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EXERGETIC AND THERMOECONOMICS ANALYSIS IN A COGENERATION PLANT IN A PULP AND PAPER MILL

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ABSTRACT
The energy conservation is a main point in the current world economy and it will follow being the same in the future, the efficient use of this energy can reduce the energetic demand. In this research an exergetic analysis was developed in one of the most demanding and wasteful industries of energy -pulp and paper mill- which has a cogeneration plant. It was analyzed in the energetic and exergetic ways, from the material and energy streams related with the cogeneration plant to the bordering equipment which allowed to analyzed the most important variables in the process operation and to identify and locate the main areas of energy loss, allowing to suggest and carry out operation changes in the recovery boiler, the turbogenerator, the thermal treatment and the evaporators lines, being able to settle down and to develop the design of a new evaporator line that will substitute the existent ones. The results have allowed the development of a software that establishes the conditions of operation and the design of a new equipment with the task to achieve the maximum use of energy in this mill with important economical and energetic savings.

KEY WORDS
Cogeneration, optimization, exergetic analysis, thermoeconomics and design.

1. Introduction

The increasing demand for industrial products joined to the world population growth and the current energy conversion technologies have generated the current energetic crisis, which causes the search of new competitive technologies, and the efficient use of the present technologies [1].

A great quantity of integration methods for the energy efficient use, such as, Pinch Technology [2,3], Techniques of Applied Energy Administration [4], Analysis of the Thermal Distribution of the Energy [5], Methods of simultaneous Optimization and heat integration [6] and the methods based on the exergy concept, like, the Exergetic Method [7,8,9], Thermoeconomics [1], and Exerconomics [10] have been developed and used in the last decades.

Exergetic Method has an universal acceptance in the analysis of the efficiency of any industrial process with their application in a systematic way, it allows the localization and account the degree of inefficiency in the use of the energy, indicating which the most important parts in a system are, and these have a big influence in the efficiency; establishing the possibility to design a new process, as well as, proposing improvements in the operation of current systems reaching and reaching the efficiency of the whole system[11]. The Exergetic Method has been applied to the analysis of different chemical plants, like, steel production[12,13], pulp and paper[12,14], oil processes [15], heat pumps [16], systems of vapor recompression [17], systems of treatment of residual gases[18], biological processes[19], systems of steam turbines[20] and in combustion processes[21], in an entire country[22] and in the design of processes[1].

Combining the use of the exergetic method with economical analysis and mathematical optimization methods, an improvement is achieved in the efficiency in economical terms (Thermoeconomics[1]) or reduce operation costs and design (Exergonomics[10]). These analyses have been applied in refrigeration systems, in the design of thermal systems[23,24], in simple and complex systems of heat and power[25,26,27], in heat pumps, in systems of flows in heat exchangers, cogeneration systems[10,28] and in industrial processes as the production of sugar cane[29].

Different technologies exist to increase the energetic efficiency like cogeneration, but they do not substitute an analysis of efficiency and integration to reach an energetic optimization in a real process that is used in several industries, like the pulp and paper industry which we have chosen to be analyzed due to a great input of heat and power energy, and at the same time a bigger output of these energies exist in the form of waste material streams, which are used in different equipment to generate a part of the input energy required.

In this case, it is a complex system, like it is indicated as follow; different techniques of energy integration were used, being one of them the exergetic analysis and the thermoeconomics study in a cogeneration plant and its surroundings.

The production of steam and electric power of the cogeneration plant depends on the demands of the system plant, and, to cover these demands it is required a production of vapor of the boiler plant and the electric power purchase, it is necessary to establish the current operation conditions, the maximum and minimum demands; therefore it is required to develop the material and energy balances of the main parts of the process which consumptions are ignored, for example, the thermal treatment (LHT) and the evaporators plant, and the cogeneration plant. The purpose of carrying out the above-mentioned it is to settle down, know and represent the current energy conditions of the cogeneration plant and of the process in general, using techniques, such as the diagram of heat and energy accounting. Begining with this information it is possible to outline and start the development of the exergetic study which allows the use of a more efficient way of the cogeneration plant and as well as the process in general.

The results of the exergetic analysis demonstrated that the biggest irreversibility exists in the area of the recovery boiler and the evaporators, for this reason, the variables were analyzed to determine which of them have the biggest influence in the irreversibility, the ratio air/fuel and water/steam are in the case of the recovery boiler and the ratio evaporates/steam is in the evaporators plant. We developed the design of a new evaporators line that will replace to the existent ones, as well as, we established new operation parameters in economics and thermoeconomics terms which it allows that the cogeneration plant and the equipments get better efficiencies and with this, an energy and exergetic optimization has been done. We have developed a software in Visual Basic Version 6.5, that suggests and makes the diary operation of the analyzed system more efficient and economical.

2. Exergy and thermoeconomic analysis

2.1 Methodology

Before carrying out the analysis exergetic, the balances of mass and energy in the system are required to determine the mass and energy flows in the control volume . The exergetic analysis then continues like a second stage[7], so, steps used to develop the exergetic analysis are:

1. Settle down the reference system or dead state, determining the temperature and reference pressure.
2. The surroundings and the control volume of the system were specified to analyze the system.
3. As it is a complex system, the global system was divided in subsystems that allowed its analysis, according to the different involved processes.
4. The exergy of all the flows of the system was calculated for mass, heat and work, to determine the points 5 -7
5. The global available work.
6. The irreversibility or global lost work and
7. The irreversibilily of each subsystem, with this
8. It is established the possible causes of the previous ones and
9. Finally it is suggested the possible improvements in the process, either the implementation of heat pumps or exchangers among others. And then,
10. Another exergetic analysis was carried out again for each improvement, it was chosen that one which has minor loss energy and bigger efficiency and economic savings.

Once it was finished, it was carried out the thermoeconomic study, its steps were:

11. The suggestions were analyzed by means of techniques of optimization,
12. The function objective and their restrictions then were established.
13. To set the best conditions of maximum use of energy in the system.

According to the outlined methodology, it is chosen as dead state the atmospheric air with the conditions of pressure, temperature and relative humidity of To = 298ºK and Po = 86.87 Kpa and 70% respectively. The global system is made up for: three evaporation lines, a thermal treatment, a system concentrator and the cogeneration plant, which it is made up by a recovery boiler and an electrical power turbogenerator. It is a complex system, so it is divided in three subsystems, due to their physical proximity and operation, being these: the evaporators, the thermal treatment and concentrator, and, the cogeneration plant. Once it was established the control system mentioned above, it was chosen as the surroundings from each subsystem to the part of the near atmosphere to the same ones. In a global form, the equations and concepts used in the exergetic analysis were:

The exergy, also well-known as availability it is a measure of the useful work that can be obtained of the system in a state given in a specific atmosphere (Yunus and Bowls, 2002).

The exergy balance for an open system that experiences physical and chemical processes can be written in the following way (Kotas, 1995):

$$\sum_{\ln} Ej - \sum_{out} Ek \pm E^{Q} \pm Wx - I = \Delta E \qquad (1)$$

where: Ej and Ek are the exergy associated with a steady stream of mass that enter and leave the system boundary respectively,; E^Q is the exergy associated with a heat transfer; W is the exergy associated with a work transfer; I is the exergy destroyed or lost work or irreversibility; ΔE is the exergy change refering to the time, for a process in stable state ΔE =0.

The most general definition of the physical exergy can be expressed in form molar like:

$$\overline{E}ph = \left(\tilde{h} - \tilde{h}o\right) - to\left(\bar{s} - so\right) \qquad (2)$$

Which can be used with the charts of appropriate properties when it is considered vapor for example, and for other liquids and solids it is very useful for the different expressions found in the bibliography [30,7,11,].

2.2 Results

The cogeneration plant and the equipment bordering, as well as the subsystems analyzed are shown in the Grassman diagram (Figure 1), which shows the distribution of the irreversibilities in the plant, being located the biggest in the recovery boiler, like it is shown in Table 1 in the region I, associated to the intrinsic irreversibility of the same combustion, joined to this the inappropriate relationships air-fuel are that lead to emissions of CO of the order of 2500 ppm. Non linear optimization techniques have been applied [31], which have established the correct operation relationships, being the excess of air of 5%, a relationship air/combustible of 3:1. Improving the energetic efficiency from 20% additional to the existent one. The second bigger irreversibility is in the evaporators plant, which besides the irreversibility for the transfer of heat, it has an inadequate operation and to the same time the equipments have surpassed their time of useful life, so, a design of a new evaporators line was carried out, this will substitute to all the existent lines, that it will allow a better efficiency and reduction of the existent irreversibility. The results of applying methods of linear and discrete optimization [3] indicated a system of four effects with a saving of costs of equipment acquisition and annual operation of $571,934.00 dollars. These are shown in Figure 2, in the modified case, the irreversibilities are reduced in the evaporators and boiler area. We also considered the costs of purchase of external electric power and the penalties in hour pick in the cogeneration plant and the system plant. In order to make more efficient their operation it was established the boiler and evaporators parameters for a production of 9000 MW using technical of thermoeconomic optimization like the proposals in [1]. Establishing that the parameters which control the system from the power electric and steam demand are the higher heat value and the black liquor and natural gas streams.

The results have been developed in a program in Visual Basic version 6.5, this is shown in Figure 3, with the purpose of allowing in a friendly way the correct operation of the plant and equipments analyzed to the different daily operation conditions. This software is being completed with the rest of the techniques of energy integration like as Pinch technology with the purpose of being a useful tool in the real process. This software has been evaluated by real operation data, having an error of ± 3%.

Table 1. Exergy losses the recovery boiler and evaporators plants

Region	Current case (%)	Modified case (%)
1	97	76
2	2	2
3	1	0.8
Efficiency	32	56

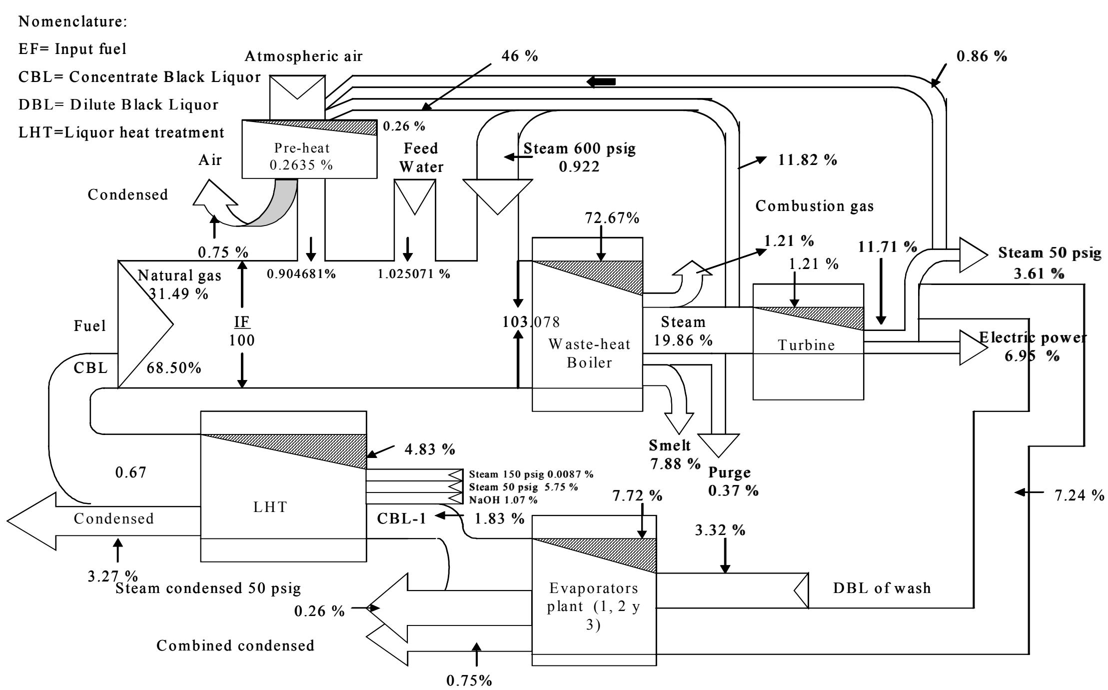

Figure 1. Grassmann Diagram current case

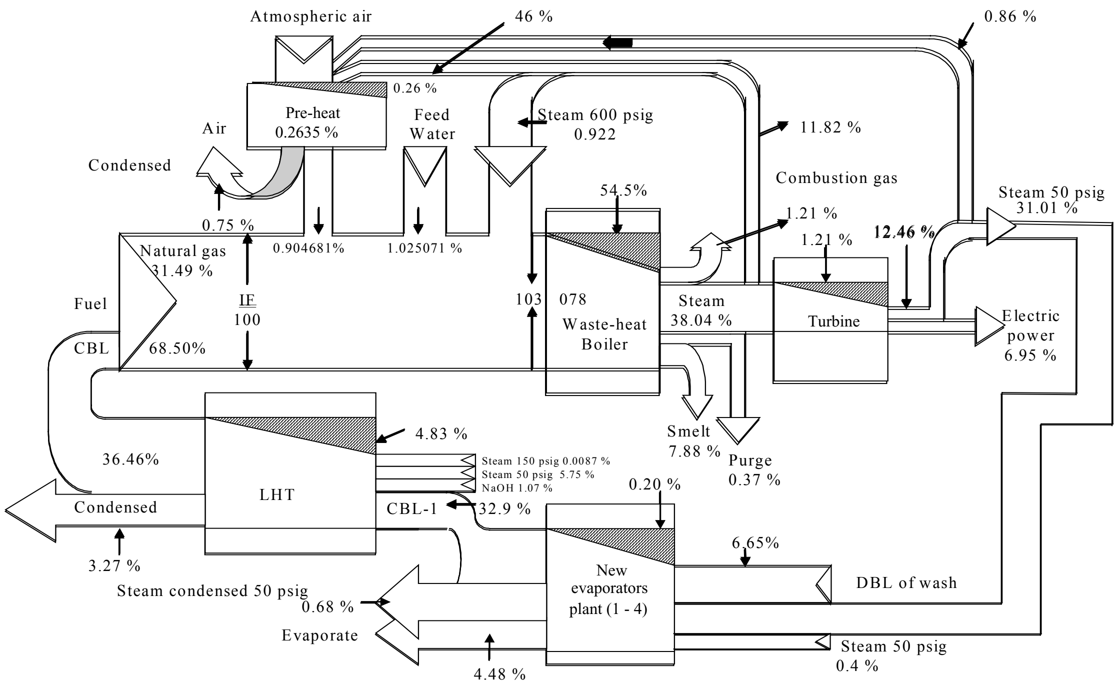

Figure 2. Grassmann Diagram modified case

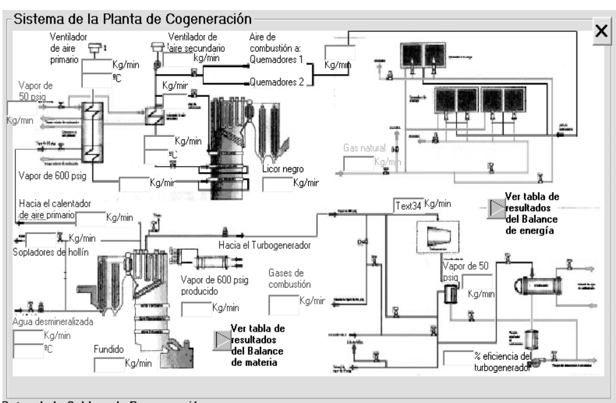

Figure 3. Developed screen software

3. Conclusion

These results belong to a stage in a project of a global energy optimization in an existent cogeneration plant. The economic savings in the current operation conditions and a better energetic control form by mean the software have been developed, and been used with acceptable results.

Demonstrating that in an optimization of any process in an existent equipment should be considered like one, avoiding negative effects to the rest of the system. Thus, it is suggested that to consider the analysis the rest of the existent force plant considering the energy demands of the system achieving with the use of other methods of energy studies, the energetic optimization of the process analyzed being the second part of this research.

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