	2,5	1,05	1175	1175	55
13	1,000	1,000	1,000	25	25	25	1,01	1,01	1,01	-	-	-
14	0,235	0,361	0,361	98	98	98	1,01	1,01	1,01	82	82	82
15	0,260	0,260	0,260	25	25	25	1,01	1,01	-	9959	9959	9959
16	0,975	1,101	1,101	25	25	25	1,01	1,01	-	2416	2416	2416
17	0,155	0,214	0,176	25	25	25	1,01	1,01	-	9959	9959	9959
18	0,105	0,046	0,084	25	25	25	1,01	1,01	1,01	9959	9959	9959
19	0,975	1,101	1,101	25	25	25	1,01	1,01	1,01	2486	2486	2486
20	0,975	1,101	1,101	90	90	90	1,01	1,01	1,01	2512	2512	2512
21	0,167	0,192	0,192	78	78	78	1,01	1,01	1,01	12058	12058	12058
22	0,793	0,901	0,901	99	99	99	1,01	1,01	1,01	98	98	98
23	0,069	0,073	0,073	78	78	78	1,01	1,01	1,01	27674	27674	27674
24	0,097	0,119	0,119	99	99	99	1,01	1,01	1,01	122	122	122
25	2,433	2,530	2,530	25	25	25	1,2	1,2	1,2	527	527	527
26	2,433	2,530	2,530	30	30	30	1,15	1,15	1,15	528	528	528
27	0,168	0,204	0,209	121,8	148,7	127,4	2,5	2,5	2,5	1148	1159	1159
28	0,168	0,204	0,209	121,8	121,8	121,8	2,1	2,1	2,1	582	582	582
29	15,329	18,336	18,336	25	25	25	1,2	1,2	1,2	527	527	527
30	15,329	18,336	18,336	30	30	30	1,15	1,15	1,15	528	528	528
31	0,015	0,002	0,002	121,8	148,7	127,4	2,5	2,5	2,5	1148	1159	1147
32	0,015	0,002	0,002	121,8	121,8	121,8	2,1	2,1	2,1	582	582	582
33	0,031	0,049	0,037	121,8	148,7	127,4	2,5	2,5	2,5	1148	1159	1147
34	0,113	0,130	0,015	121,8	148,7	127,4	2,1	2,1	2,1	1148	1159	1147
35	0,031	0,049	0,044	121,8	121,8	127,4	2,5	2,5	2,5	582	582	1147
36	0,113	0,130	0,037	121,8	121,8	121,8	2,1	2,1	2,1	582	582	582
37	0,144	0,179	0,015	121,8	121,8	121,8	2,1	2,1	2,1	582	582	582
38	0,328	0,385	0,044	121,8	148,7	121,8	2,5	2,5	2,5	1148	1159	582
39	0,008	0,008	0,008	88	88	88	1,01	1,01	1,01	26397	26101	26397
40	0,235	0,361	0,361	25	25	25	1,01	1,01	1,01	50	50	50
41	-	-	0,096	-	-	121,8	-	-	2,1	-	-	582
42	-	-	0,14	-	-	41,71	-	-	1,05	-	-	2488
43	-	-	0,977	-	-	81,92	-	-	1,2	-	-	2517
44	-	-	0,124	-	-	90	-	-	1,05	-	-	2512
45	-	-	0,977	-	-	90	-	-	1,05	-	-	2512
46	-	-	0,361	-	-	44,53	-	-	1,01	-	-	53
47	-	-	0,124	-	-	25	-	-	1,05	-	-	2486
48	-	-	0,977	-	-	25	-	-	1,05	-	-	2486
49	-	-	0,119	-	-	40	-	-	1,05	-	-	81
50	-	-	0,073	-	-	40	-	-	1,05	-	-	27660