SUGAR CANE JUICE EXTRACTION SYSTEMS COMPARISON - MILL VERSUS DIFFUSER

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Abstract. The sugar and alcohol production is one of the most important economical activities in Brazil, mainly due its high efficiency and competitiveness. The sugar production is done by several steps: juice extraction, treatment, preheating and evaporation, syrup treatment, crystallization, centrifugalization and drying. In the alcohol production the steps productions are: juice extraction, fermentation and distillation. 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 and the bagasse. Recently another juice extraction system named diffuser was introduced in some sugar and alcoohol factories in Brazil. On diffusers, after sugar cane preparation stage with knives and shredders, it passes through a bed, where the juice is separated from bagasse by addition of imbibitions water and steam, in a process named lixivization. This study pretends to analyse and compare this two juice extraction systems, performing an exergetic cost analysis by The Theory of Exergetic Cost where are compared the results of exergetic efficiency, irreversibility generation and unitary exergetic cost of products of those two extraction systems.
Keywords:, sugar cane juice, extraction system, exergetic cost analysis.

1. Introduction

The sugar cane plants are constituted by three basic arrangements. Those that produce exclusively sugar or alcohol and those that produce sugar and alcohol 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 matter 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 of 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 the mechanical work of the mills to extract the juice by compression. Mills are generally connected to drive turbines that consumes medium pressure vapor (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 piece of equipment 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 (Revista AlcoolBras, 2004).

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 piece of equipment exit that are used as pre-dryers, reducing the moisture of the bagasse to 50% approximately and extracting the remaining juice for re-circulation.

There are only 10 diffusers installed in 324 Brazilian sugar cane plants in operation (Revista AlcoolBras, 2004). The problems in the past inhibited the application of these pieces of equipment but other experiences showed 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% (IdeaNews, 2003). 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% (Revista AlcoolBras, 2004).

Moreover the maintenance costs with a diffuser are 70% lower than milling and the operation can be done with 3 operators, while milling needed 8 or 9 of them (IdeaNews, 2003).

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 (Birkett, 1999).

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 rock removal system installed in that factory contributed for that result. The equipment removed rocks, loose gravels and sand with a variable-speed spiked roller that picked up cane from the feeder table before discharge into the main cane carrier (Cargill & Winterbach, 1996)

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 vapor bleed from first and/or second effects of evaporation station of the sugar production process, or from turbine extractions at low pressure in a alcohol production process.

Comparison of the energy consumption between milling and diffusers has been done by some authors (Birkett,1999; van Hengel,1990; Hoekstra, 1995). The change of traditional milling systems by diffusers should increase 3 to 6% the sugar production at very reasonable cost (van Hengel,1990).

2. Description of the system

In order to compare the performance between mills and diffusers, a simple cogeneration system has been proposed. 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.

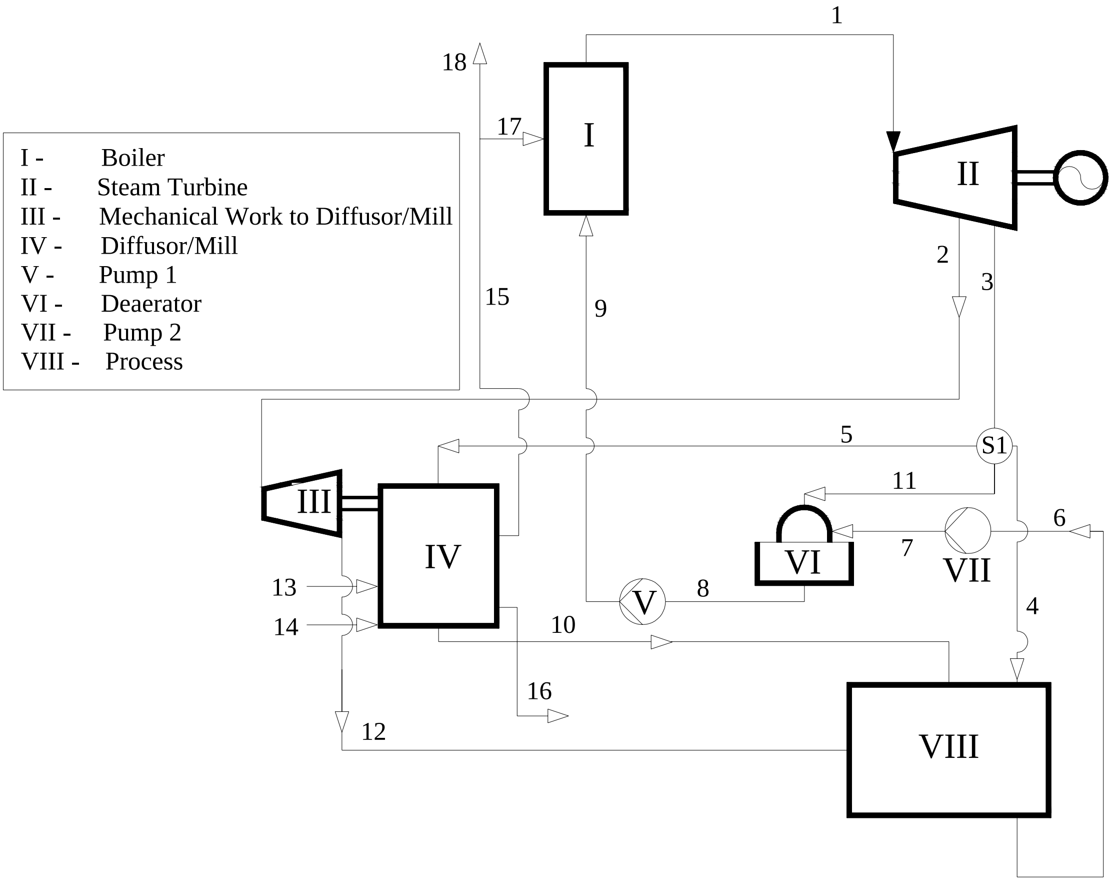

Figure 1 Sketch of Cogeneration and Extraction Systems

The set is composed by a boiler, a steam turbine, a deaerator, a juice extraction system (mill or diffuser), two pumps and a control volume that represent the production process. The thermodynamic data of this system are shown in Table 1. 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 alcohol 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 500°C and a pressure of 80 bar. The steam from boiler is expanded in a steam turbine with a extractions, at a pressure of 20 bar, is used to generate mechanical energy for the diffuser or milling the steam is expanded until 2 bar used to supply heating steam to diffuser and deaerator. The steam expanded, flow (4), in the steam turbine is used in the process. The other condensed flows from diffuser, flow (10), and mechanical work generators, flow (12), are joined in the process and return to the system by the flow (6). All condensed flows are pressurized in the electric pump 1 (VII), passed through the deaerator (VI), 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):

$$\dot{m}_{cane} = (1 - x)\dot{m}_{juice} + (x)\dot{m}_{bagasse} \quad (1)$$

Where: "x" is a percentage of fiber in the cane, adopted as 14% in this simulation.

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 per cane kilogram was estimated by Barreda (1999), for the mill and Fernández Parra (2003) for the diffuser. Mechanical work consumption adopted for the mill and the diffuser were obtained in Macedo e Horta (2005) and Fernández Parra (2003) respectively.

Some parameters adopted to juice extraction system comparison are shown in the Table 1.

Table 1 Parameters adopted for juice extraction systems

	Mill	Diffuser
Bagasse fiber (%)	14	14
Direct Drive Power (kWh/ kg of cane)	15.00	9.00
Energy consumed (kW / kg of cane)	56.9	245.9
Imbibitions Water (kg/ kg of cane)	0.231	0.3608
Juice production (kg/ kg of cane)	0.9950	1.1208
Electrical Consumption kWh/ ton cane	330.00	
Energy to process (kWh/ton cane	43.2	

Table 2 shows the thermodynamics data used to simulate these systems. Table 3 shows the mechanical and electrical power consumption in both systems.

Table 2 Thermodynamics data of the cogeneration and extraction system

	Steam (kg/s)		T(°C)		P(bar)		Exergy (kJ/kg)	
	Mill	Diffuser	Mill	Diffuser	Mill	Diffuser	Mill	Diffuser
1	0.5356	0,6392	500	500	80	80	1399	1399
2	0.2948	0,1658	338.7	338.7	20	20	1055	1055
3	0.2408	0,4734	158.5	158.5	2	2	609.2	609.2
4	0.2092	0,3455	158.5	158.5	2	2	609.2	609.2
5	-	0,0936	-	120.9	-	2	-	609.2
6	0.5040	0,6049	120.2	120.2	2	2	53.23	53.23
7	0.5040	0,6049	120.3	120.3	8	8	53.91	53.91
8	0.5356	0,6392	150	150	5	5	90.27	78
9	0.5356	0,6392	153.3	153.3	88	88	100	100
10	-	0,0936	-	120.2	-	1.35	-	53.23
11	0.0317	0,0343	158.5	158.5	2	2	609.2	609.2
12	0.2948	0,1658	222.8	222.8	2	2	655.4	655.4
13 (bagasse)	1.0000	1,0000	25	25	1.013	1.013	20341	20341
13 (juice)	1.0000	1,0000	25	25	1.013	1.013	3195	3195
14	0.2350	0,3608	25	25	1.013	1.013	34.09	34.09
15	0.2800	0,2800	25	25	1.013	1.013	9200	9200
16	0.9550	1,0808	25	60	1.013	1.013	2416	2416
17	0.2308	0.2751	25	25	1.013	1.013	9200	9200
18	0.0492	0.0049	25	25	1.013	1.013	9200	9200

3. Exergetic Cost Analysis

The classic evaluation of thermal power plant performance is done through the energetic analysis based in the First Law of Thermodynamics. Such analysis permits, from an energetic point of view, a quantitative analysis of the plant performance and each of its equipments. 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 irreversibilities, can be used the analysis by the Second Law of Thermodynamics, also called exergetic analysis. (Kotas, 1985). 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, respectively.

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

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

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

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 was used the Equation 5:

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

Where: h_i = enthalpy of the flux at point "i"; h_o = enthalpy of the reference; s_i= entropy of the flux at point "i" s_o = entropy of reference; e_{ch} = chemical exergy of water

For the determination of sugar cane bagasse exergy, was adopted a methodoly presented by Szargut et al.(1988) for wood with the necessary changes in the composition of the fuel and its Low Heat Value. For a bagasse at the reference environment conditions, its total exergy is equal to its chemical exergy, being possible to be calculated by the refered methodology. It was assumed the folowing composition for the bagasse: 47% of Carbon, 6,5% of Hidrogen, 44% of Oxigen and 2,5% of Ash presented by Tone Baloh (1995). The value found in flow [13] for bagasse dry and point [15] bagasse with 50% of humidity.

The juice exergy was calculated following the methodology described by Nebra and Fernandez Parra (2005).

3.1 First Law Analysis

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

$\eta_{boiler}=0.85$ Energetic efficiency of boiler

$\eta_{st}=0.812$ Isentropic efficiency of steam turbine

$\eta_p=0.8$ Isentropic efficiency of electric

$\eta=0.4$ Isentropic efficiency of direct drive turbines

Table 3 Energetic consumptions of the juice extraction systems

Power	Mill	Diffuser
Steam Turbine Power (kW/ kg of cane)	232.2	319.8
Direct Drive Power (kW/ kg of cane)	57.6	32.4
Pump 1 (kW/ kg of cane)	5.605	6.72
Pump 2 (kW/ kg of cane)	0.400	0.481
Energy Consumption (kW/ kg cane)	57.6	245.9
Bagasse excess (%)	18.48	2.161
Net Power (kW/ kg of cane)	166.3	268.4

The juice extraction system based in diffuser has an electric net power generation 61% larger than system based in mills. The direct drive power in mill is 40% larger than diffuser, the electrical consumption in pumps 1 and 2 are similar. The energy consumption in the diffuser is 76,5% larger than mills, the bagasse excess is 16% larger to mills than diffuser. In order to improve the diagnostic of the two juice extraction systems, the exergetic analysis was performed for the determination of exergetic efficiency and irreversibility generated in both juice extraction systems.

3.2 Second Law Analysis

The exergy equation balances applied in each component are shown in the Table 4. 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:

$$\dot{m}_{14}e_{14}+\dot{m}_{juice\_13}\ e_{Juice\_13}+\dot{m}_{bagasse\_13}\ e_{bagasse\_13} +W_{ele}+\dot{m}_5 e_5-\dot{m}_{10}e_{10}-\dot{m}_{15}e_{15}-\dot{m}_{16}e_{16}=\dot{I}_{IV} \quad (6)$$

$$\dot{m}_{14}e_{14}+\dot{m}_{juice\_13}\ e_{Juice\_13}+\dot{m}_{bagasse\_13}\ e_{bagasse\_13}+ W_{mill}-\dot{m}_{15}e_{15}-\dot{m}_{16}e_{16}=\dot{I}_{IV} \quad (7)$$

Where: W_{ele} : 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 by EES® software, determining the irreversibility generated in each component of the systems. The efficiency of each component was calculated according Kotas, (1995), Szargut et. Al. (1988), Guarinell et al. (2000) and shown in Table 5. The efficiency of Second Law and irreversibility generated are shown in Table 6.

Table 4 Exergy balance equation

Control volume	$\dot{m}_{in} e_{in}$	$\dot{m}_{out} e_{out}$	$\sum \dot{Q}_{vc}\left(1-\frac{T_o}{T_i}\right)$	$\dot{W}_{vc}$	$\dot{I}_{vc}$
I (Boiler)	$\dot{m}_9 e_9 + \dot{m}_{15} e_{15}$	$\dot{m}_1 e_1 k_1$	-	-	$\dot{I}_I$
II (Steam Turbine)	$\dot{m}_1 e_1$	$\dot{m}_2 e_2 + \dot{m}_3 e_3$	-	-	$\dot{I}_{II}$
III (direct Drive Turbine)	$\dot{m}_2 e_2$	$\dot{m}_{12} e_{12}$	-	W_m	$\dot{I}_{III}$
V (pump 1)	$\dot{m}_8 e_8$	$\dot{m}_9 e_9$	-	W_{p1}	$\dot{I}_V$
VI (deareator)	$\dot{m}_7 e_7 + \dot{m}_{11} e_{11}$	$\dot{m}_8 e_8$	-	-	$\dot{I}_{VI}$
VII (pump 2)	$\dot{m}_6 e_6$	$\dot{m}_7 e_7$	-	W_{p2}	$\dot{I}_{VII}$
VIII (process)	$\dot{m}_4 e_4 + \dot{m}_{10} e_{10} + \dot{m}_{12} e_{12}$	$\dot{m}_6 e_6$	$\dot{Q}_{process}\left(1-\frac{T_o}{T_6}\right)$	-	$\dot{I}_{VIII}$

Table 5 Exergetic efficiency equation

Control volume	
Boiler	$\frac{\dot{m}_1 e_1 - \dot{m}_9 e_9}{\dot{m}_{17} e_{17}}$
Steam Turbine	$\frac{W}{\dot{m}_1 e_1 - \dot{m}_2 e_2 - \dot{m}_3 e_3}$
Direct Drive Turbine	$\frac{W_m}{\dot{m}_2 e_2 - \dot{m}_{12} e_{12}}$
Pump 1	$\frac{\dot{m}_9 e_9 - \dot{m}_8 e_8}{W_{p1}}$
Deareator	$\frac{\dot{m}_8 e_8}{\dot{m}_7 e_7 + \dot{m}_{11} e_{11}}$
Pump 2	$\frac{\dot{m}_7 e_7 - \dot{m}_6 e_6}{W_{p2}}$
Diffuser	$\frac{\dot{m}_{15} e_{15} + \dot{m}_{16} e_{16} + \dot{m}_{10} e_{10}}{\dot{m}_{14} e_{14} + \dot{W}_m + \dot{m}_5 e_5 + \dot{m}_{13(bag)} e_{13(bag)} + \dot{m}_{13(juice)} e_{13(juice)}}$
Mills	$\frac{\dot{m}_{15} e_{15} + \dot{m}_{16} e_{16}}{\dot{m}_{14} e_{14} + \dot{W}_m + \dot{m}_{13(bag)} e_{13(bag)} + \dot{m}_{13(juice)} e_{13(juice)}}$

Table 6 Exergetic Efficiency and Irreversibility in Cogeneration and Juice Extraction Systems

	Second Law Efficiency		$\dot{I}(kW)/$ kg of cane	
	Diffuser	Mill	Diffuser	Mill
Boiler	0.297	0.297	1910	1596
Steam Turbine	0.783	0.797	93.47	54.64
Extraction System	0.941	0.884	391.4	663.2
Pump 1	0.850	0.850	2.38	0.836
Pump 2	0.848	0848	0.07	0.06
Deaerator	0.997	0.997	0,108	0.08
Direct Drive Turbines	0.488	0.488	33.89	60.26

The exergetic analysis is a powerful tool to assess thermal systems. This analysis allows quantify and identify the components that most produce irreversibility in the system. The main difference between two systems is the juice extraction system. The mill generates 61% more irreversibility than diffuser and has an exergetic efficiency 6.8% lower. The juice extraction system is responsible by 20,41% (diffuser) and 29,34% (mill) of total irreversibility generated in the system. The set cogeneration and juice extraction system with mill produce 11% more irreversibility than the juice extraction with diffuser.

3.3 Theory of Exergetic Cost

The methodology used to perform the exergetic cost analysis is the Theory of Exergetic Cost formulated by Lozano and Valero [9]. This methodology can be used to determine the exergetic and monetary cost of each one of the flows that compose the system. Several studies were found in the literature using Theory of Exergetic Cost: Silva and Nebra (1996) showed a thermoeconomic analysis for four cement production process, obtaining the exergetic and monetary costs in function of different electric energy rate and making a sensibility analysis for the cement production costs for the four processes studied in terms of the entrance costs. Guarinello Jr. et. al. (2000) determined the exergetics and monetary costs in a gas turbine system with HRSG using gas turbine simple cycle and the STIG cycle, demonstrating that the exergetic and monetary costs are larger for STIG cycle. Sanchez and Nebra (2002) determined 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. Fernandez Parra (2003) used the thermoeconomic 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. (8)

$$\sum k_{in} E_{in} - \sum k_{out} E_{out} = 0 \qquad (8)$$

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 (8) 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. Cerqueira et al (1999) reported in a simple way the postulates of the methodology to define these additional equations. In the Table 7, the cost balance equations are shown.

Table 7 Exergetic cost balance equations

Control volume	$k_{in} E_{in}$	$k_{out} E_{out}$
I	$\dot{m}_9 e_9 k_9 + \dot{m}_{17} e_{17} k_{17}$	$\dot{m}_1 e_1 k_1$
II	$\dot{m}_1 e_1 k_1$	$\dot{m}_2 e_2 k_2 + \dot{m}_3 e_3 k_3 - W k_p$
III	$\dot{m}_2 e_2 k_2$	$\dot{m}_{12} e_{12} k_{12} - W_m k_m$
V	$\dot{m}_8 e_8 k_8 - W_{p1} k_p$	$\dot{m}_9 e_9 k_9$
VI	$\dot{m}_7 e_7 k_7 + \dot{m}_{11} e_{11} k_{11}$	$\dot{m}_8 e_8 k_8$
VII	$\dot{m}_6 e_6 k_6 - W_{p2} k_p$	$\dot{m}_7 e_7 k_7$
VIII	$\dot{m}_4 e_4 k_4 + \dot{m}_{10} e_{10} k_{10} + \dot{m}_{12} e_{12} k_{12}$	$\dot{m}_6 e_6 k_6 + E_{process}\ k_{process}$

In the special case of the extraction system the exergetic cost balance equation is written for the diffuser (eq. 9) and the mill (eq 10) as follows:

$$\begin{aligned} &\dot{m}_{14} e_{14} k_{14} + \dot{m}_{juice\_13}\ e_{Juice\_13}\, k_{Juice\_13} + \dot{m}_{bagasse\_13}\ e_{bagasse\_13}\, k_{bagasse\_13} \\ &+ W_{ele} k_p + \dot{m}_5 e_5 k_5 - \dot{m}_{10} e_{10} k_{10} - \dot{m}_{15} e_{15} k_{15} - \dot{m}_{16} e_{16} k_{16} = 0 \end{aligned} \qquad (9)$$

$$\begin{aligned} &\dot{m}_{14} e_{14} k_{14} + \dot{m}_{juice\_13}\ e_{Juice\_13}\, k_{Juice\_13} + \dot{m}_{bagasse\_13}\ e_{bagasse\_13}\, k_{bagasse\_13} \\ &+ W_{mill} k_m - \dot{m}_{15} e_{15} k_{15} - \dot{m}_{16} e_{16} k_{16} = 0 \end{aligned} \qquad (10)$$

The set of additional equations were following the considerations proposed by Lozano and Valero (1993).

To the unitary exergetic costs of the inputs (juice and bagasse) a unitary value is assigned, and therefore:

$$k_{juice\_13} = 1 \qquad (11)$$

$$k_{bagasse\_13} = 1 \qquad (12)$$

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

$$k_1 = k_2 = k_3 = k_4 = k_{12} \quad (13)$$

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

S1

$$k_3 = k_4 = k_5 = k_{11} \quad (14)$$

In the process, the unitary exergetic cost of the condensed is the same at the inlet and exit, and consequently all the irreversibility generation is carried by the unitary exergetic cost of the process heat. Thus:

$$k_6 = k_4 \quad (15)$$

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, in the flow (10) the diffuser;

ii) The unitary exergetic cost of the imbibition water is adopted like the same of the condensed steam; flow (10);

iii) 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). Thus:

$$k_5 = k_{10} \quad (16)$$

$$k_{14} = k_{10} \quad (17)$$

$$k_{15} = k_{bagasse\_13} \quad (18)$$

With this set equations above, the number of equations is equal the number of variables. The system was solved using the EES® software (EES, 2004). 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 8 shows the values of the unitary exergetic cost to both systems.

Table 8 Unitary exergetic cost of cogeneration and extraction system

	Unitary exergetic cost			**Unitary exergetic cost**	
	Mill	Diffuser		Mill	Diffuser
1	3.371	3.372	12	3.371	3.372
2	3.371	3.372	13 (bagasse)	1	1
3	3.371	3.372	13 (cane juice)	1	1
4	3.371	3.372	14	3.371	3.372
5		3.372	15	1	1
6	3.371	3.372	16	1.443	1.197
7	3.391	3.393	17	1	1
8	3.399	3.401	18	1	1
9	3.616	3.630	k_p	4.226	4.303
10		3.372	k_m	6.898	6.899
11	3.371	3.372	k_{heat}	3.443	3.422

The products of this cogeneration and juice extraction system are the electrical power (k_p), juice (k_{16}), mechanical power (k_m) and heat to process (k_{heat}). The juice extraction system using mill has a value of (k_p) 1.82% lower , to (k_{heat}) the value is 0.6% higher mechanical power (k_m) has a similar value and to (k_{16}) the value is 17% higher than diffuser. Considering that the juice is a main product of the juice extraction system, the diffuser produce a juice sugar cane with more efficiency and cheaper than mill.

4. Conclusion

This study analyzed a cogeneration system integrated with juice extraction system using a mill and a diffuser. Both systems were compared using the First, Second and Exergetic Cost Analysis.

The mill has higher consumption of mechanical energy than diffuser, what decreases the electric energy generated for the steam turbine. In spite of its lower mechanical energy consumption, the diffuser needs more thermal energy, decreasing the heat available for the process.

The comparison showed that the mill generates more irreversibility than diffuser, once it needs much more mechanical energy than diffuser, consuming for this, 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 products.

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

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