# EXERGOECONOMIC COMPARASION BETWEEN A SINGLE EFFECT AND DOUBLE EFFECT LITHIUM BROMID-WATER ABSORPTION REFRIGERATION SYSTEM

**Hugo Lima Moreira,** hugolimabr@yahoo.com.br
Centro de Perícias Científicas "Renato Chaves", Rodovia dos Trabalhadores s/n, Belém-Pa, CEP: 66640-000.

**Carlos Antonio Cabral dos Santos,** cabral@les.ufpb.br
UFPB/LES, Laboratório de Energia Solar, Campus I, João Pessoa-PB, CEP: 58059-900.

***Abstract.*** *This work presents the exergoeconomic comparison between a single-effect and double-effect absorption refrigeration systems with lithium bromide-water pair, operating with the direct combustion of natural gas. The method combines exergetic and economic analysis and this study was done after the energetic analysis of all system's components. The exergoeconomic evaluation of the thermodynamic flows, which go through these cycles, was performed for operational conditions aimed at a refrigerating capacity from 5 to 15 TR. It was applied to the present systems to reveal which component in the cycle would be wasting energy. This method was also based on the incidence matrix that represents the physical structure of the above-mentioned systems. The exergoeconomic method combines the exergetic and economic analysis, and was applied to each system to reveal which one is thermoeconomically more efficient.*

***Keywords***: *Absorption system, exergoeconomy, thermoeconomy.*

## 1. INTRODUCTION

Today, the absorption cooling systems have received a lot of attention, both from the perspective of thermal analysis and the use of different energetic sources. Its use in cogeneration systems has been seen as the best appropriate and the most energetically and economically thrifty.

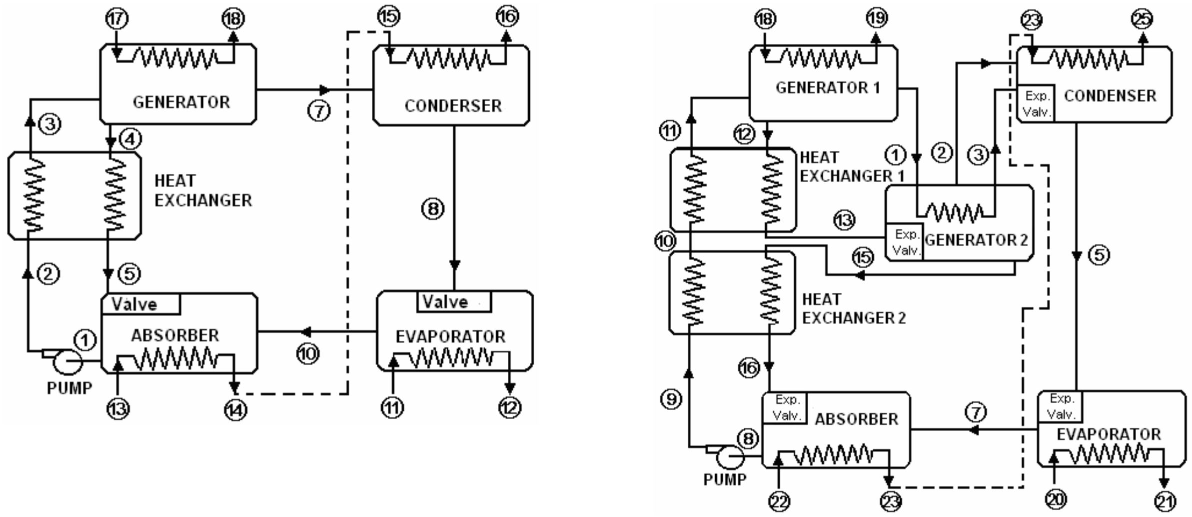
More recently, thermal systems analyses have been followed by an economic consideration. These analyses have been followed by a simultaneous approach from the thermodynamic and the economic perspectives. The exergetic analysis has been used to evaluate thermal systems so as to include the energy quality concept in the thermodynamic analysis, which otherwise is not attained when only the first law of thermodynamics or the energetic analysis is applied. The exergetic analysis has already become an essential parameter for the equipments' and thermal systems' optimization by reducing the detected irreversibilities (Bejan *et al.*, 1996).

Several important methodologies for the exergetic analysis can be found in the literature (Kotas, 1985; Szargut, 1988 and Tsatsaronis, 1993). Aphornratana and Eames (1995) have shown the influence of the flow rate in the irreversibility of a single-effect absorption cooling system. Moreira (2004) presented the exergetic study for a single and double-effect LiBr-water unit under way with local technology, with capacities varying between 5 and 15 tons of cooling. Berlitz *et al.* (1999) presented economic studies related to the thermodynamic model for double effect LiBr-water absorption refrigerators.

The thermoeconomic analysis, also known as exergoeconomic, has followed two ways: the first can be described as a costs calculating method, i.e., a method that uses the mean cost as basis to evaluate the rational price. This method includes the mean cost approach introduced by Hernandez *et al*. (2003). They have proposed the mean cost approach to the thermoeconomic optimization of the heat supplied to the generator of the single-effect absorption cooling system, using both water-lithium bromide and water-ammonia pairs. That paper offers a detailed energetic analysis followed by the mean cost calculation for each exergy unity, for all the cogeneration plant flows.

The second comprises a method that uses the marginal costs so as to minimize the components' or the products' costs. These methods include the functional thermoeconomic analysis as presented by Erlach *et al.* (1999). Those researchers introduce a structural theory as a reference and a mathematical formulation common to all methodologies, using thermoeconomic models that can be described by linear equations. The pros and cons in each method can be found in each one of the above mentioned method.

The present paper shows the exergetic cost theory applied to a serial single and double-effect absorption cooling system using water-lithium bromide, operating between 5 and 15 tons of cooling. The systems is formed by the high pressure generator, the low pressure generator, two intermediate exchangers for double-effect system, the absorber, the condenser, the evaporator, a pump and the expansion valves for each systems. For this application it is necessary to suppress the flows after the expansion valves, because these are isoentalpic processes. Thus, for our analysis, each valve will be part of the corresponding subsequent equipment, as schematically described in Fig. 1.




Single-effect system for exergoeconomic analysis. Double-effect system for exergoeconomic analysis.

Figure 1 – Representation of single and double effect systems for exergoeconomic analysis.

## 2. METODOLOGY OF THE EXERGONOMIC ANALISYS

The exergoeconomic analysis have as a meaning objective, among others, determine the exergetics and monetary costs of all system components; allowing the knowledge and the comprehension of the forming process of these costs; promoting the optimization not only of the specific variables of each system component, but of the whole system.

This detailed analysis was obtained with the contribution of the Thermodynamics Second Law in conjunction with exergetic analysis, in which, according to Tsatsaronis (1993), would permit a better measurement to evaluate the magnitude of lost energy in relation to the amount of supplied energy under the form of energetic resource; it would also permit a better measurement of quality or loss from a thermodynamic point of view, thus becoming a good variable to define the reasonable efficiency for the energetic system.

### 2.1. The Exergoeconomic Analysis Formulation of the Systems

For analysis the following simplifying hypotheses were made:

- The lithium bromide-water solution, both in the generator and the absorber, are presumed to be in balance as regards to corresponding temperatures and pressures;
- The work to pump the solution in the recirculation is negligible;
- The working fluid is in a saturation state at the condenser's and the evaporator's outputs;
- The concentrated solution at the generator's output, and the diluted solution at the absorber's output, are considered saturated;
- The temperatures are uniform in the mean components (generator, condenser, evaporator, and absorber).

The exergoeconomic analysis, is preceded by the energetic and exergetic analyses and have the input data used as a basis indicated in Table 1. The thermophysical properties of the solution and the cooling liquid, to the exception of the entropy, are obtained from the Engineering Equation Solver [EES] software. The energetic and exergetic analysis details are given by Moreira (2004), who uses the solution properties' equations supplied by Kaita (2001) and Sun (1997).

To calculate the exergetic cost, the exergy of each physical flow must be known. After the operational conditions were defined, all the thermodynamic properties necessary to calculate the exergies were estimated. Table 3 shows theses properties as well as each flow's exergy specification.

The incidence matrix for the plant on Figure 1 is presented by the $\mathbf{n} \times \mathbf{m}$ order $\mathbf{A}$ matrix, where $\mathbf{n}$ is the equipments number, and $\mathbf{m}$ are the flows for each system. Each line in the matrix represents an equipment, and each column is a flow. Their elements $\mathbf{a_{ij}}$ are +1 if the flow $\mathbf{j}$ enters the equipment $\mathbf{i}$; and -1 if the flow leaves the equipment, or zero, if the flow is not related to the equipment. Table 2 shows the dimensions (6 × 15) of the resultant incidence matrix for single effect system and Table 3 show the (8 × 20) of the resultant incidence matrix for double-effect system.

The economic rating of the thermodynamic flows that perform one cycle will be set up for the operational conditions later defined, always focusing the utilization of the available exergy from burning process of single and double effect absorption refrigeration systems. The exergoeconomic method combines the exergetic and economic analysis, and was applied to each system to reveal which one is thermoeconomically more efficient.

Table 1. Input data for simulation and energetic and exergetic analyses of the cooling systems.

| | |
|---|---|
| Available heat at the generator 1 | 21,1 kW |
| Condenser temperature | 37ºC |
| Evaporator temperature | 5ºC |
| Strong solution concentration | 64% |
| Wake solution concentration | 48% |
| Temperature difference in the heat exchanger 1 | 38ºC |
| Temperature difference in the heat exchanger 2 | 20ºC |
| Combustion gas temperature in the generator input | 300ºC |
| Combustion gas temperature in the generator output | 200ºC |
| Cold water temperature in the evaporator input | 12ºC |
| Cold water temperature in the evaporator output | 7ºC |
| Cooling water temperature in the absorber input | 29,5ºC |
| Cooling water temperature in the absorber output | 35ºC |

Table 2. Input data for simulation and energetic and exergetic analyses of the single effect system.

| **Flows →** | 1 | 2 | 3 | 4 | 5 | 7 | 8 | 10 | 11 | 12 | 13 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Equipment↓** | | | | | | | | | | | | | | | |
| Generator | 0 | 0 | +1 | -1 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | +1 | -1 |
| Condenser | 0 | 0 | 0 | 0 | 0 | +1 | -1 | 0 | 0 | 0 | 0 | +1 | -1 | 0 | 0 |
| Evaporator | 0 | 0 | 0 | 0 | 0 | 0 | +1 | -1 | +1 | -1 | 0 | 0 | 0 | 0 | 0 |
| Absorber | -1 | 0 | 0 | 0 | +1 | 0 | 0 | +1 | 0 | 0 | +1 | -1 | 0 | 0 | 0 |
| Heat Exchanger | 0 | +1 | -1 | +1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pump | +1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 3. Input data for simulation and energetic and exergetic analyses of the double-effect system.

| **Flows→** | 1 | 2 | 3 | 5 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 15 | 16 | 18 | 19 | 20 | 21 | 22 | 23 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Equipment↓** | | | | | | | | | | | | | | | | | | | | |
| Generator 1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | +1 | -1 | 0 | 0 | 0 | +1 | -1 | 0 | 0 | 0 | 0 | 0 |
| Generator 2 | +1 | -1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | +1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Condenser | 0 | +1 | +1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | +1 | -1 |
| Evaporator | 0 | 0 | 0 | +1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | +1 | -1 | 0 | 0 | 0 |
| Absorber | 0 | 0 | 0 | 0 | +1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | +1 | 0 | 0 | 0 | 0 | +1 | -1 | 0 |
| Pump | 0 | 0 | 0 | 0 | 0 | +1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Heat Exchanger 1 | 0 | 0 | 0 | 0 | 0 | 0 | +1 | -1 | 0 | 0 | 0 | +1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Heat Exchanger 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | +1 | -1 | +1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

The exergy balance for each equipment is given by Eq. 1:

$$\sum_{entrance} B_i^* - \sum_{exit} B_j^* = D \tag{1}$$

It is possible to express this balance by means of the incidence matrix **A** and the vector **B** through:

$$[A]\times[B]=[D] \tag{2}$$

where **D** is the dimension vector (**n** x 1 ) that determines the exergetic destruction; each one of its **n** elements represents one specific equipment.

The exergy balance supplies the exergy destruction value for each equipment in the system, and this destruction is the difference between the input exergy and the output exergy in each component. This happens because in every real process there will always be destructions and losses, which cause a higher exergy in the process input related to the product exergy. By definition, the exergetic cost of a product is the exergy amount necessary to obtain it (B*).

The product's obtaining will be more efficient the smaller the relation between B* and B. Thus, the unitary exergetic cost (**k**) is defined as the exergy necessary to obtain the exergy unit of the product:

Appling the proposition of the Valero et al (1986), of the subsystem that compound the plant, determinate the system of (**m** - **n**) equations that will calculate the cost that the referred flux of the plant will have form the following form.

$$\begin{pmatrix} A \\ --- \\ \alpha \end{pmatrix} \times B^* = \begin{pmatrix} 0 \\ --- \\ \omega \end{pmatrix} \qquad (3)$$

Valero *et al.* (1986) has formulated an endowment proceeding of exergetic costs, based only in thermodynamics precepts, such as:

- The exergetic cost of a flow ($B^*$), resource (F*), or product ($P^*$) is the real quantity of exergy needed to produce it;
- A detailed analysis of the global nature of the process and of the function of each subsystem in progressive formation of the final products, is the only requirement needed to solve the endowment problem of exergetic costs;
- The exergetic costs in the entrance of an equipment or component of the system should be rated with the flow that outcomes from it.

Based on these postulates, a collection of proposition has been created and the systematic application on the equipments will permit us value the exergetic costs of the flows. These propositions will be set up in a general way, and afterwards will be applied in the systems to be considered.

- Proposition 1 – The exergetic cost is a conservative property

$$\sum_{entrance} B_i^* - \sum_{exit} B_j^* = 0 \qquad (3)$$

- Proposition 2 – for a system or control of volume with more than one energetic resource, the exit unitary exergetic costs must be equal to the entrance ones (resource rules)

For a general system example as shown on Fig. 2, we have:

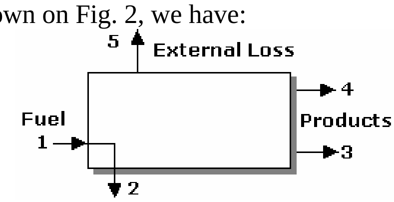



Figure 2. General System Example (Torres, 1999)

$$\frac{B_1^*}{B_1} = \frac{B_2^*}{B_2} \qquad (4)$$

- Proposition 3 – if a system has a product formed by various flows, the exergetic cost will be the same for each one of them (product rule). In the Fig. 2 example we have:

$$\frac{B_3^*}{B_3} = \frac{B_4^*}{B_4} \qquad (5)$$

- Proposition 4 – in the absence of value of an external loss flow, we shall admit a null exergetic cost. In this example we have:

$$\frac{B_5^*}{B_5} = 0 \qquad (6)$$

- Proposition 5 – in the absence of external value, the exergetic cost of the entrance flows in the system is equal to its exergy. In this example we have:

$$B_1^* = B_1 \qquad (7)$$

The methodology to value the monetary costs is an application of a cost balance to a subsystem or equipment as shown on Fig. 3.

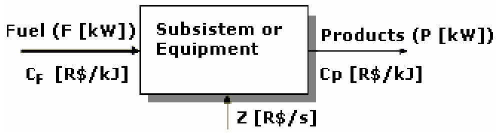



Figure 3. Balance of Monetary Costs.

The balance shown on Fig. 3 can be mathematically represented as follows:

$$C_P.B_P = C_F.B_F + Z \tag{4}$$

Where $C_F$ and $C_p$ represent the costs in monetary unit per exergy unit for the resource and the product respectively; in the same way $B_f$ and $B_p$ represent the amount of exergy for the resource and the product, and Z is the invested capital. In the particular case of a plant in operation and already paid, we can take Z as a null value, although that's not the case, because the capital invested in each internal combustion engine is an important economic parameter for comparison. To determine Z, we shall consider:

$$Z_{(i)} = \frac{3600\cdot(A/P)}{t_{op}}\cdot F_i \tag{5}$$

Where $t_{op}$ represents the useful life time (in seconds); $F_i$ represents the investment for each equipment or subsystem; (A/P) represents the capital recovering factor and will be calculated by Eq. (6), considering I the interest rate (varying from zero to 1); and N represents the reimbursement period (in years).

$$\left(\frac{A}{P}\right) = \frac{I*(1+I)^N}{(1+I)^N - 1} \tag{6}$$

## 3. RESULTS AND DISCUSSION

The results obtained from computer simulation for the single and double-effect system are showed in Tab. 4 and Tab. 5 respectively. They were based on the thermodynamics model carried out by Moreira *et al.* (2005), having as initial parameters those indicated in Tab.1, and are: temperature values (T), pressure (p), solution concentration (X), flow rate (m), enthalpy (h), entropy (s), and exergy (B), referring to the points as represented in Fig. 1.

Table 4 - Thermodynamics analysis results of the single effect system.

| Points | T (ºC) | p (kPa) | X (%) | $\dot{m}$ (kg/s) | h (kJ/kg) | s (kJ/kg.K) | b (kJ/kg) | B (kW) |
|---|---|---|---|---|---|---|---|---|
| 1 | 34,44 | 0,87 | 54,9 | 0,050 | 83,4 | 0,2211 | 22,22 | 1,116 |
| 2 | 34,44 | 6,275 | 54,9 | 0,050 | 83,41 | 0,2211 | 22,22 | 1,116 |
| 3 | 63,6 | 6,275 | 54,9 | 0,050 | 143,2 | 0,4053 | 27,09 | 1,360 |
| 4 | 91,13 | 6,275 | 64 | 0,043 | 231,2 | 0,4864 | 90,89 | 3,914 |
| 5 | 52,13 | 6,275 | 64 | 0,043 | 161,5 | 0,2827 | 81,92 | 3,528 |
| 6 | 52,13 | 0,87 | 64 | 0,043 | 161,5 | 0,2827 | 81,92 | 3,528 |
| 7 | 80,59 | 6,275 | 0 | 0,007 | 2654 | 8,56 | 94,34 | 0,673 |
| 8 | 37 | 6,275 | 0 | 0,007 | 154,9 | 0,5319 | 1,06 | 0,007 |
| 9 | 5 | 0,87 | 0 | 0,007 | 154,9 | 0,5577 | -6,633 | -0,046 |
| 10 | 5 | 0,87 | 0 | 0,007 | 2510 | 9,025 | -176,3 | -1,251 |
| 11 | 12 | – | – | 0,804 | 50,24 | 0,1804 | 1,176 | 0,946 |
| 12 | 7 | – | – | 0,804 | 29,31 | 0,1063 | 2,337 | 1,880 |
| 13 | 29,5 | – | – | 1,673 | 123,5 | 0,4296 | 0,1513 | 0,253 |
| 14 | 32,45 | – | – | 1,673 | 135,9 | 0,4702 | 0,4041 | 0,676 |
| 15 | 32,45 | – | – | 1,673 | 135,9 | 0,4702 | 0,4041 | 0,676 |
| 16 | 35 | – | – | 1,673 | 146,5 | 0,505 | 0,7173 | 1,200 |
| 17 | 300 | – | – | 0,196 | 290,6 | 7,642 | 305,5 | 52,75 |
| 18 | 200 | – | – | 0,196 | 183,3 | 7,422 | 263,9 | 51,87 |

Table 5 - Thermodynamics analysis results of the double-effect system.

| Points | T (ºC) | p (bar) | X (%) | ṁ (kg/s) | h (kJ/kg) | s(kJ/kg.K) | b(kJ/kg) | B (kW) |
|---|---|---|---|---|---|---|---|---|
| 1 | 134,5 | 77,52 | 0 | 0,006 | 2747 | 7,66 | 468,1 | 3,254 |
| 2 | 92,64 | 77,52 | 0 | 0,006 | 388 | 1,223 | 28,14 | 0,195 |
| 3 | 80,58 | 6,275 | 0 | 0,007 | 2651 | 8,562 | 102,6 | 0,741 |
| 4 | 36,99 | 6,275 | 0 | 0,006 | 388 | 8,312 | -2086 | -14,50 |
| 5 | 37 | 6,275 | 0 | 0,014 | 154,9 | 0,5319 | 1,06 | 0,015 |
| 6 | 4,959 | 0,87 | 0 | 0,014 | 154,9 | 0,5577 | -6,633 | -0,094 |
| 7 | 5 | 0,87 | 0 | 0,014 | 2510 | 9,025 | -176,3 | -2,499 |
| 8 | 30,83 | 0,87 | 52,9 | 0,096 | 70,25 | 0,2089 | 12,7 | 1,227 |
| 9 | 30,85 | 77,52 | 52,9 | 0,096 | 70,3 | 0,2091 | 12,7 | 1,227 |
| 10 | 50,85 | 77,52 | 52,9 | 0,096 | 113 | 0,3416 | 15,91 | 1,537 |
| 11 | 88,85 | 77,52 | 52,9 | 0,096 | 191,4 | 0,576 | 24,39 | 2,357 |
| 12 | 139,6 | 77,52 | 57 | 0,089 | 302,1 | 0,8003 | 68,24 | 6,120 |
| 13 | 101,6 | 77,52 | 57 | 0,089 | 226,8 | 0,6032 | 51,7 | 4,636 |
| 14 | 75,46 | 6,275 | 57 | 0,089 | 226,8 | 0,4576 | 95,1 | 8,529 |
| 15 | 86,54 | 6,275 | 62 | 0,082 | 213,1 | 0,4778 | 75,37 | 6,215 |
| 16 | 66,54 | 6,275 | 62 | 0,082 | 196,4 | 0,3713 | 90,41 | 7,455 |
| 17 | 77,57 | 0,87 | 62 | 0,082 | 196,4 | 0,4307 | 72,73 | 5,997 |
| 18 | 300 | – | – | 0,122 | 290,6 | 7,642 | 78,85 | 9,690 |
| 19 | 200 | – | – | 0,122 | 183,3 | 7,422 | 37,18 | 4,569 |
| 20 | 12 | – | – | 1,596 | 50,24 | 0,1804 | 1,176 | 1,876 |
| 21 | 7 | – | – | 1,596 | 29,31 | 0,1063 | 2,337 | 3,729 |
| 22 | 29,5 | – | – | 2,809 | 123,5 | 0,4296 | 0,1515 | 0,425 |
| 23 | 32,45 | – | – | 2,809 | 135,9 | 0,4702 | 0,4045 | 1,136 |
| 24 | 32,45 | – | – | 2,809 | 135,9 | 0,4702 | 0,4045 | 1,136 |
| 25 | 35 | – | – | 2,809 | 146,5 | 0,505 | 0,7175 | 2,015 |

From the Eq. (2) determine the balance of exergy for each component in both the systems. Thus, like the destruction exergetic to the respective components. The matricidal form for the system of simple effect is showed in the Eq. (7) e for the system of double effect having Eq. (8).

$$\begin{pmatrix} 0 & 0 & 1 & -1 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 \\ 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 1 & -1 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 & -1 & 0 & 0 & 0 \\ 0 & 1 & -1 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \times \begin{pmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \\ B_7 \\ B_8 \\ B_{10} \\ B_{11} \\ B_{12} \\ B_{13} \\ B_{15} \\ B_{16} \\ B_{17} \\ B_{18} \end{pmatrix} = \begin{pmatrix} D_g \\ D_c \\ D_{ev} \\ D_{ab} \\ D_{tc} \\ D_b \end{pmatrix} \quad (7)$$

$$\begin{pmatrix} -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 \\ 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \times \begin{pmatrix} B_1 \\ B_2 \\ B_3 \\ B_5 \\ B_7 \\ B_8 \\ B_9 \\ B_{10} \\ B_{11} \\ B_{12} \\ B_{13} \\ B_{15} \\ B_{16} \\ B_{18} \\ B_{19} \\ B_{20} \\ B_{21} \\ B_{22} \\ B_{23} \\ B_{25} \end{pmatrix} = \begin{pmatrix} D_{g1} \\ D_{g2} \\ D_c \\ D_{ev} \\ D_{ab} \\ D_b \\ D_{tc1} \\ D_{tc2} \end{pmatrix} \tag{8}$$

To the system of single effect the component that reveled having the more destruction exergetic was the generator following of absorber like showing Fig. 4:

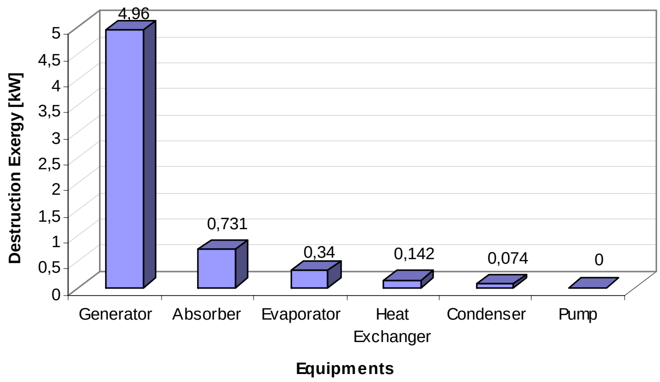



Figure 4. Exergetic destruction of the single-effect system components.

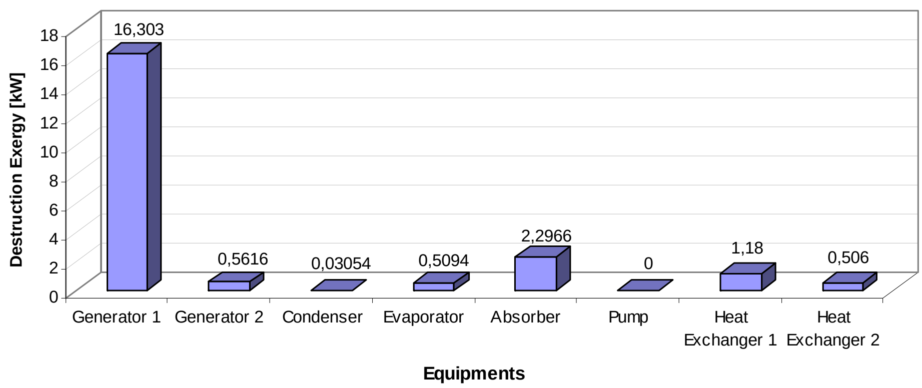



Figure 5. Exergetic destruction of the double effect system components.

The system of double effect developed the same behavior with the destruction exergetic of Generator 1 being the more, followed of absorber, as shown in Fig. 5.

Applying the preposition of Valero *et al* (1986) to the system of single effect having:

$$
\begin{pmatrix}
0 & 0 & 1 & -1 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 \\
0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 1 & -1 & 0 & 0 & 0 & 0 & 0 \\
-1 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 & -1 & 0 & 0 & 0 \\
0 & 1 & -1 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{B_8} & \frac{-1}{B_{10}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{1}{B_4} & \frac{-1}{B_5} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\frac{-1}{B_1} & 0 & 0 & 0 & \frac{1}{B_5+B_{10}} & 0 & 0 & \frac{1}{B_5+B_{10}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & \frac{-1}{B_3} & \frac{1}{B_4+B_7} & 0 & \frac{1}{B_4+B_7} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{1}{B_4} & 0 & \frac{-1}{B_7} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{pmatrix}
\times
\begin{pmatrix}
B_1^* \\ B_2^* \\ B_3^* \\ B_4^* \\ B_5^* \\ B_7^* \\ B_8^* \\ B_{10}^* \\ B_{11}^* \\ B_{12}^* \\ B_{13}^* \\ B_{15}^* \\ B_{16}^* \\ B_{17}^* \\ B_{18}^*
\end{pmatrix}
=
\begin{pmatrix}
0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ B_{11} \\ B_{13} \\ B_{17} \\ 0
\end{pmatrix}
\qquad (9)
$$

For the system of double effect having:

$$
\begin{pmatrix}
-1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 \\
1 & -1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 \\
0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & -1 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\frac{1}{B_1} & 0 & \frac{-1}{B_3} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\frac{-1}{B_1+B_{12}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{B_{11}} & \frac{-1}{B_1+B_{12}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{1}{B_5} & \frac{-1}{B_7} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \frac{-1}{B_2+B_3} & \frac{-1}{B_2+B_3} & \frac{1}{B_5} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \frac{-1}{B_7+B_{16}} & \frac{1}{B_8} & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{B_7+B_{16}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{B_{15}} & \frac{-1}{B_{16}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\frac{1}{B_1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{B_{12}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \frac{1}{B_2} &  & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{B_{15}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0
\end{pmatrix}
\times
\begin{pmatrix}
B_1^* \\ B_2^* \\ B_3^* \\ B_5^* \\ B_7^* \\ B_8^* \\ B_9^* \\ B_{10}^* \\ B_{11}^* \\ B_{12}^* \\ B_{13}^* \\ B_{15}^* \\ B_{16}^* \\ B_{18}^* \\ B_{19}^* \\ B_{20}^* \\ B_{21}^* \\ B_{22}^* \\ B_{23}^* \\ B_{25}^*
\end{pmatrix}
=
\begin{pmatrix}
0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ B_{18} \\ B_{20} \\ B_{22} \\ 0
\end{pmatrix}
\qquad (10)
$$

The results obtained the behavior at cost exergetic (B*) of each flux to the systems of simple and double effect in the Fig. 6 and 7 respectively.

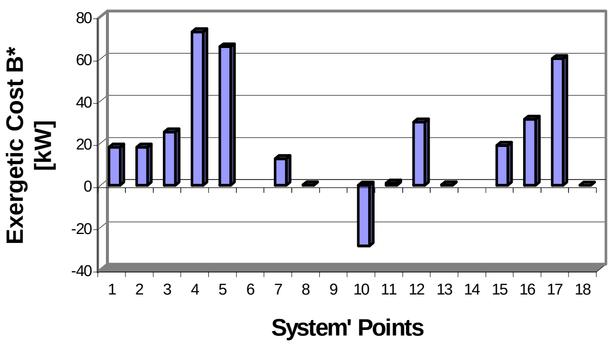



Figure 6. Single effect system exergetic cost.

The flux 4 (exit of concentrated solution of the generator) shows more onerous for the system of simple effect, because this flux is entalpic end transports itself a big part of heat changed with the gas of combustion (source of energy primary ).

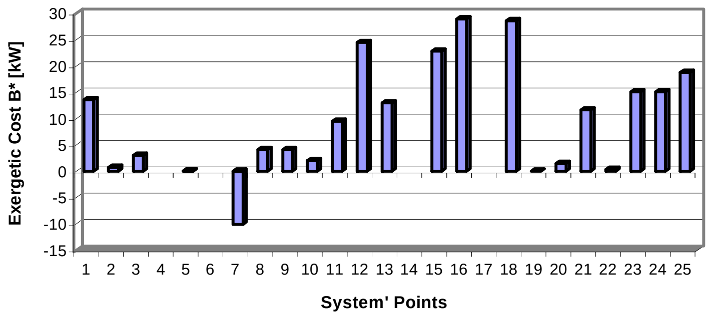



Figure 7. Exergetic Cost of the various fluxes of the system of double effect.

The behavior of the exergetic cost to the double effect of system, compared to systems of the simple effect, showed the same tendency, that is the flux 16 (exit of generator 2) is the current that absorbs as the heat exchanged by gases of combustion (flux 13), as the heat stand up of water steam came of Generator 1.

The capital invested in each component is determined by the equation 11, considering the initial investments to be shown individually for each subsystem, in real (R$).

Table 5 - Initial investment of each subsystem.

| Subsystems | Investment ($F_i$) REAL(R$) |
|---|---|
| Generator | 4.882,40 |
| Condenser | 4.164,40 |
| Evaporator | 5.054,72 |
| Absorber | 5.973,76 |
| Heat Exchanger | 2.326,32 |
| Pumps | 1.306,80 |

Applying the rocking of costs according to Eq. (4), to get the results of the monetary costs:

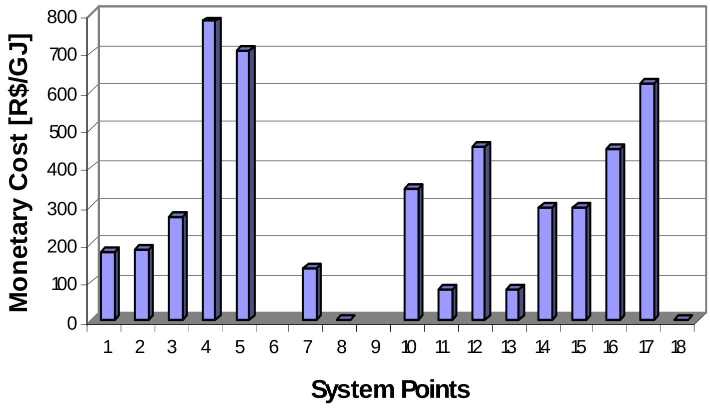



Figure 8. Monetary costs of the single effect of system.

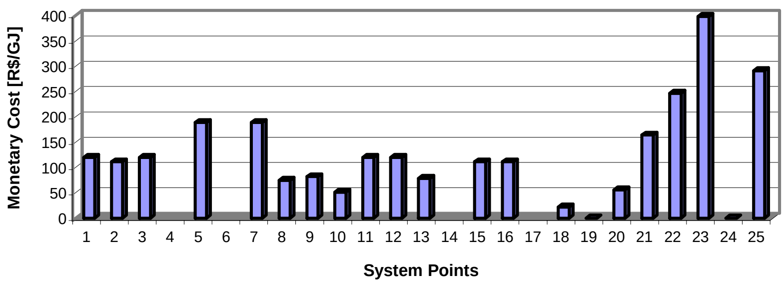



Figure 9. Monetary costs of the double-effect of system.

Chain the high cost of the flows, 22, 23 and 25 a consequence of them to be an attribution of high reasons of mass of the system (cooling water), beyond this chain respectively to receive heat in the cooling from the absorber and condenser.

An important comparison is to show the monetary current costs that play similar functions in the two systems. Fig. 10 shows to these flows and the costs related they, in the graph the system of simple more onerous exergoeconomicment.

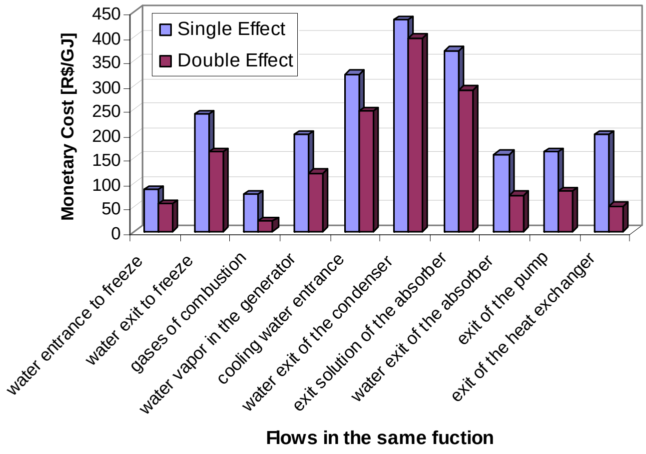



Figure 10. Comparison of monetary costs in the two systems.

## 4. CONCLUSIONS

The system of double effect besides being thermicment more efficient than the system of simple effect for the insertion of as generating one, can be affirmed that exergoeconomicment also is, since for insume energy the same proceeding from the natural gas (same power in the generator), the system of double effect is 47% as than system of simple effect, another important confirmation was perceiving that the monetary costs of the double fluxes that cool the system of effect, are also more economical in relation to the system of simple effect, since it has left of the heat that would be rejected by the condenser is used to advantage in as the generator for producing more vapor cooling.

## 5. REFERENCES


Aphornratana S., Eames, I.W., 1995, “Thermodynamic Analysis of Absorption Refrigeration Cycles Using the Second Law of Thermodynamics Method”, Int. Journal of Refrigeration, 18:244-252.

Bejan A., Tsatsaronis G., Moran M., 1996, “Thermal Design and Optimization”, 1st Ed. New York, Wiley & Sons.

Berlitz T., Satzger P., Summerer F., Ziegler F., Alefeld G., 1999, “A Contribution to the Evaluation of the Economics Perspectives of Absorption Chillers”, Int. Journal of Refrigeration, 22:58-67.

Erlach B., Serra L., Valero A., 1999, “Structural Theory as Standard for Thermoeconomics”, Energy Conversion & Management , 40:1627-1649.

Kaita, Y., 2001, “Thermodynamic Properties of Lithium Bromide_Water Solutions at High Temperatures”, International Journal of Refrigeration, Vol. 24, pp. 374-390.

Kotas T.J., 1985, “The Exergy Method of Thermal Plant Analysis”, 1st Ed. London: Anchor Brendon Ltd.

Moreira, H. L., Santos, P. H. D., Ribeiro, C. M. C., Torres, E. A., Leite, A. P. F. and Santos, A.C., 2005, “Exergoeconomics Analysis of Double-Effect Lithium Bromide-Water Absorption Refrigeration System”, Proceedings of 18$^{th}$ Brazilian Congress of Mechanical Engineering, Ouro Preto, MG, Brazil, pp. 1258.

Moreira, H. L., 2004, “Avaliação Termoeconômica de Sistemas de Refrigeração por Absorção com o par Água-Brometo de Lítio”, LES/UFPB, Tese de Doutorado, João Pessoa, PB.

Newnan, D. G., Lavelle, J. P., 2000,“Fundamentos de Engenharia Econômica”, RJ, Ed.LTC.

Sun, D. W.; 1997, “Thermodynamic Design Data and Optimum Design Maps for Absorption Refrigeration Systems”, Applied Thermal Engineering, Vol.17, N0. 3, pp.211-221.

Szargut J., Morris D.R., Steward F.R., 1988, “Exergy Analysis of Thermal, Chemical and Metallurgical Process”, 1st Ed. New York: Hemisphere Publishing Corporation.

Torres, E. A., 1999, “Avaliação Exergética e Termoeconômica de um Sistema de Cogeração de um Pólo Petroquímico”, FEM/UNICAMP, Tese de Doutorado, Campinas, SP.

Tsatsaronis, G., (quest editor) 1993, “Thermoeconomic Analysis and Optimization of Energy Systems”, Evergy Combust, V. 19, pp 227-257.

Valero, A., Losano, M. A., Muñoz, M., 1986, “General Theory of Exergy Saving”, ASME, WAM, V. 2-3, pp. 1-21.