NEGENTROPY EFFECTS ON EXERGOCONOMICS ANALYSIS OF THERMALS SYSTEMS

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Abstract. *To be familiar with all information, such as the cost, of a thermal system's flow is becoming, at each day, more and more essential for engineering analysis and surveys. In the thermoeconomics/exergoeconomics cost study, one interesting thermal factor to be included is the negentropy from dissipative components. As it is usually considerate as a process loss, its inclusion and distribution to thermal components can make sensitive changes on system's thermoeconomics and exergoeconomics cost. In this way, the aim of this work is to evaluate, with a case of study as an example, the variation of exergoeconomics' costs results when it is or not considered the negentropy distribution effects using the Structural Methodology. In the case study evaluated, it was experienced changes of more than 100% on exergoeconomics results when negentropy effects were distributed. By the end, important conclusions about the importance of negentropy effects are made in order to convince the necessity of its inclusion.*

Keywords*: negentropy, exergoeconomics, cogeneration*

1. INTRODUCTION

The necessity of more efficient process with attractive costs benefits is one of the challenges for engineers in this new century, where the resources are considered limited than ever.

In thermal engineering, for example, system's detailing is becoming common in order to get know, in a system's process, the costs of each thermal flow.

Thermoeconomics is a methodology of exergy application for the formation and allocation of economics costs very used for this propose.

However, being familiar with the costs of each flow, it is not simply to apply the thermoeconomics theory. It is needed to considerate all factors that occurs in the thermal system.

One important consideration to be done are negentropys.

2. THERMOECONOMICS

Thermoeconomics is used to indicate the synergy of exergy and economical analysis. The fundamental characteristic of this type of analysis is the costs allocation using the exergy as a cost function.

As it is a kind of methodology where there are flows interactions (massic, energetic and exergetic) of each component, usually the inlet flow of a component came from the outlet of another one.

Besides, if well structured, termoeconomics methodology can be applied for systems optimization, making possible to operate the system in a great point, on the optics of the Thermodynamic and economy.

When it is applied monetary values to the system and its components, thermoeconomics turns to exergeconomics.

2.1. Theories

Among the different theories existents for thermoeconomics/exergoeconomics calculus, for example, Functional Analysis (Frangopoulos, 1983), Exergoeconomic Methodology (Tsatsaronis and Winhold, 1985), (Tsatsaronis and Pisa, 1994) and Exergetic Cost Methodology (Lozano, 1993), a variation of the last, named Structural Methodology explained in Cuadra and Valero (2000) was the one used and developed in this paper.

The proposal of this methodology, besides cost calculation, is to facilitate the visualization of the productive structure by including ramifications and junctions on it (already proposed in the functional analysis) and with that, make easier the equation methodology by turning it friendlier to be applied in complex thermal system analysis.

In general, the equation system of the Structural Methodology is initiated by the principle that the equation of the second Law of Thermodynamic is reduced to:

$$\text{(Entry Exergy) - (Exit Exergy) = Irreversibility} > 0 \tag{1}$$

Or alternatively:

$$Fuel\ (F) - Product\ (P) = Irreversibility\ (I) > 0 \quad (2)$$

The exergetic efficient (ε) can be defined as:

$$\varepsilon = \frac{Product\ (P)}{Fuel(F)} \quad (3)$$

where the Fuel, F, is considered as the supplies consumed for the product generation, P, which is the net result generated by a system component.

As the exergetic efficient is always lower than one, the obtainment of a product generates residues or products not whished, the irreversibility. Due to this parameter it is relevant to quantify and identify the irreversibilities in the process in order to determine the thermoeconomic cost, B^* *(kW)*, which is given by.

$$B^* = B + \sum_{process} I \quad (4)$$

where B is the exergy. This way is possible to affirm that the thermoeconomic cost of a flow is equal to its exergy plus the irreversibilities, I, accumulated in the process.

One very important factor in thermoeconomics is the non-dimensional thermoeconomics cost, k, which is applied for a simple process. It is represented by:

$$k = \frac{F}{P} = k^* \quad (5)$$

When denoted as k^*, specific thermoeconomics cost, means that F and P are already applied in a chain process of many flows and components through thermoeconomics. Hence, applying equation (4) in (5), the thermoeconomics cost B^* can also be calculated by the following equation:

$$B^* = k^* \cdot B \quad (6)$$

Those are the main premises of thermoeconomics. However, to apply this cost allocation methodology, engineers must be sure that the Thermodynamic values, such as, energy and exergy of flows, must be correctly calculated.

With the exergetic flows calculated and with the knowledge of the following aspects, it is possible to assemble the identification table with the Fuel (F) and products (P) of each component and to define the thermoeconomics costs.

- The limits of a process and its components;
- The components functions which defines its production goals;
- The supplies used in the process and on its components;
- The process and components' efficient.

In the Structural Methodology, its productive structure, all thermals components are identified by rectangles, the bifurcations as circumferences and junctions as lozenges.

With the F and P table and with the productive structure well assembled, it is possible to distribute the components' equations, bifurcations and junctions in one matrix equation in the mode:

$$[A]x[D]=[Ce] \quad (7)$$

where [A] is the square matrix containing k_{io} (Fuel and Product ratio inlet, i, and outlet, o, of each component), [D] is the column vector containing $k^*_{F,i}$ (Fuel thermoeconomics specific cost, of the component' inlet, i), this is the vector that wants to be calculated and [Ce] is the column vector with the external valorizations $k^*_{P,o}$, of the outlet, o, Product, P.

For each component the equation is:

$$k^*_{P,o} = k^*_{F,i} \cdot k_{io} \quad (8)$$

Bifurcations' equations, which serves to distribute supply or product flow to others components, have the following equation:

$$k_{P,o}^{*} = k_{F,i}^{*} \tag{9}$$

The junctions, used to connect components' commons products or supplies points or external supplies to another component or that together will be net product produced, is represented by the equation:

$$k_{P,o}^{*} = \sum r_{io} \cdot k_{F,i}^{*} \tag{10}$$

where r_{io} is the ratio between the exergy of the outlet flow and exergy of each inlet flow at the junction, this parameter is also called exergetic recirculation ratio.

3. NEGENTROPY

In thermodynamic means entropy reduction. In other words, it involves the thermal process where there are heat dissipation, for example, the steam condensation in thermoelectric condensers plants and cooler towers.

As the most part of thermals cycles and processes has those kinds of components, hence there is the interest of knowing the negentropy effects in the productive structure.

In general terms, the dissipation effects of those components are treated as process losses.

However, in some situations, it is interesting to considerate the exergoeconomics costs of negentropys in order to define its distribution in the components' supplies which are interrelated with these negentropy's generation. That consideration will influence, by its time, all exergoeconomics system's results.

Cuadra and Valero (2000) define negentropy, *BQ*, by the following form:

$$BQ = \sum \sigma_{nj} \cdot B_i \tag{11}$$

where σ_{nj} is the proportion of the generated entropy referring to each equipment/component, *n*, which influences on dissipative components, *j*. In this case σ_{nj} has the following equation:

$$\sigma_{nj} = \frac{\Delta s_n}{\Delta s_j} \tag{12}$$

4. CASE STUDIED

The evaluated case studied was a cogeneration plant that has 2,6 MW electric power (EP) motor group generator (GMG) as primary actuator, shown in Fig. 1, and a 630 TR absorption cooled water refrigerator. Detailed description and information about this plant can be consulted in Pousa (2009).

Figure 1. Picture of the cogeneration plant motor generator group

This plant was built in a commercial center (CC) located in northeast of Brazil. The keys objectives were:

1. To provide electric demand, bringing saves through avoided cost of electric power from the electric power concessionary and;
2. To adequate its thermal energy.

The following Fig. 2 shows the thermal scheme of the cogeneration plant evaluated.

In summary, the two GMGs presented receive natural gas (NG) as supply combustible. Their combustion generates the exhaust gas, which by its time, serves as supplement of the chiller. Yet, the GMGs have one device that generates hot water (HW). This hot water, together with the exhaust gas, serves as chiller's additional supplement.

The chiller also has the option of direct burn by natural gas if the amount of exhaust gas energy and hot water are not enough.

In this case, the cooling tower and radiator are common equipments found in this type of plant and are two examples of dissipative components that must be considered its negentropy effects in the system.

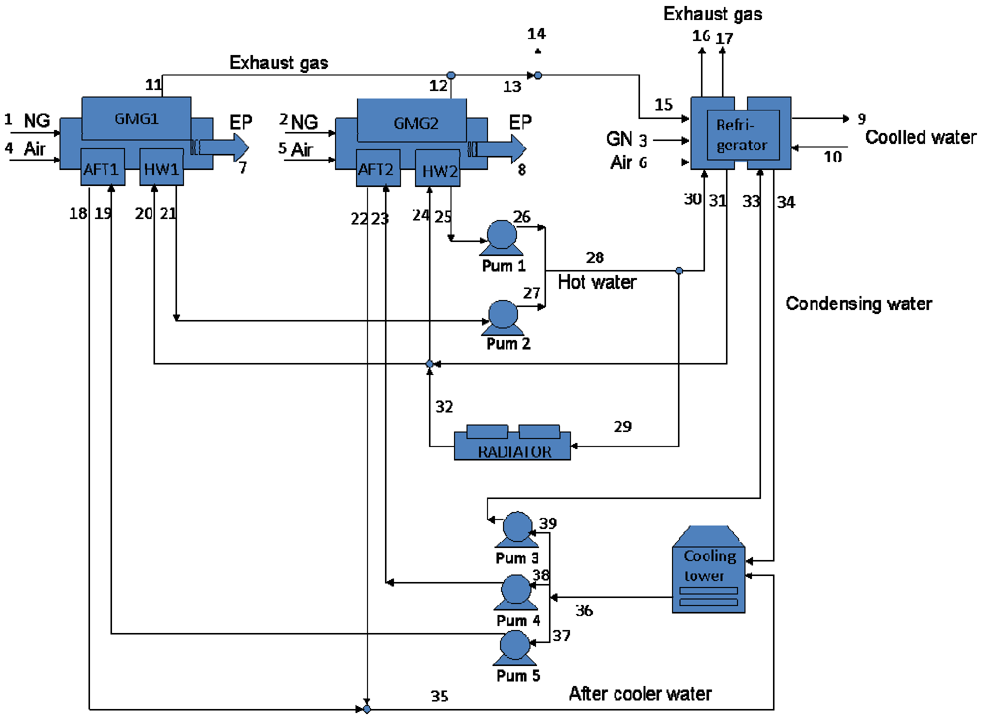

Figure 2. Thermal scheme of the cogeneration plant evaluated

4.1. Thermodynamic table

The following table (Tab. 1) shows the main data of the Thermodynamics' flows from Fig. 2 above.

In this table, it is also possible to identify, for each flow: entropy (*s*), specific exergy (*b*), exergy (*B*), negentropy of the cooling tower (*BQto*), electric power ($\dot{W}$) and the power of the combustible ($\dot{Co}$). The radiator negentropy (*BQro*) is not present, because the situation evaluated in this case studied has considered the GMGs operating at 100%. In this case the hot water is completely transferred to be a chiller Fuel together the GMGs' exhaust gas.

The last four points, presented in the table, are not listed in the Fig. 2 due the fact they are pure exergy flows.

Table 1. Thermodynamics properties

Point	*s* (kJ/ kgK)	*b* (kJ/kg)	*B* (kW)	*BQto* (kW)	$\dot{W}$ (kW)	$\dot{Co}$ (kW)
1	0	0	3955	3,14	0	3767
2	0	0	3955	3,14	0	3767
3	0	0	0	135,5	0	0
4	5,695	0	0	0	0	0
5	5,695	0	0	0	0	0
7	0	0	0	0	1356	0
8	0	0	0	0	1356	0
9	0,106	2,505	190,6	0	0	0
10	0,209	1,032	78,54	0	0	0
11	8,308	294	645,116	0	0	0
12	8,308	294	645,116	0	0	0
16	7,618	73	295,689	0	0	0
18	0,511	0,887	4,525	0	0	0
19	0,436	0,399	2,038	0	0	0
20	1,147	23,44	294,7	0	0	0
21	1,25	29,85	375,3	0	-56,79	0
22	0,511	0,887	4,525	0	0	0
23	0,436	0,399	2,038	0	0	0
24	1,147	23,44	294,7	0	0	0
25	1,25	29,85	375,3	0	-56,79	0
26	1,261	31,05	390,4	0	0	0
27	1,261	31,05	390,4	0	0	0
33	0,436	0,419	76,15	0	0	0
34	0,527	1,096	199	0	0	0
36	0,433	0,156	30,04	147,1	0	0
37	0,433	0,156	0,798	0,14	-6,38	0
38	0,433	0,156	0,798	0,14	-6,38	0
39	0,433	0,156	28,44	5,04	-230,5	0
41	External electric Power				0	
42	GMGs electric Power				2712	
43	Commercial center delivered electric power				2355	

5. RESULTS

The results presented considerate the thermal system of the case studied in two situations:

- Negentropy of the cooling tower distributed to all Fuels' components responsible for its formation (chiller, GMGs and pumps);
- Negentropy of the cooling tower not distributed.

The following figures (Fig. 3 and Fig. 4) represents schematically these two situations above presented.

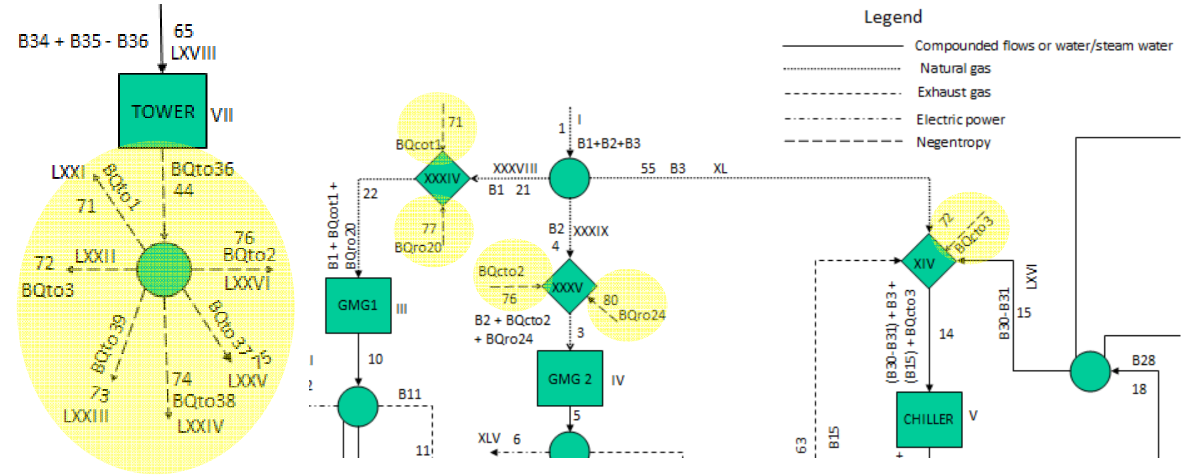

Figure 3. Productive Structure of the cogeneration system evaluated with negentropy distribution to all components responsible for its formation in the cooling tower. In the left side (yellow bright part) shows the cooling tower negentropy formation and its net distribution. The right side shows the Chiller, GMG1 and GMG2 receiving in its Fuels the cooling tower negentropy parcel (smalls yellow bright parts).

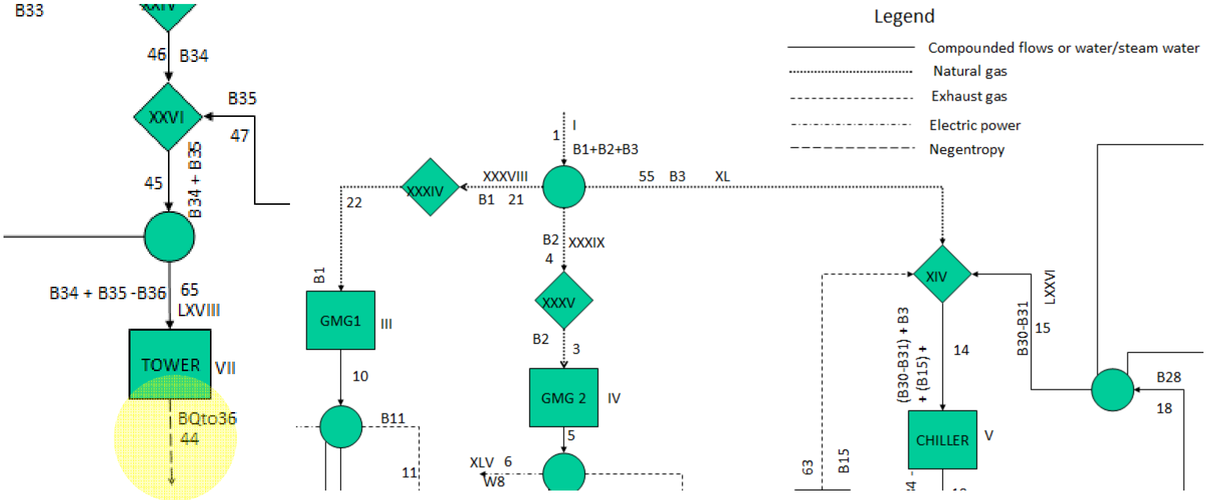

Figure 4. Productive Structure of the cogeneration system evaluated without any negentropy distribution. The left side shows the cooling tower negentropy formation. The right side shows the components with its Fuels free of negentropy from the cooling tower.

The following table (Tab. 2) is the Fuel – Product table showing the irreversibilities values and its percentage for each component.

Table 2. Fuel – Product table

Components	Fuel (kW)	Product (kW)	*Negentropy dist. to all components*		Without any dist.	
			I (KW)	I (%)	I (KW)	I (%)
GMG1	B1 + *BQcot1* + *BQro20*	W7 + (B21-B20) + (B18-B19) + B11	1.873,94	34,43	1.870,80	34,37
GMG2	B2 + *BQcto2* + *BQro24*	W8 + (B25-B24) + (B22-B23) + B12	1.873,94	34,43	1.870,80	34,37
TOWER	B34+B35-B36	BQto36	30,91	0,57	30,91	0,57
CHILLER	(B30-B31) + B3 + (B15) + *BQcto3*	(B9-B10) + (B34-B33)	1.279,16	23,50	1.143,66	21,01

P1	W25 + *BQro25*	B26-B25	41,69	0,77	41,69	0,77
P2	W21 + *BQro21*	B27-B21	41,69	0,77	41,69	0,77
P3	W39 + *BQto39*	B33-B39	187,83	3,45	182,79	3,36
P4	W38 + *BQto38*	B23-B38	5,28	0,10	5,14	0,09
P5	W37 + *BQto37*	B19-B37	5,28	0,10	5,14	0,09
3WV	B13	B15	103,45	1,90	103,45	1,90
RADIATOR	W29+B29-B32	BQro32	-	0,00	-	0,00
COGENERATION SYSTEM	B1+B2+B3+W41	W43 + (B9-B10)	5.442,94	100,00	5.442,94	97,30

For "negentropy distribution to all components", the components' Fuels equations receives *BQ* and for "without any distribution", none of the components receives any *BQ*.

As it can be seen, the first situation has the sum of the irreversibilities column, I (%), at 100%, on the contrary, the second situation due the lack of negentropy distribution, is not able to have I (%) at 100%.

The following two graphics (Fig. 5 and Fig. 6) shows the thermoeconomics and exergoeconomics values from these two situations.

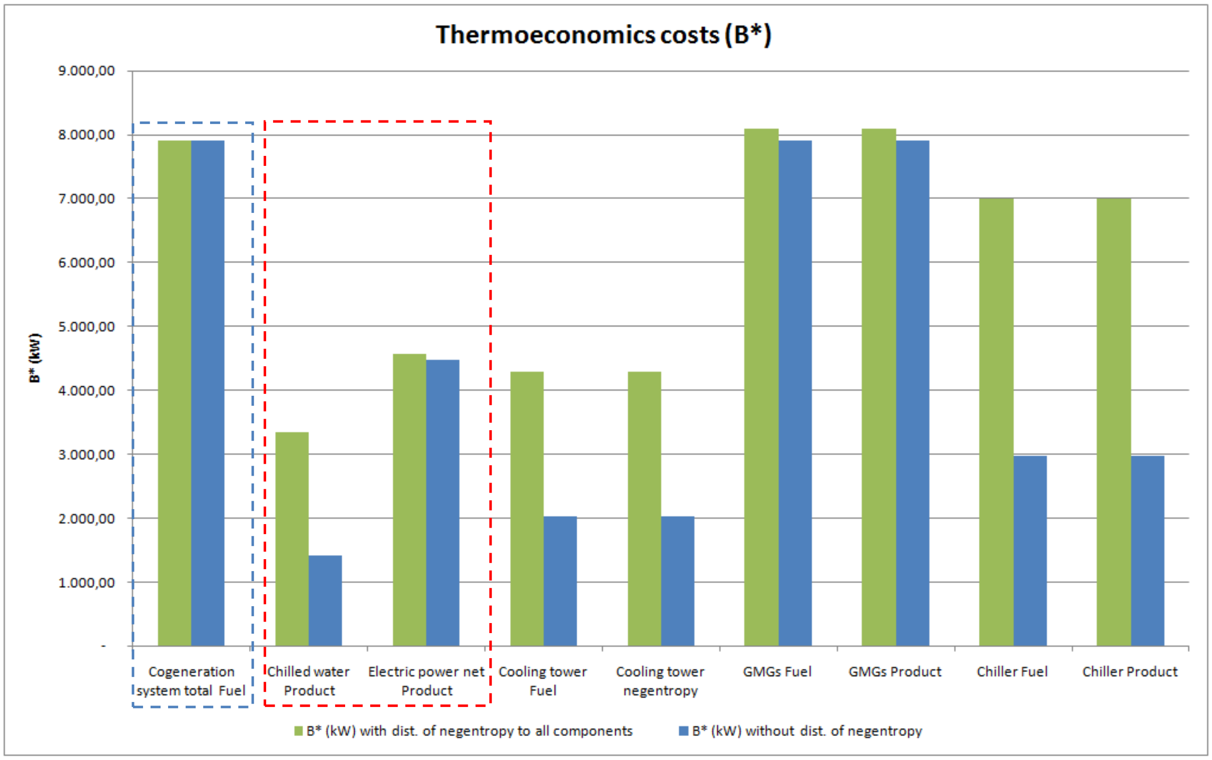

Figure 5. Thermoeconomics results for each situation. Blue dot line shows the plant Fuel and red dot line shows the plant Product (electric power and chilled water).

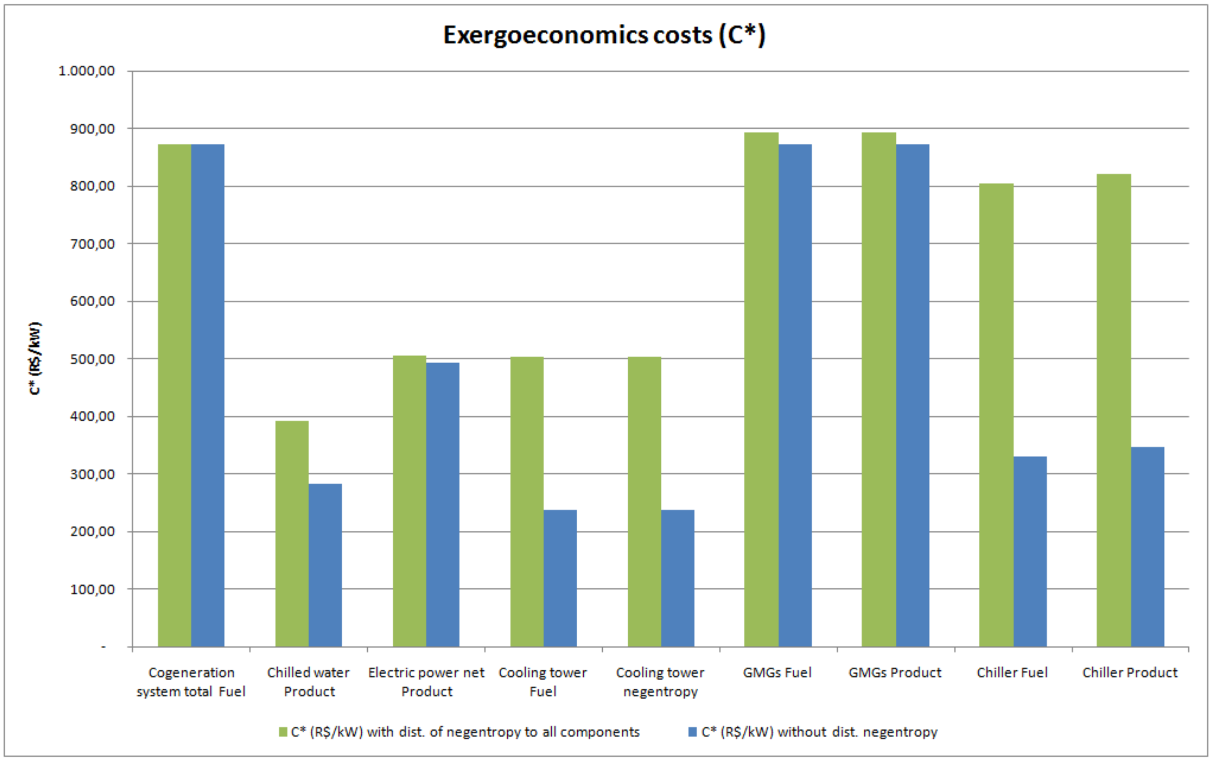

Figure 6. Exergoeconomics results for each situation.

The thermoeconomics results clearly show for the first situation that the balance of the plant (cogeneration system) is correctly, *Plant's Fuel = Plant's Product*. In the second one, the difference missing for that rule is just the value of the cooling tower negentropy (2.023,40 kW) that was not distributed to any components Fuels.

The exergoeconomics results, by its time, due the addiction of monetary values of the components, don't follow the rule: *Plant's Fuel = Plant's Product*. It happens because the exergoeconomics values of the Products are higher than the Fuels due to initial cost (Fuel) receives the interference of irreversibilities through the chain of flows. In the order hand, again because of the lack of negentropy distribution, the second situation has *Plant's Product < Plant's Fuel* which violates the exergoeconomics costs rule. Some components, when negentropy has been distributed, have differences of more than 100% than when not distributed, for example, chiller.

From the figure (Fig. 7) bellow, it is possible verify the thermoeconomics' outputs differences between the two situations. When distributed to all components (1^o situation) the thermoeconomics results are correctly balanced. In the 2^o situation, it can only be balanced when negentropy is considered as a Product of the plant, which is thermodynamically mistake in this case study.

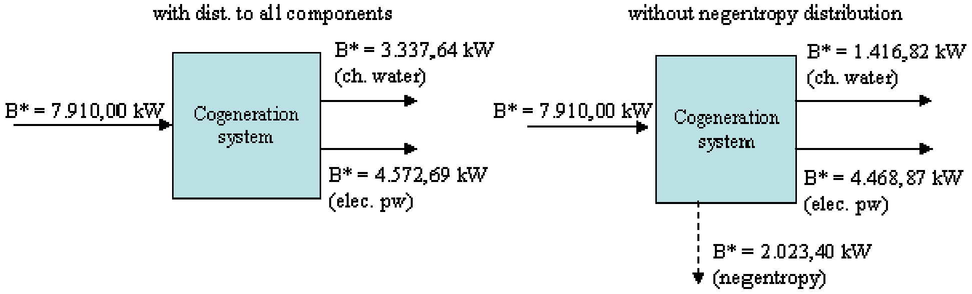

Figure 7. Thermoeconomics results for each situation.

6. CONCLUSIONS

It is possible to conclude that, if it is desired to minutely get know about the costs of a thermal system, it is very important to include all thermal aspects.

One important aspect is the negentropy. Although it is considerate as a kind of process loss, if deeply analyzed, negentropy has a thermal value that engineers should paid attention in order to try to reduce it or take advantage of it by using its exergy in other process, in this case it could be considered as a Product.

The omission of negentropy calculus and its distribution can be considered as an error, because leaves to lower outputs plants' Products, breaking the rule of the thermoeconomics and exergoeconomics costs. If the engineer is not attempt to find the main sources of negentropy, its calculus and distribution necessity, it will generate significant differences in the results coming to wrong conclusions.

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