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# CONVENTIONAL AND ADVANCED EXERGETIC ANALYSIS FOR THE COMBINED CYCLE OF POWER PLANT WITH GAS TURBINE OF A REFINERY

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## ABSTRACT

*This article shows the results of the performance study of a combined cycle plant made up of a Siemens STG-800 gas turbine and a MACCHI heat recovery boiler (HRSG) designed to produce 47.5 MW of electricity and 81908 kg / h of steam operating under ISO conditions (15 ° C and 60% relative humidity and 1 atm), the system is part of the steam and electric power generation section of a crude oil refinery in the city of Cartagena de Indias.*

*The objective of this research is to quantify the real inefficiencies in each of the equipment applying conventional and advanced exergetic analysis, to achieve this the investigation has been ordered as follows: first, the basic thermodynamics at the equipment boundaries is defined, define performance parameters that compare the adjustment of the thermodynamic model with the values provided by the manufacturer, the rate of exergy destruction and exergy efficiency are obtained from conventional analysis, advanced exergetic analysis allows obtaining avoidable, unavoidable, endogenous, exogenous exergies and the combined, finally, the mexogenous exergetic analysis allows to know the amount of energy that is lost due to the interactions between the equipment.*

*The thermodynamic model is adjusted with an average error of 2% using design KPIs such as net power, heat rate and thermal efficiency, it was obtained that the exergy destruction reaches 83.5MW, 15% is avoidable and the 8% is avoidable endogenous, the mexogenous analysis shows that inefficiencies in the compressor refer to all equipment, by focusing efforts on improving its conditions, up to 25% of the total exergy destruction can be recovered.*

***Keywords**: combined cycle power plant, exergetic analysis, advanced exergetic analysis, exergy destruction.*

## 1. INTRODUCTION

Industries are classified as large consumers of electricity, generally seeking to reduce their dependence on the external electricity grid by generating their own energy using fuels such as coal, oil and natural gas, the latter being the most widely used [1], combined cycles power plant are considered the best choice when generating electrical energy, their steam cycle allows obtaining between 30% and 40% more energy than conventional generation methods [2], this is due to the fact that their rate of heat is lower compared to gas turbines (GT) or steam turbines (ST) [3], its low cost, stability and availability are other advantages that have led to it being used more and more all over the world [ 4], are considered as the solution to reduce pollution and the cost of energy production [5], this makes it very important to develop more efficient combined power cycles, analyze their behavior as a function of degradation parameters and operating conditions different from ISO conditions (15 ° C and 60% relative humidity and 1 atm).

To evaluate thermodynamic systems, studies based on the first and second law of thermodynamics are used, these studies allow to develop real models of the systems with a low percentage of error, however, these models fall short if what is really sought is to optimize or develop new processes that allow obtaining a more rational use of energy, to compensate for this, exergy analysis is introduced, this analysis allows us to know the magnitude and sources of thermodynamic inefficiencies in a thermal system [6] and allows us to detail how it looks Affected the process by each one of the inefficiencies [7], the exergetic analysis allows us to quantify the useful energy and the irreversibilities that are handled in a process, this makes it a useful tool when making decisions regarding design and optimization [8].

The exegetical analysis has been evolving in the timeline F. Cziesla and G. Tsatsaronis begin to divide the destruction of exergy into inevitable and avoidable parts, this they do taking into account that it is only possible to avoid that a part is destroyed while the physical, technological and economic limitations generate a minimum rate of exergy destruction that cannot be recovered [9], later S. Kelly and G. Tsatsaronis [7] perform another division to the exergy destruction in two parts, one of them takes into account the irreversibilities caused by the inefficiency of the equipment known as endogenous and the other party takes into account the inefficiencies caused by the inefficiencies of the other equipment with respect to the so-called exogenous system structure.

The exergy terms can be related to obtain the crossed exergies, that is, the avoidable and unavoidable part of the endogenous and exogenous exergies, this method allows to have a clearer idea of the avoidable and unavoidable parts that are due to the equipment itself or its interaction with the others [9], but there is a difference between the exogenous exergy destruction rate and the effect of the exergy destruction of all the other components within the system on the k'th component, the need arises to quantify this difference by which introduces the mexogenous exergetic analysis [10].

Boyaghchi and Molaie [11] applied the exergy analysis to a combined cycle power plant in Iran, they estimated the destruction of inevitable, avoidable, endogenous and exogenous exergy, as well as their combination, in order to evaluate the behavior of $\boldsymbol{CO_2}$ emissions. carbon and the total destruction of exergy avoidable according to the variation of parameters such as the air inlet temperature to the turbine, the compression ratio of the compressor and the mass flow through the burner ducts, their results show that for the range of compression from 9 to 14 with a decrease in temperature improves $\boldsymbol{CO_2}$ emission while increasing the percentage of avoidable exergy destruction by 19%.

Ameri, Ahmadi and Hamidi [12] evaluate the effect that the variation of the load and the ambient temperature has on the exergetic efficiency of all the equipment of the steam power plant in Hamedan, obtaining the destruction rate and the loss of exergy for each component and with this they proceed to carry out the exergoeconomic analysis, as a result they obtained that between 5 and 24 ° C the highest rate of irreversibilities is obtained while between 125 and 250 MW of load the exergetic efficiency of most equipment increases , this operating range is based on conventional exergetic analysis and falls short when what is sought is to optimize and establish improvement actions taking into account more important factors such as the interaction between equipment and the degradation of efficiency.

Ahmadi and Dincer [13] using a multimodal genetic algorithm seek to obtain the optimization of a cogeneration plant, for this they apply energy, exergy and exergoeconomic analysis in the algorithm to which they subsequently introduce objective optimization functions such as increasing the efficiency of the processes conversion of energy which translates into a decrease in the amount of fuel used and environmental impacts, however the results obtained do not represent in the clearest way all the potential for improvement that can be applied to the system since they only evaluate the exergy in the conventional way, taking into account that by applying advanced exergy analysis as proposed in this research, it is possible to obtain an operating range in which the cost-benefit ratio taking into account fuel consumption is the most appropriate.

Petrakopoulou, Tsatsaronis and Morosuk [14] apply conventional and advanced exergy analysis to a combined cycle power plant, they obtain that most of the exergy destruction is inevitable and is restricted due to physical and technological limitations, for this case they obtained that the great part of exergy is endogenous, so they conclude that the interactions between the equipment do not contribute to thermodynamic inefficiencies in a significant way. This conclusion can be reaffirmed or denied by carrying out a mexogenous analysis such as the one proposed in this work, which allows us to know in a way the deeper the interactions between each of the equipment, as a result they obtained that of all the components, the combustion chamber has the greatest environmental impact, in which 68% is unavoidable [15].

Tsatsaronis [16] [17] has shown that conventional exergetic analysis has weaknesses that advanced, exergoeconomic and exergoenvironmental analysis solve, in the literature there are few articles that show from the most basic of exergetic analysis to mexogenous analysis, that is why The purpose of this article is to apply conventional and advanced exergetic analysis to a combined cycle plant in order to quantify the inefficiencies and irreversibilities of the system, for future work it is intended to make decisions and establish maintenance actions taking into account the results obtained in this study.

## 2. POWER PLANT LAYOUT AND METHODS

The system under study is the combined power cycle with gas turbine of a refinery, it consists of a gas turbine (SIEMENS STG-800) coupled to a heat recovery boiler (HRSG MACCHI) which supplies steam to electric generation turbine, nominal power of the gas turbine is 47.5 MW and steam production rate is 81908 kg / h. The plant scheme is made by taking separately each of equipment using the black box method, in which only the inlet and outlet currents to each of these are taken into account, this allows defining conditions for each of the states listed from the air inlet to the steam outlet to the medium pressure header.

The process starts with the entry and compression of air in the turbine compressor, it passes directly to the combustion chamber where natural gas also enters, the combustion reaction takes place and gases pass through gas turbine to go to recovery boiler which is composed of 2 superheaters, 1 evaporator and 1 economizer, from the boiler gases are released to atmosphere and the line that entered as treated water comes out as steam to the high pressure header that feeds the back pressure turbine in charge of producing electric energy and reducing pressures to feed medium and low pressure steam headers.

Figure 1 shows a detailed diagram of each of the equipment and streams that belong to the study system.

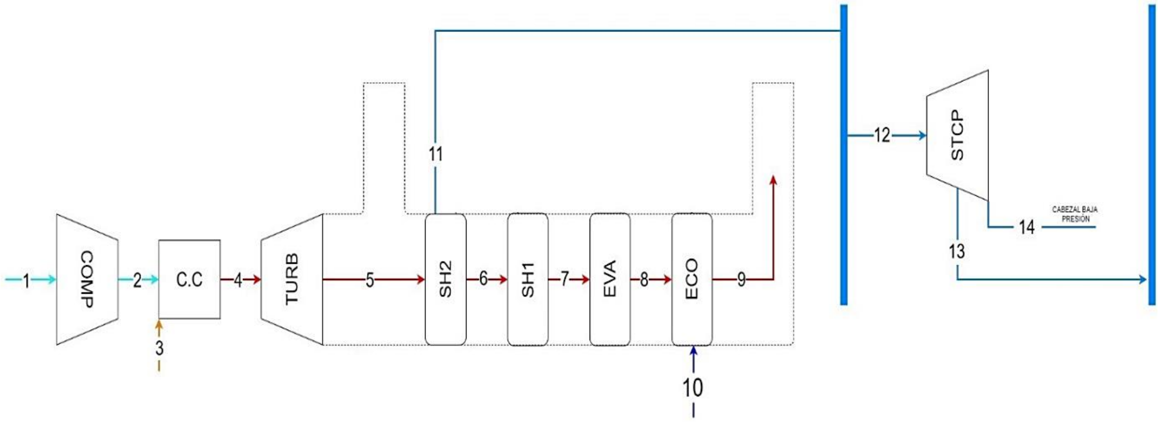

Figure 1: Scheme of the study system.

## 2.1 Power Plant Layout

The combined cycle plant was designed based on first law equations of thermodynamics, declaring thermodynamic states at the equipment boundaries and establishing the inlet and outlet currents, the reading of the pressure, temperature and flow sensors was obtained for each state with which thermodynamic properties such as enthalpy, entropy and exergy are determined.

The first law thermodynamic parameters selected to validate the model created in the EES (Engineering Equation Solver) software with values provided by the manufacturer are the thermal efficiency, which allows knowing the ratio between the net electrical energy generated and the total energy available for the fuel; it is calculated by means of equation (1).

$$\mathrm{n_{TH}} = \frac{\dot{\mathrm{W}}_{\mathrm{elect}}}{\dot{\mathrm{W}}_{\mathrm{f}}} \tag{1}$$

The heat rate is calculated by equation (2) and shows the ratio of the heat energy supplied by the fuel required to produce one kilowatt per hour of electrical energy.

$$\mathrm{HR} = \frac{3600 * \dot{\mathrm{W}}_{\mathrm{f}}}{\dot{\mathrm{W}}_{\mathrm{elect}}} \tag{2}$$

The electrical power W ̇_elect is obtained from the difference between power generated by the turbine and that consumed by the compressor, the fuel power W ̇_f is obtained from its mass flow and lower calorific value.

## 2.2 Conventional and Advanced Exergetic Analysis

Exergy is a useful tool to determine the quality of energy conversion, the destruction of exergy can be expressed and calculated as shown in equation (3) [18].

$$\dot{\mathrm{E}}_{\mathrm{D,k}} = \dot{\mathrm{E}}_{\mathrm{F,k}} - \dot{\mathrm{E}}_{\mathrm{P,k}} \tag{3}$$

Where $\dot{\mathrm{E}}_{\mathrm{D,k}}$ , $\dot{\mathrm{E}}_{\mathrm{F,k}}$ $y$ $\dot{\mathrm{E}}_{\mathrm{P,k}}$ are the exergy destruction, the fuel exergy and the product exergy respectively.

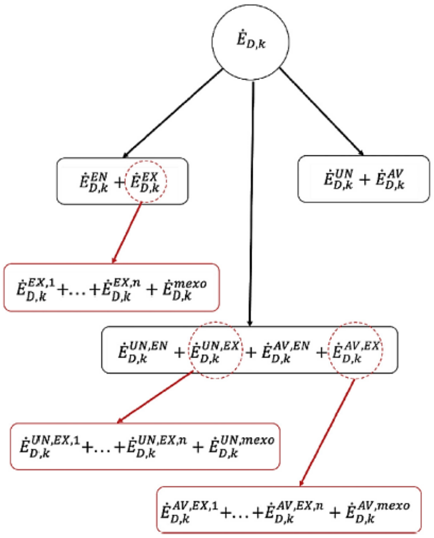

Figure 2: Subdivisions of exergy destruction [18].

As shown in figure 2, the destruction of exergy is subdivided into 11 parts, in each of these the efficiency with which the system works is taken into account in order to evaluate and obtain a real value of the amount of useful energy that is being obtained in that process.

Thermodynamic systems have an unattainable performance in spite of the technological development, given these limitations the need arises to know the rate of exergy destruction that can be avoided by applying improvements to the process and the part that definitely given these limitations is not possible to recover, the unavoidable exergy destruction is obtained by equation (4) finding the unavoidable factor $\left(\frac{\dot{\mathrm{E}}_{\mathrm{D}}}{\dot{\mathrm{E}}_{\mathrm{P}}}\right)_{k}^{UN}$ which is determined by the destroyed exergy and product exergy found operating the equipment k at maximum design conditions, which for this case is the efficiency provided by the manufacturer, while the other equipment operates at actual conditions, the avoidable exergy destruction is found by subtracting the unavoidable exergy destruction from the total exergy destruction of the equipment as shown in equation (5) [19].

$$\dot{E}_{D,k}^{UN} = \dot{\mathrm{E}}_{\mathrm{P,k}} * \left(\frac{\dot{\mathrm{E}}_{\mathrm{D}}}{\dot{\mathrm{E}}_{\mathrm{P}}}\right)_{k}^{UN} \quad (4)$$

$$\dot{\mathrm{E}}_{\mathrm{D,k}} = \dot{E}_{D,k}^{UN} + \dot{E}_{D,k}^{AV} \quad (5)$$

To calculate the destruction of endogenous exergy, equation (6) is used and the component that is being analyzed is taken under real operating conditions while the other components are taken operating under ideal conditions, equation (7) shows how destruction is obtained of exogenous exergy from the subtraction of the destruction of total exergy with the destruction of endogenous exergy [20].

$$\dot{E}_{D,k}^{EN} = \dot{E}_{F,k}^{EN} - \dot{E}_{P,k}^{EN} \quad (6)$$

$$\dot{E}_{D,k}^{EX} = \dot{\mathrm{E}}_{\mathrm{D,k}} - \dot{E}_{D,k}^{EN} \quad (7)$$

The endogenous unavoidable exergy destruction is obtained by equation (8) which uses the same unavoidable factor described in equation (4) and the product exergy part calculated in the endogenous exergy destruction, then to calculate the endogenous avoidable exergy destruction just subtract the endogenous exergy destruction with the endogenous unavoidable exergy found as shown in equation (9) [21].

$$\dot{E}_{D,k}^{UN_{EN}} = \dot{E}_{P,k}^{EN} * \left(\frac{\dot{\mathrm{E}}_{\mathrm{D}}}{\dot{\mathrm{E}}_{\mathrm{P}}}\right)_{k}^{UN} \quad (8)$$

$$\dot{E}_{D,k}^{AV_{EN}} = \dot{E}_{D,k}^{EN} - \dot{E}_{D,k}^{UN_{EN}} \quad (9)$$

The unavoidable and avoidable exogenous exergy destruction of each component is calculated by subtracting the unavoidable and avoidable exergy destruction from the endogenous unavoidable and avoidable exergy destruction, as shown in equations (10) and (11) [21].

$$\dot{E}_{D,k}^{UN\_EX} = \dot{E}_{D,k}^{UN} - \dot{E}_{D,k}^{UN_{EN}} \quad (10)$$

$$\dot{E}_{D,k}^{AV\_EX} = \dot{E}_{D,k}^{AV} - \dot{E}_{D,k}^{AV_{EN}} \quad (11)$$

The exogenous exergy destruction allows us to determine the exogenous exergy destruction in a k equipment due to an n equipment, as shown in equation (12) to the exogenous exergy destruction of the k equipment, we subtract the sum of the exogenous exergy of all the other equipment calculated when both work with real efficiency while all the others work in ideal conditions [20].

$$\dot{E}_{D,k}^{MEXO\_EX} = \dot{E}_{D,k}^{EX} - \sum_{n=1}^{k-1} \dot{E}_{D,k}^{EX_n} \quad (12)$$

The unavoidable exogenous exergy destruction allows us to determine the unavoidable exogenous exergy destruction in a k equipment due to a n, both equipment work with unavoidable efficiency while all others work under ideal conditions [6] as shown in equations (13) and (14).

$$\dot{E}_{D,k}^{MEXO_k UN-EX} = \dot{E}_{D,k}^{UN-EX} - \sum_{n=1}^{k-1} \dot{E}_{D,k}^{UN-EX_n} \quad (13)$$

$$\dot{E}_{D,k}^{MEXO_k AV-EX} = \dot{E}_{D,k}^{AV-EX} - \sum_{n=1}^{k-1} \dot{E}_{D,k}^{AV-EX_n} \quad (14)$$

The conventional analysis will provide preliminary information on the behavior of the inefficiencies of the equipment, it will allow to know if these are caused by themselves, if these can be avoided or on the contrary if these are due to external causes or cannot be avoided, with the advanced exergetic analysis we will obtain more detailed information on the amount of exergy for each equipment that can be avoided or not, due to the same or to the outside and how the inefficiencies of one equipment interact on all the others.

## 3. RESULTS AND DISCUSSION

The study system is governed by the thermodynamic equations of the 1st and 2nd law, they are compared with the design parameters to obtain the percentage of error and to know how well it adjusts to reality, the following considerations and the design efficiencies from table 1.

- The study is carried out under ISO conditions (T = 15 ° C and 60% humidity) for the air at the compressor inlet.
- The charge level remains constant over time.
- The properties of the dead state are taken as T = 3.4 ° C and P = 38.15kPa.
- The water inlet to the pump is taken at T = 30 ° C and P = 101.32kPa.
- It is considered complete combustion in the combustion chamber.

Table 1: Operating efficiency given by the manufacturer.

| Condition | Unavoidable |
|---|---|
| Compressor | η=97% |
| Turbine | η=98% |
| Combustion Chamber | η=99,5%<br>ΔP=2% |
| HRSG | η=96%<br>ΔP=2% |
| Steam Turbine | η=98% |
| Pump | η=90% |

For the validation of the model, the comparison of essential design parameters in the gas turbine was used, such as net power, heat rate and thermal efficiency, table 2 shows the design values and those obtained in the model.

Table 2: comparison of design KPIs vs model

| | **Power** | **Heat Rate** | **Thermal Efficiency** |
|---|---|---|---|
| **Design** | 47,5 MW | 9547 | 37,7% |
| **Model** | 47,4 MW | 9750 | 36,92% |
| **Error** | 0,21% | 2,13% | 2,07% |

The percentage of error is admissible since it is around 2% for the heat rate and thermal efficiency, while the most adjusted parameter is the net power of the turbine with 0.21% error, with the adjusted and validated model. The destroyed exergy evaluation is carried out taking into account for each equipment the exergy required to obtain the desired product. Table 3 shows the equations that define the input and output of each equipment.

Table 3: Equations to obtain the exergy of fuel and product in each of the equipment.

| **Equipment** | **Fuel** | **Product** |
|---|---|---|
| COMP | $\dot{W}_{comp}$ | $\dot{m}_2 e_2 - \dot{m}_1 e_1$ |
| C.C | $\dot{m}_{gas} e_{gas}$ | $\dot{m}_4 e_4 - \dot{m}_2 e_2$ |
| TURB | $\dot{m}_4 e_4 - \dot{m}_5 e_5$ | $\dot{W}_{turb}$ |
| HRSG | $\dot{m}_5 e_5 - \dot{m}_9 e_9$ | $\dot{m}_8 e_8 - \dot{m}_7 e_7$ |
| PUMP | $\dot{W}_{pump}$ | $\dot{m}_7 e_7 - \dot{m}_6 e_6$ |
| CPTURB | $\dot{m}_8 e_8 - \dot{m}_{10} e_{10} - \dot{m}_{11} e_{11}$ | $\dot{W}_{CPTURB}$ |

The values obtained for each of the currents described in Table 3 and these are listed in Table 4, which also presents the exergetic efficiency, which allows obtaining the ratio of how well the input energy is used to carry out the transformation process, the equipment with the highest consumption is the combustion chamber, the one with the best efficiency is the compressor with 97%, while the equipment with the lowest efficiency is the heat recovery boiler with 51%.

Table 4: Conventional real cycle exergy analysis.

| **Equipment** | $\dot{E}_F$**(kWh)** | $\dot{E}_P$**(kWh)** | $\dot{E}_D$**(kWh)** | $\eta\dot{E}$**(%)** |
|---|---|---|---|---|
| COMP | 58130 | 56393 | 1737 | 97 |
| CC | 167101 | 132615 | 34486 | 79 |
| GT | 118667 | 106599 | 12068 | 90 |
| HRSG | 62167 | 31465 | 30702 | 51 |
| CPTURB | 15015 | 10586 | 4429 | 71 |
| PUMP | 236 | 189 | 47 | 80 |

The results of the evaluation of conventional exergy are shown in figure 3, it was obtained that the component that contributes the most to the destruction of exergy is the combustion chamber followed by the heat recovery boiler with 42% and 36.7% respectively, this finds their reasons due to the fact that the equipment in which there are chemical and heat transfer reactions show this trend [15], this percentage is similar to that obtained in [11] who obtained a total of 87% for all the equipment involving reactions chemicals and heat transfer.

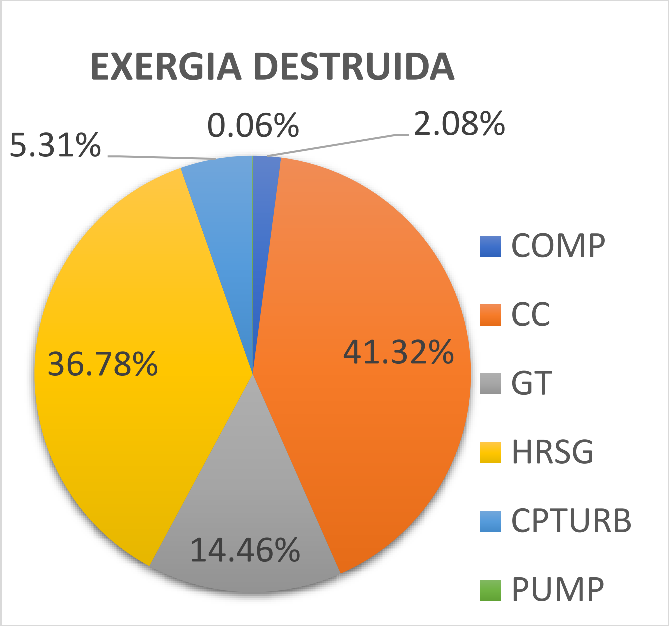

Figure 3: Percentage exergy destruction per team.

Figures 4 and 5 represent the exergy destruction in its avoidable-unavoidable and endogenous-exogenous parts respectively, it can be established that all teams have more than 50% of their exergy destruction as unavoidable, like all except for the heat recovery boiler, present more than 90% destruction of exergy as endogenous, very similar to the result obtained by Ahmadi and Hamidi in [12] who conclude that with this result it is not significant to verify the irreversibilities that are caused due to the interaction between the components.

From the avoidable and unavoidable analysis, it is evidenced that the combustion chamber, in addition to having the greatest destruction of exergy, 98.40% of this is unavoidable and this is due to the technological limitations of the component, the component that would improve its behavior by improving the conditions external to it is the water pump since little more than half of its exergy destruction as avoidable.

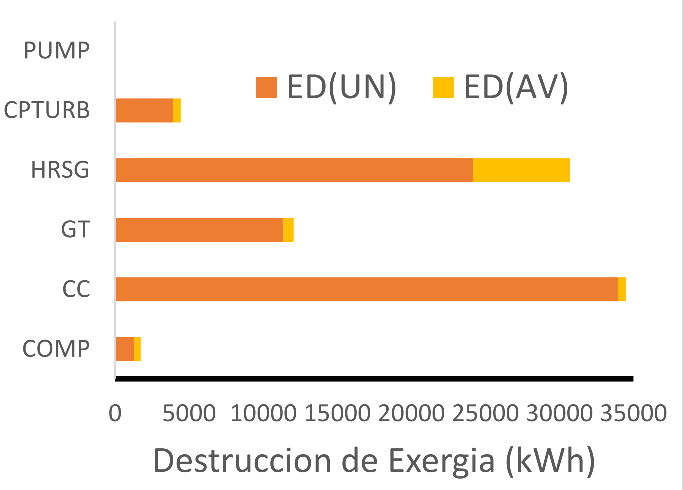

Figure 4: Unavoidable and avoidable exergy destruction.

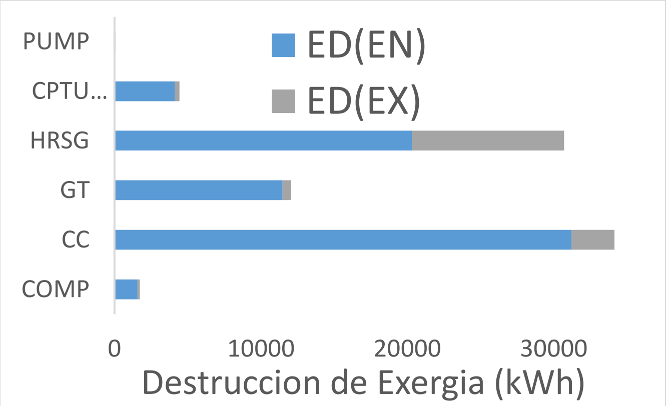

Figure 5: Destruction of endogenous and exogenous exergy.

In figure 6 the combined exergies are shown, it is observed that, for the heat recovery boiler, the feed water pump, the compressor and the gas turbine, they have the highest amount of exergy destruction as avoidable-exogenous, therefore This can be avoided by improving the external conditions to each one of them or the process conditions, while, in the combustion chamber, the greater destruction of exergy is inevitable and endogenous, which reaffirms its potential as an option for improvement.

From the endogenous and exogenous unavoidable part, it was obtained that the heat recovery boiler and the combustion chamber have all the inevitable irreversibilities due to themselves since their endogenous inevitable destroyed exergy has 99.5% with respect to all the destroyed exergy. Inevitably, in the case of the water pump it is clearly endogenous, however, the effect caused by the other equipment is to improve its irreversibilities by 1.24%.

From the endogenous and exogenous avoidable part of all the components, it is confirmed that the irreversibilities of the combustion chamber are due only to itself and that the external components improve their operation by up to 32.03%, while equipment such as the heat recovery boiler Heat is influenced by the operation of the others because 87.7% of its avoidable exergy is exogenous, the back pressure steam turbine has an equilibrium since it has around 50% of exergy as endogenous, it can be concluded that by improving the conditions of equipment such as the compressor and the combustion chamber, other equipment such as the boiler and the gas turbine will be improved.

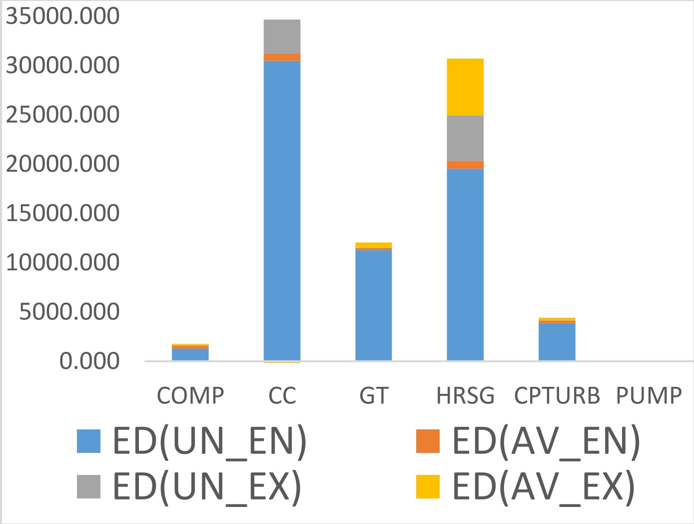

Figure 6: Combined exergy destruction for each of the equipment in kWh.

The mexogenous analysis is represented by table 5 and was carried out in order to know how the inefficiencies of the external equipment affect the one being analyzed in a way that improves or worsens its irreversibilities, a diagonal of zeros is obtained because at these points what is really being found is the endogenous exergy of the study team.

In the mexogenous result, it is observed that the equipment that most interacts with the entire process are the compressor, the combustion chamber and the gas turbine, while the equipment that is most influenced by all the others is the back pressure steam turbine. It can be concluded that the equipment that causes the most inefficiencies to the others is the gas turbine since it generates 68.7% of all the exogenous exergy of the system.

From the inevitable exogenous mexogenous analysis, it can be concluded that the compressor is the equipment to which the irreversibilities caused by the others can be recovered, while the equipment that causes the most destruction of exergy on the others is the gas turbine affecting the chamber. of combustion with 1829.3 kW, the negative values shown in table 6 are interpreted as an improvement in the operation of equipment k due to the inefficiencies of equipment n.

It can be established from the avoidable exogenous mexogenous analysis that the heat recovery boiler is the most affected by the inefficiencies of the others and therefore it is the one that can recover the most exergy by improving equipment such as the gas turbine and compressor that cause 81.8% and 24.6% of the avoidable exergy destruction in the boiler, the compressor has little exergy destruction caused by external factors, so no great exergy recovery capacity is obtained, the values obtained in this analysis are you can see in table 7.

Table 5: Endogenous exergy of component k and the exogenous part caused by component n.

| $E_{EX_k}^{EX_n}$ | | | | | | |
|---|---|---|---|---|---|---|
| n<br>k | COMP | CC | GT | HRSG | CPTURB | PUMP |
| COMP | **1584** | 6 | 117 | 0 | 0 | 0 |
| CC | 342 | **31215** | 2657 | 0 | 0 | 0 |
| GT | 526 | 19 | **11480** | 0 | 0 | 0 |
| HRSG | 2698 | -509 | 7314 | **20326** | 0 | 0 |
| CPTURB | -93 | 18 | -246 | 595 | **4128** | -2 |
| PUMP | 0 | 0 | 0 | 0 | 0 | **46,78** |

Table 6: Unavoidable endogenous exergy of component k and the unavoidable exogenous part caused by component n.

| $E-UN_{EX_k}^{EX_n}$ | | | | | | |
|---|---|---|---|---|---|---|
| n<br>k | COMP | CC | GT | HRSG | CPTURB | PUMP |
| COMP | **1273,9** | 0,9 | 37,2 | 0,0 | 0,0 | 0,0 |
| CC | 741,3 | **30489** | 1829,3 | 587,3 | 587,3 | 587,3 |
| GT | 42,4 | -227,6 | **11319** | -230,6 | -230,6 | -230,6 |
| HRSG | -2643,2 | -4395,2 | -723,2 | **19520** | -4196,2 | -4196,2 |
| CPTURB | -47,6 | 14,4 | -113,6 | 199,4 | **3879,4** | 9,4 |
| PUMP | -0,5 | -0,5 | -0,5 | -0,5 | -0,5 | **23,47** |

Table 7: Avoidable endogenous exergy of component k and the avoidable exogenous part caused by component n

| $E-AV_{EX_k}^{EX_n}$ | | | | | | |
|---|---|---|---|---|---|---|
| n<br>k | COMP | CC | GT | HRSG | CPTURB | PUMP |
| COMP | **310,7** | 5,1 | 79,8 | 0,0 | 0,0 | 0,0 |
| CC | -399,3 | **727** | 827,7 | -587,3 | -587,3 | -587,3 |
| GT | 483,6 | 246,6 | **161,5** | 230,6 | 230,6 | 230,6 |
| HRSG | 5341,2 | 3886,2 | 8037,2 | **806** | 4196,2 | 4196,2 |
| CPTURB | -45,4 | 3,6 | -132,4 | 395,6 | **248,6** | -11,4 |
| PUMP | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | **23** |

## 4. CONCLUSION

This study carried out on the combined power cycle of a refinery in the city of Cartagena using conventional and advanced exergy analysis provides key information to implement improvement actions, in addition to knowing the critical equipment that causes the greatest amount of exergy destruction. establish that the equipment with the greatest destruction of exergy is the combustion chamber, with 41% of which 98% is unavoidable and 90% of that unavoidable exergy is endogenous.

The equipment that most affects the performance of the others is the compressor and this agrees because it is the equipment located higher in the system chain, to focus efforts on recovering the 25.5% avoidable exergy destruction that it possesses, a 55.9% improvement would be achieved in the exogenous avoidable exergy destruction of the other components.

The importance of performing the mexogenous analysis is established since, despite the fact that all the equipment has more than 90% destruction of exergy as endogenous, to conclude that the irreversibilities due to the interactions between the components is not significant as they did in [ 14] is an error given that thanks to this analysis it was possible to establish that the equipment that causes the most destruction of exergy on the others is the compressor, while the equipment that is most affected by the irreversibilities of the others is the boiler heat recovery.

## NOMENCLATURE

| | |
|---|---|
| T | Temperature (°C) |
| $\dot{m}$ | Mass flow ($kgs$) |
| $\dot{W}$ | Power ($K$W) |
| e | Specific exergy ($kJkg$) |
| $\dot{E}$ | Exergía (kW) |
| COMP | Compressor |
| CC | Combustion Chamber |
| GT | Gas Turbine |
| HRSG | Heat Recovery Steam Generator |
| AV | Avoidable |
| UN | Unavoidable |
| EN | Endogenous |
| EX | Exogenous |
| CPTURB | Steam Turbine |
| PUMP | Pumpo of wáter |

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