EXERGETIC AND THERMOECONOMIC ANALYSIS OF A THERMOELECTRIC POWER PLANT
CASE STUDY: THERMOELECTRIC PLANT UTE - RIO MADEIRA

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Abstract.
This paper discusses the theory and application of two performance analyses: exergetic and exergoeconomic one, applied on a real power generation system – the gas turbine LM-6000 system, from Rio Madeira Thermoeletric Power Plant, that is localized in Porto Velho, State of Rondônia, Brazil.
The exergetic analysis shows exergetic values for every flow, and quantifies and identifies irreversibilities and losses of each component of the system. Since the study is developed on an existing system, the exergoeconomic analysis quantifies and depicts costs for each flow based on just fuel cost, namely diesel oil fuel cost. Since the capital costs of all components represents sunk costs for existing system, it is ignored for this evaluation.
In this work, the results of the analyses are compared by two different methods of analysis: Exergoeconomic Method (ME) – developed by Tsatsaronis and Winhold – which is based on balance equations by scalar computation, and Exergetic Cost Theory (ECT) – developed by Valero e fellows from the University of Zaragoza – which is based on calculation by matrixes.

***Keywords**: exergy, thermoeconomic, exergoeconomic*

1. INTRODUCTION

Nowadays many of the socio-political, economic and environmental concerns are focused on energy production and energy systems. The debate of those activities is the core of important global issues. Due to that, the scientific community and engineers have focused their endeavor both on researches that help to improve the energy process for obtaining better use of natural resources, more efficiency and less environmental and social impact, and on analytical skills that help to understand and identified the real inner behavior of energy systems.

As defined Rezac, P. and Metghalchi, H. (2004) the correct word for the power obtained in those systems is not energy, it is exergy. Exergy is a maximum useful energy (work) that can be obtained from a non-equilibrium thermodynamic state between the system and its reference state. Kotas (1985) defined it as a standard of energy quality. The exergy method is a technique based on the concept of exergy, that scientist and engineers utilize to quantify how much usable work potential is supplied to and obtained from the process, and also to quantify the process inefficiencies (irreversibilities and losses).

The objective of this article is the study of exergy concept thru the application of an exergetic and exergoeconomic analysis by two different thermoeconomic methods on a real power generation system – gas turbine LM-6000, General Electric – unit installed at the Rio Madeira Thermoelectric Power Plant. This article is based on the dissertation work elaborated by the authors (Palma, R.S (2007)); in addition of the exergetic and exergoeconomic analysis, the dissertation presents an environmental analysis based on exergy concept where two environmental impact indicators are described and the environmental performance of the gas turbine LM-6000 of the case study is analyzed.

The origins of the exergy concept were approximately 2 centuries ago; when in 1824 the French Sadi Carnot introduced the idea of quantify the maximum work and years later, William Gibbs started to study the available energy of a body and its medium. Since its origins and, in Europe as well as in United States of America, the concept that today is known as "exergy" had been denominated by different terms and symbols. The term Exergy was coined by Zaron Rant in 1956 in his article *Exergie, ein neues Wort fur technische Arbeitsfähigkeit* (Exergy, a new word for work capability) where he explained the foundation of this word. Tsatsaronis (1993) affirmed that *the term has gained acceptance in all countries except the United States where the parallel use of the terms exergy and available in both textbooks and research articles continues to contribute to some misconceptions and confusion surrounding the exergy method.*

In 1983 the term "exergoeconomics" was coined by George Tsatsaronis to express in a precise and unambiguous way the combination of exergetic and economic analysis. Tsatsaronis (1993) appoint out that the term "thermoeconomic" analysis should be used in a more general sense to indicate the combination of any thermodynamic analysis with an economic one.

In this work, the results of the analyses are compared by two different methods of analysis: Exergoeconomic Method (ME) – developed by Tsatsaronis and Winhold – which is based on balance equations by scalar computation, and Exergetic Cost Theory (ECT) – developed by Valero e fellows from the University of Zaragoza – which is based on calculation by matrixes, in this method the system is represented by an incident matrix A where the physic flows and the subsystems are interconnected by digits 1, -1 or 0, depend on their interrelation.

2. EXERGY DEFINITION

Kotas (1985) pointed out that *energy manifests itself in many forms, each with its own characteristics and its quality.* The quality is the capacity of a form of energy to cause change, and this depends on its mode of storage. This mode may be ordered or disordered. An ordered form of energy has an invariant quality, and by work interactions is fully convertible in another form of energy. A disordered form of energy has a variable quality, and depends on both the form of energy and its parameters, and on the environmental parameters.

Accordingly to Kotas (1985), to account for the variable quality of different disordered energy forms, a universal standard of quality is needed. Kotas (1985) expressed that *the most natural and convenient standard is the maximum work which can be obtained from a given form of energy using the environmental parameters as reference.* This standard is known as "*Exergy*". Exergy is work or ability to work due to non-equilibrium thermodynamic state of a flow and its environment or reference state.

The kinetic, potential and electrical energy are forms of ordered energy, and as a result, they can be fully converted to work. When they are related to environmental parameters, they are equal to kinetic, potential and electrical exergy respectively – they are pure exergy. The physical and chemical energy are associated to disordered forms of energy, the exergy components can be determined by the evaluation of the stream under consideration and its reference state. When is assumed the stream have negligible kinetic and potential energy, considering a system at rest relative to the environment, the exergy is defined by eq.1:

$$b = (h - h_o) - T_o \cdot (s - s_o) + \sum_j X_j \cdot (\mu_j - \mu_{(j,o)}) \tag{1}$$

Where the first part of the equation represents the physical component of a mass flowrate, and the second part represents the chemical component composed of a chemical potential (μ_j) of substance j at the environment pressure p_0 and temperature T_0, and a chemical potential ($\mu_{j,0}$) at the dead state, that mean at the concentration of this substance in the atmosphere. The enthalpy and entropy of the energy carrier are representative, respectively, by h and s, and X is a mole fraction of the substance j. The method to calculate exergy for various homogeneous substances has been explained in Palma, S. (2007).

The exergy method is a technique based on exergy, which aim the effective use of the energetic resources. Tsatsaronis (1993) explained that exergetic analysis provides: *a measure to judge the magnitude of the energy waste in relation to energy supplied or transformed in the analyzed process or component; a measure of the quality of energy; and a variable to defined rational efficiencies for energy systems.*

Exergy is considered as a unique rational base for determining costs of the reciprocal actions that a thermal system experiments with its environmental and of the inner irreversibilities of the system. Exergoeconomic analysis quantifies costs from the exergetic values of Flows F, P of each component.

3. POWER PLANT DESCRIPTION

The system studied is a simple Brayton cycle, the LM-6000 is a dual-rotor gas aeroderivate turbine, made by General Electric (GE) and installed at the Rio Madeira Thermoelectric Power Plant. This gas turbine consists of two compressors, low and high pressure; an annular combustion chamber and two gas turbine, low and high pressure. It produces currently 38 MW and utilizes as Fuel Diesel Oil.

Air enters the engine at the variable inlet guide vane, the stream of air enters firstly at the plenum where is chilled by a chiller system to low the inlet temperature of air and increases the efficiency of the turbine system in 2MW. After the stream enters the engine passes into the Low Pressure Compressor (LPC). The LPC compresses the air by a ratio of approximately 2,4:1. Air leaving the LPC is directed into the High Pressure Compressor (HPC). The HPC compresses the air by a ratio of 12:1. The total compression ratio is 30:1 in relation to the environment.

The air leaving the HPC is directed into the Combustion Chamber (CC) where is mixed with the fuel provided by thirty annular nozzles. The fuel/air mixture is initially ignited by an igniter and, once combustion is self-sustaining, the igniter is turned off (GE technical manual, 2003).

The hot gases from the combustor are addressed into the High Pressure Turbine (HPT) which drives the HPC. The combustion gases exit from the HPT and enter into the Low Pressure Turbine (LPT), which drives both the LPC and the output load. The exhaust gases pass through the LPT and discharge into the exhaust duct, where are relieve to the environment at 460°C (GE technical manual, 2003).

The LM-6000 turbine is designed to run with liquid fuel, gas fuel – Gas Natural – and dual fuel; how was indicated above, currently the system is running with the liquid fuel system.

There are measuring instruments located in specific positions of the gas turbine to measure and compare the on-site data with the typical operation level data indicated in the GE technical manual.

Table 2 presents the on-site thermodynamic parameters (see fig. 3).

Table 2. Reference state and gas turbine on-site information

Parameter	Value	Description
T_0	32°C	Environmental temperature
p_0	101,28kPa	Environmental temperature
T_1	15°C	Inlet air temperature
p_1	99kPa	Ambient inlet pressure
T_2	104,5°C	HPC inlet temperature
T_3	537°C	HPC discharge temperature
p_3	2.861,5kPa	HPC discharge pressure
T_5	857,5°C	LPT inlet temperature
p_5	689,5kPa	LPT inlet pressure
T_6	460˚C	Exhausting gases temperature
$\dot{m}_{10}$	2,3kg/s	Fuel mass flow rate
$\dot{m}_1$	108kg/s	Air mass flow rate

The figure 3 shows a flow diagram of the gas turbine LM-6000, which represents the participating flows and their directions, the borders of the system and its aggregation level – the minimum aggregation level was chosen for more accurate results, where each component represents a subsystem.

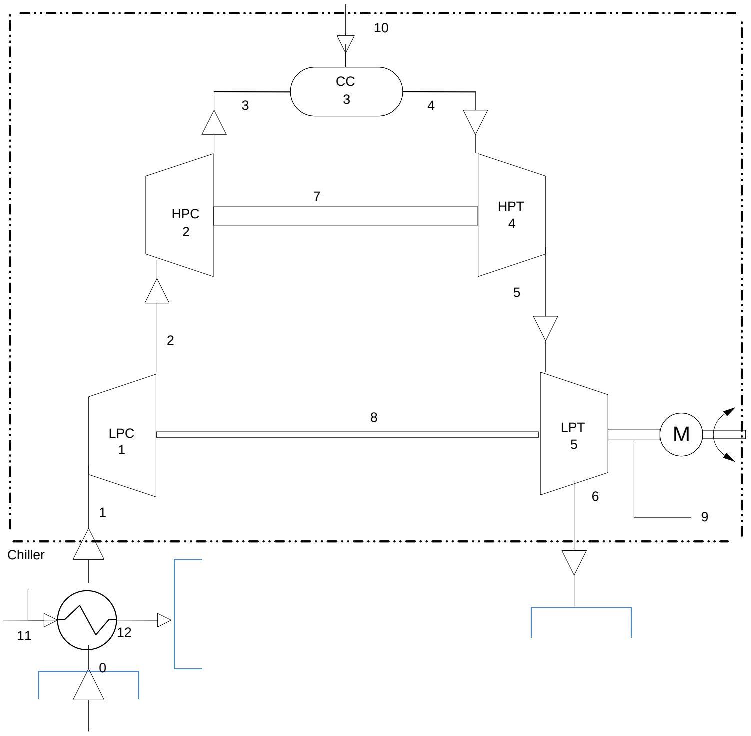

Figure 3. Schematic flow diagram for the unit LM-6000

4. EXERGY ANALYSIS

For calculating the values of exergy for the different flows, are taking into consideration these following criterions:

1. Any effect of heat transfer into each component is considered as exergy destruction of the component. Exception LPT with stream 6 (see fig. 3);
2. It is ignored any nuclear effect, magnetism, electricity and surface tension of any exergetic flow;

3. The components of kinetic and potential energy of any exergetic flow are assumed as zero;
4. The molar chemical composition from the fuel - Diesel Oil is: carbon - 86,3%; hydrogen - 12,8% and sulfur - 0,9%. And its Lower Heating Value (LHV) is considered as 42MJ/kg and its Higher Heating Value (HHV) is considered as 45,58 MJ/kg;
5. Air, combustion gases and exhaust gases are considered as ideal gases;
6. The molar composition of the combustion gases are considered as: Air - 0,9047%; N_2 - 75,625%; O_2 - 14,3451%; CO_2 - 4,1161%; H_2O - 4,9669%; SO_2 - 0,0018%; CO - 0,0006%; HC - 0,0002%; NOx - 0,0397% (GE technical manual);
7. The chemical exergy standard data for combustion gases are taking from the chart supplied by Kotas (1985). Tsatsaronis (1993) affirms that any change of temperature and pressure of the reference state, in relation to the reference state standard (T_0=298,15K andP_0=1,013bar), in the chemical exergy standard of the substances may be negligible;
8. The boundaries of the studied system exclude the chiller system and its streams as was represented in fig. 3, only is taken into consideration the outlet air cooled by the chiller system. It reduces inlet air temperature from 32C to 15C and increases the output power generated in 2 MW that are used for feeding that same chiller system according to Eletronorte information and;
9. It is ignored any cost related to the chiller system, i.e. any cost charged in the inlet air is taken as zero.

The physical exergy of the air flows (1, 2 and 3) and the combustion gases (flows 4, 5 and 6) are calculated by eq.2:

$$b_f = C_p \cdot \left(T - T_o - T_o \cdot LN\left(\frac{T}{T_o} \right) \right) + R \cdot T_o \cdot LN\left(\frac{p}{p_o} \right) \tag{2}$$

Where C_p is the specific heat at constant pressure and R is the ideal gas constant.

The chemical exergy of those flows is zero because they are in chemical equilibrium with the environment. When a flow is in physical or chemical equilibrium with its environment, it is not possible to attain any work, so its physical or chemical exergy is zero.

The chemical exergy of the combustion gases (flows 4, 5 and 6) are calculated by eq.3:

$$b_q = \sum_i X_i \cdot \bar{b}_{q,i} + \bar{R} \cdot T_o \cdot \sum_i X_i \cdot LN(X_i) \tag{3}$$

Where i represents the substance analyzed, and the standard chemical exergy and the ideal gases constant are in mole units.

The chemical exergy of the Diesel Oil (flow 10) is calculated by eq. 4:

$$b_q = \left(1{,}0401 + 0{,}1728 \cdot \frac{h}{c} + 0{,}043 \cdot \frac{o}{c} + 0{,}2169 \cdot \frac{s}{c} \cdot \left(1 - 2{,}0628 \cdot \frac{h}{c} \right) \right) \cdot LHV \tag{4}$$

Where h,c,o,s are mass fractions of H (Hydrogen), C (Carbon), O (Oxygen) and S (Sulfur), and LHV is the Lower Heating Value of the used fuel.

The ECT method represents the LM-6000 system by an incidence matrix **A** that is showed in tab. 3.

Table 3. Incidence Matrix **A** of the LM-6000 system

Subsystems/flow	1	2	3	4	5	6	7	8	9	10
1	1	-1	0	0	0	0	0	1	0	0
2	0	1	-1	0	0	0	1	0	0	0
3	0	0	1	-1	0	0	0	0	0	1
4	0	0	0	1	-1	0	-1	0	0	0
5	0	0	0	0	1	-1	0	-1	-1	0
Perspective from the system	1	0	0	0	0	-1	0	0	-1	1

The exergy destruction D is the direct result of the internal irreversibilities of the system and can be calculated by eq. 5 where **B** is the vector of the exergetic values and **D** is the resulting vector of the exergy destruction.

$$\boldsymbol{A}x\boldsymbol{B} = \boldsymbol{D} \tag{5}$$

Each system and subsystem is composed of physical flows characterized as *Fuel* flow (F) and *Product* flow (P). *Fuel* flow represents the resources expended to generate the desired product, and is not restricted to being fuel as oil, coal or natural gas. *Product* flow represents the productive purpose of the process or system. In a real system exists the *Loss* flows (R), which are not strictly energetic but are part of the result of the process and are associated with material or energy release into the environment. *Fuel*, *Product* and *Loss* are expressed in terms of exergy (MW).

By the ME method, the exergy destruction of each component can be calculated by the scalar relation F-P-R, eq.6:

$$D_k = F_k - P_k - R_k \tag{6}$$

In the above equation the subscript k represents the studied subsystem. The exergetic efficiency (η) – Eq.7 – measures the perfection degree of processes and/or systems, providing a true measure of the performance of a system from thermodynamic and economic viewpoints. It shows how much percentage of *Fuel* in the k-component is present in the *Product* of the same k-component (see tab. 4).

$$\eta = \frac{P}{F} \tag{7}$$

Table 4. Values of the exergetic flows, exergy loss, exergy destruction and exergetic efficiency of each subsystem of the LM-6000 system

Subsystem	**F (MW)**	**P (MW)**	**R (MW)**	**D (MW)**	**η**
LPC	11,99	8,71	0	3,28	0,73
HPC	46,84	45,1	0	1,73	0,96
CC	159	130,7	0	28,31	0,82
HPT	49,5	46,84	0	2,67	0,95
LPT	81,22	49,99	22,89	8,34	0,62

Figure 4 depicts the Grassmann Diagram for the results of the exergy analysis of the LM-6000 system. This diagram is a valuable representation that helps to assess the performance of a plant. It shows not only the exergy flows, exergy losses but also the splitting of exergy streams, recirculation of exergy, and helps to identify the largest contribution for total plant efficient defect. (Kotas, 1985).

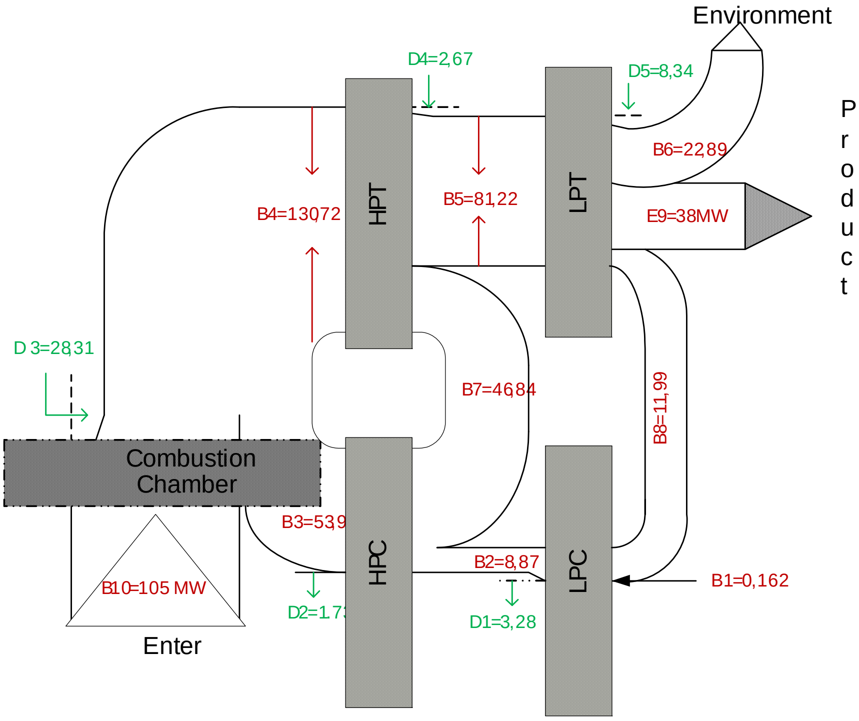

Figure 4. Exergetic Characterization of the LM-6000 system, represented by a Grassmann Diagram

5. EXERGOECONOMIC ANALYSIS

This analysis is applied by the criterion that capital investment and operation and maintenance cost are zero. The gas turbine LM-6000 was installed at the Rio Madeira Plant approximately 10 years ago, and its capital investment represents *sunk cost* because the cost of buying it cannot be reversed. The effect of the operation and maintenance cost are neglected, that way the analysis is based just on the fuel cost, being the fuel cost a weigh economic factor in the exergoeconomic analysis. The gas turbine LM-6000 can used as fuel either oil diesel or natural gas – currently the plant used oil diesel as fuel.

The cost rate of the fuel utilized in the LM-6000, according to information from Eletronorte – Project Management Office – is R$2,00/Lt, including 17% from ICMS tax – Brazilian Tax on the Circulation of Goods and Services – where the engine consumes 550Lt/hr of fuel. The thermoeconomic cost of oil is R$3,055/sec and the thermoeconomic cost of air is zero. The thermoeconomic cost of a physical flow is a quantity of monetary units per seconds required to produce this flow (Valero, Muñoz and Lozano, 1986).

The ECT method presents a methodology based on an incidence matrix **A** (nxm). First of all, to obtain the cost of each stream by a Cost matrix **Â** (mxm) is necessary to define a cost sub-matrix **α** ((m-n)xm) of the system. To construct that sub-matrix of the LM-6000 system may take in consideration some propositions:

Proposition 2F: the HPT discharge flow (stream 5) is part of the *fuel* flow (stream 4) of the same component. So, the unitary exergetic cost of stream 5 has the same unitary exergetic cost of stream 4:

$$\frac{B_4^*}{B_4} - \frac{B_5^*}{B_5} = 0,$$

where $B_4^* - x_1 \cdot B_5^* \rightarrow x_1 = \dfrac{B_4}{B_5}$.

Proposition 2P: the LPT *product* flow is divided in two streams – stream 8 and stream 9 – all the products of a generic equipment have the same unitary exergetic cost:

$$\frac{B_8^*}{B_8} - \frac{B_9^*}{B_9} = 0,$$

where $B_9^* - x_2 \cdot B_8^* \rightarrow x_2 = \dfrac{B_9}{B_8}$

Proposition 1R: all exergetic cost of a exergy loss is zero because this does not have a posterior use, for LM-6000 system the stream 6 – flow leaving LPT – has a exergetic cost equal to zero.

Proposition: the input flows – entering the system – have an exergetic cost equal to its exergetic value $B_{10}^* = B_{10}$, external fuel entering the system. The exergetic cost of stream 1 is considered zero.

With these prepositions the cost sub-matrix is represented as in tab. 5:

Table 5. Cost sub-matrix of the system LM-6000

α	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**ω**
6	1	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	1	B_{10}
8	0	0	0	0	0	0	0	$-x_2$	1	0	0
9	0	0	0	1	$-x_1$	0	0	0	0	0	0
10	0	0	0	0	0	1	0	0	0	0	0

The exergetic cost of a physical flow is defined as the quantity of external resources required to obtain a specific product. All physical flows in a system have an associated unitary exergetic cost. Valero, Lozano and Muñoz (1986) define the exergetic cost as the amount of exergy per unit time required to produce this flow. The unitary exergetic cost of a flow is obtained by the division of its exergetic cost by its exergetic value.

The exergetic cost balance of each subsystem is defined by eq.8:

$$\sum_k^e B_k^* = \sum_k^s B_k^* \tag{8}$$

Where e and s express the flows entering and leaving each k-subsystem, respectively.

Since the system can be defined by a Cost matrix, the exergetic cost balance is defined by eq.9:

$$\hat{A}xB^{*} + \hat{Y}^{*} = 0 \tag{9}$$

Where $\hat{A} = \frac{A}{\alpha}$ and the exergetic amortization vector is represented by $\hat{Y}^{*} = \left(\begin{array}{c} 0 \\ \hline -B_{10} \end{array}\right)$

The thermoeconomic cost of a physical flow of a system can be defined as the quantity of monetary units per second required for producing this flow (Valero, Muñoz and Lozano (1986)). It assesses the impact of both the capital cost and fuel cost on the exergetic flows, and can be calculated by the follow matrix operation in eq.10:

$$\hat{A}x\pi = Z \tag{10}$$

Since the capital cost for the studied system is considered zero, Z=0

The unitary exergoeconomic cost is defined by Valero, Muñoz and Lozano (1986) as the cost, in monetary units per GJ, of each unit of exergy of this flow, and can be calculated by eq.11:

$$\pi_i = c_i \cdot B_i \tag{11}$$

And, the unitary thermoeconomic cost is defined by Valero, Muñoz and Lozano (1986) as the cost, in monetary units per GJ, of each unit of exergy expended in producing the flow, and can be calculated eq.12:

$$\pi_i = c_i^{*} \cdot B_i^{*} \tag{12}$$

Where i expresses the analyzed flow.

Table 4 shows the values of the exergetic cost, unitary exergetic cost, thermoeconomic cost, unitary thermoeconomic cost and unitary exergoeconomic cost of the flows of the LM-6000 system.

Table 6. Thermoeconomic parameters of the LM-6000 system

Flow	**B^* (MW)**	**κ^***	**π (R$/seg)**	**c^* (R$/GJ)**	**c (R$/GJ)**
1	0,00	0,00	0,00	0,00	0,00
2	33,15	3,74	0,96	29,08	108,65
3	117,38	2,18	3,42	29,09	63,27
4	222,44	1,70	6,47	29,09	49,49
5	138,21	1,70	4,.02	29,08	49,49
6	0,00	0,00	0,00	0,00	0,00
7	84,23	1,80	2,45	29,10	52,33
8	33,12	2,76	0,96	29,08	80,41
9	105,00	2,76	3,06	29,08	80,41
10	105,00	1,00	3,06	29,08	29,08

By the ME method the balance equation of each component is essential to calculate costs. The thermoeconomic cost balance equation is:

$$\sum_{k=1}^{e} \pi_k = \sum_{k=1}^{s} \pi_k \tag{13}$$

The solution of the balance equations depend on the auxiliary thermoeconomic relations and the relation of Eq.(11) and Eq.(12). The auxiliary thermoeconomic relations for the LM-6000 system are:

$c_8 = c_9$ for LPT and;

$c_4 = c_5$ for HPT.

All components of a system with m exiting exergy flows require m-1 auxiliary thermoeconomic relations to solve the cost balance. In the case of a component having only one exit stream, the cost balance may be solved for the cost of exergy unit of the exiting stream without requires auxiliary thermoeconomic relation (Bejan, Tsatsaronis and Moran (1996)).

For the calculation of exergetic cost and unitary exergetic cost Bejan, Tsatsaronis and Moran (1996) based their calculation on the unitary exergoeconomic cost of the external fuel – Diesel Oil, stream 10.

$$B_i^* = \sum_{i=1}^{10} \frac{\pi_i}{c_{10}} \tag{14}$$

$$k_i^* = \sum_{i=1}^{10} \frac{c_i}{c_{10}} \tag{15}$$

6. CONCLUSION

This analytic study of the LM-6000 system was made by two methods of calculation – the Exergoeconomic Method (ME), implemented by Tsatsaronis and Winhold (1985a) and the Exergetic Cost Theory (ECT), development by Valero, Muñoz e Lozano (1986) – by this analysis is concluded that both methods come from the same theoretical base. All the results were comparative by both methods, obtaining the same values.

It is concluded that the ECT is a method of calculation more viable for complex system, where more components, physics flows, bifurcations and flow recirculation are present; this method allows also a simple implementation in calculation software. Meanwhile, the Exergoeconomic Method become easier for simpler systems, as the system analyzed in this work.

The results of the exergetic analysis show that the combustion gases (stream 4) has the larger exergetic value of all flows, followed by the exergetic value of the external fuel – diesel oil. The exergetic value of the exhaust gases (stream 6) is 22,89MW (major as physical exergy component), this fact is an environmental concern due to the disequilibrium thermodynamic between the flow and the environment.

The combustor chamber obtained the largest rate of exergy destruction of all the subsystem, with 28,31 MW, this value represents 3,39 times larger that the second component with larger value of exergy destruction – LPT with 8,345 MW. This result is due to the large inner irreversibilities arising in chemical reactions.

The exergetic efficiency for the combustor chamber is 82%, and this value means that 82% of the exergy supplied to the subsystem is recovered in the combustion gases, and just 18% of the exergy supplied represent the exergy lost in the process.

The results from the exergoeconomic analysis show that the LM-6000 system needs much exergy, per second, to produce the combustor gases (stream 4) that any other stream of the system. The exergetic cost of the combustor gases is 222,4 MW.

The unitary exergetic cost of each flow is always greater that one, and depends on the quality of performance and expresses how many times the expended exergy by the subsystem to produce the flow is greater that the exergetic value of that flow. The stream 2 has the largest unitary exergetic cost, provoked by the LPC. The LPT increase the unitary exergetic cost in the process of energy generation, this result is showed by the values of the unitary exergetic cost of the stream 5 and 4 that are 1,7; meanwhile the unitary exergetic cost of the stream 9 (Product of the system) is 2,76.

The stream 4 (combustion gases) needs more quantity of monetary units per second to be produced, with a thermoeconomic cost equal to R$6,47/sec. the stream 5 (combustion gases) needs R$4,02/sec for being produce, being the second flow with larger thermoeconomic cost of the system.

The unitary exergoeconomic cost for the final product (stream 9) is $80,41/GJ, the value means that the energy generated in the system costs R$0,289 kW-hr, value without the ICMS tax as in Feb 2007. This result allows assessing in objective way, the impact due to just external fuel cost, working as a comparative parameter in relation to other external fuel that can be used in this LM-6000 system such as Natural Gas.

The thermoeconomic cost of an external fuel is equal to the sum of the thermoeconomic costs of the final products of the system. For the system in consideration, both the thermoeconomic cost of the external fuel (stream 10) and the thermoeconomic cost of the stream 9 – final product – are equal R$3,06/sec. as in Feb 2007

7. ACKNOWLEGDEMENT

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