ANALYSIS OF A STEEL MILL POWER SYSTEM USING EXERGOECONOMIC FACTORS

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Abstract: The rational use of the energy in all productive sectors in Brazil became essential, mainly after the energy rationing in 2001. Methodologies that quantify and improve the performance of the plants that consume and generate electricity and thermal energy are being used to reach this objective. Exergoeconomic analysis provides the complete diagnostic of a plant, in exergetic and monetary values. This study shows the methodology used to evaluate the power generation system of the Companhia Siderurgica Tubarão (CST). This plant uses the regenerative Rankine cycle, fueled by Blast Furnace Gas (BFG) and Coke Oven Gas (COG), gases originated from the steel production process. The use of the Exergetic Cost Theory permits the determination of the monetary and exergetic costs and moreover, the indicators such as cost variation, relative cost variation and exergoeconomic factors; determinates the influence of each component in the composition of plant costs and the better way of decreasing the generation cost of the energy and the steam to process.

Keywords: exergoeconomic analysis, power generation, steel mills.

1 . Introduction

The high consumption of electric energy necessary for the steel production classifies the steel mill industry as being electrointensive. The main raw materials are iron ore and mineral coal. Coal is transported from the storage to the coke plant where metallurgical coke is obtain. Iron ore is sintering and carried to the blast furnace where it is mixed with coke, limes and blowed air, forming pig iron. Pig iron produced in the blast furnace is carried to the reduction oven where pure oxygen is injected to get the reduction from pig iron to steel. The steel can then be molded into sheets, blocks and others forms, according to the production necessity of the company. Details can be found in Araújo (1997).

These processes need big quantities of electrical energy, steam, liquid and gaseous fuels. The central of utilities of the steel mill plant must supply the electrical energy demand of the company and the other necessities such as steam, oxygen, air, argon, nitrogen, amongst others. The use of the residual fuels of the steel production process allows the power generation to supply the demand of electrical energy and to sell exceeding energy. The gases produced in the production processes of coke and pig iron are used in the power generation. The Coke Oven Gas (COG), produced in the coke plant, is constituted by methane (CH_4) and hydrogen (H_2), it must be treated before being used as fuel, because it contains ammonia, light oils, tar and a small quantity of sulphur. Its density is 0.43 kg/Nm^3 and has lower heat value (LHV) about 42,300 kJ/kg. The Blast Furnace Gas (BFG) is a consequence of the production process of pig iron formed basically by N_2 and CO_2 and must undergo a cleaning process in an electrostatic precipitator before being used as a fuel. Its density is 1.43 kg/Nm^3 and it has a low heat value power of 2600 kJ/kg.

The objective of this study is to carry out an exergoeconomic analysis in the power generation system in the utility sector in the Companhia Siderurgica Tubarão located in the town of Serra –State of Espírito Santo - Brazil. The exergoeconomic analysis in this work is based on the methodology described by Lozano and Valero (1993) and Tsatsaronis and Winhold (1985). By means this methodology it is possible to measure the costs of the steam, electrical and mechanical power in the generation system. The costs can be expressed on an exergetic or monetary bases. In the case of the exergetic cost, the cost is a function of the exergy of the fuel and the make-up water. When the monetary costs are considered, these can be calculated considering the investment and maintenance costs of the equipment. The value of the exergetic and monetary costs are calculated in this work taking into consideration the investment and operation costs of the system. The calculation was performed for two situations: project data and operation condition data. The project data were obtained from the technical archives of the company.

2. Plant Description

The project of the CST power plant is made up of three generator plants. The two first units, installed in 1981, are called "plants 1 and 2", each one having, one CBC-MITSUBISHI - Type VU - 50 boiler, with nominal steam generating capacity of 263 ton/h, operating with 86 bar pressure and at a temperature of 510°C, respectively; one condensation steam turbine with 12 stages and 4 extractions, operating with the same levels of pressure and temperature of the boiler. The turbine turns an electric generator, with nominal power of 36 MW and gives another 30 MW to a blower, totalizing 66 MW. This blower sends air to the blast furnace. Normally, only one of the blowers operates, the being other in stand-by. The steam expanded in the steam turbine is condensed in a condenser that uses seawater. After the condensation, the condensate is pressurized in a pump, heated in a heat exchanger which operates with the steam from the turbine's extractions, passed in a desaerator and in a feed pump, which supply the necessary pressure to the boiler inlet water.

The third unit, called "plant 3" was installed in 1998. It consists in a MITSUBISHI MB-EB boiler with nominal steam production capacity of 251 ton/h, operating with 110 bar of pressure and at a temperature of 540°C, and a condensation steam turbine with 14 stages and 5 extractions. The turbine turns a electric generator with nominal power of 69 MW. This set operates also in a regenerative Rankine cycle. Besides the electric energy production and the supply of atmospheric air to the blast furnace, the project foresee supply of steam to process at a rate of 10 ton/h in plants 1 and 2. These systems use BFG and COG as fuel. The main changes on the plant regarding to the original project are: in the plant 1 and 2 are: the last heat exchanger that pre heated the feed water, work with steam from an external source, eliminating the use of the one extractions of the steam turbine, increasing the power generated. In the plant 3, the main changes are small increase in the steam rate in boiler, decrease and/or eliminate of the use the extractions of the steam turbine that feed the two last heat exchanges, increasing the power generated, but increasing the fuel consumption. The layouts of plants 1e 3 are shown in Fig. (1) and (2). Table (1) shows the thermodynamic data of the principal flow of plants 1 and 3. Table (2) shows power generate, fuel consumption and steam flow

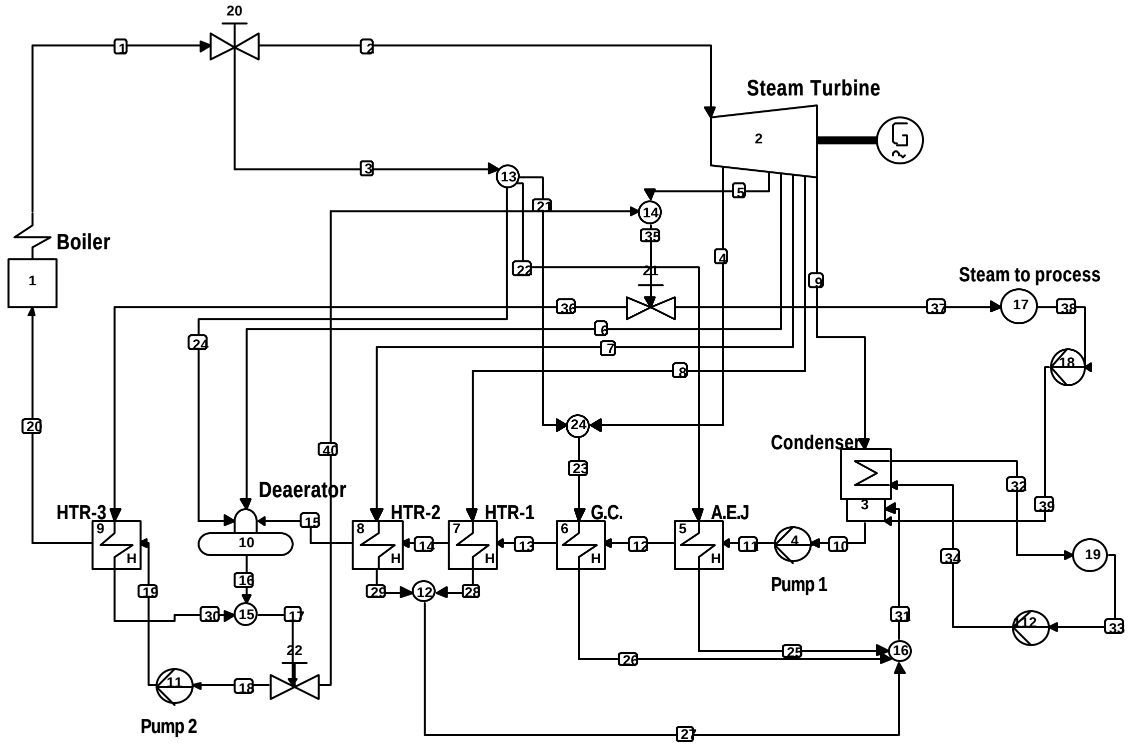

Figure 1: Sketch of Plant 1

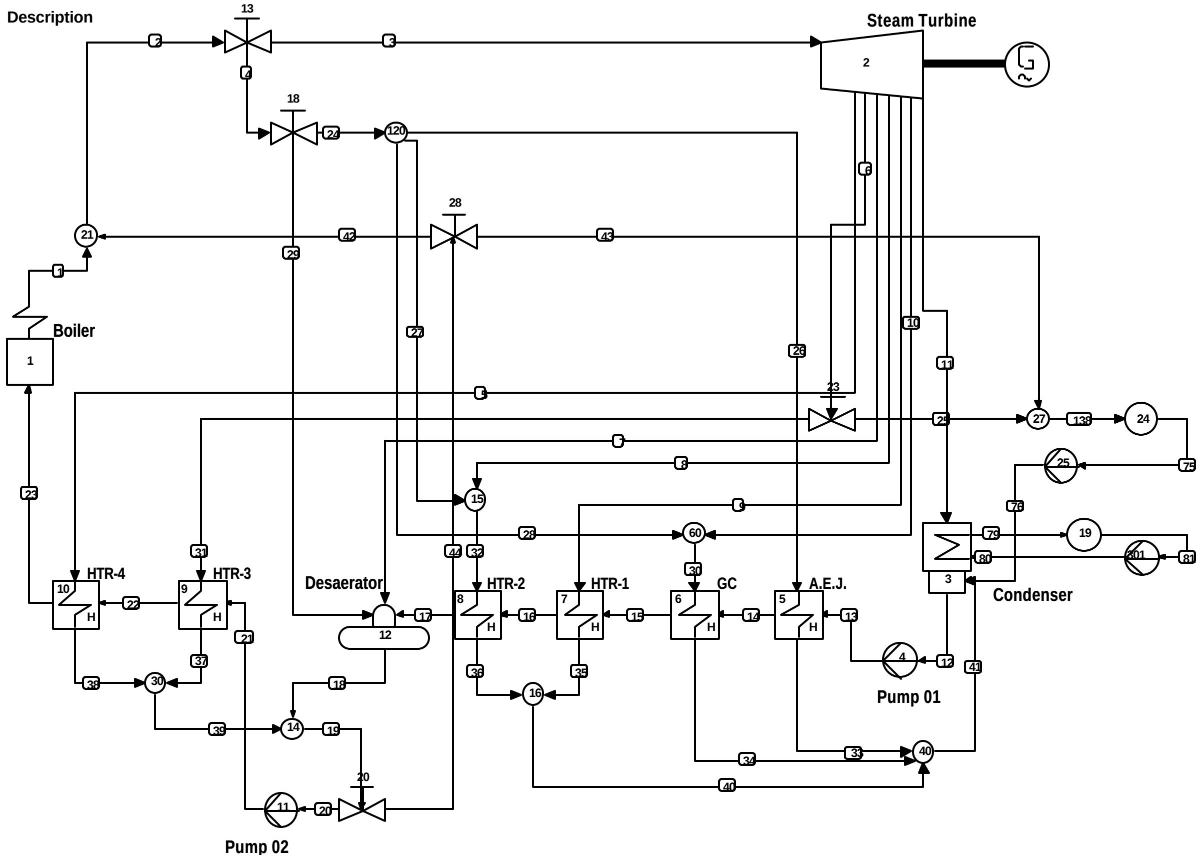

Figure 2: Sketch of Plant 3

Table 1: Thermodynamic data of project of plants 1 e 3

Localization	Steam (kg/s)		T (°C)		P(bar)		Enthalpy (kJ/kg)		Exergy (kJ/kg)	
	Plant 01	Plant 03	Plant 01	Plant 03	Plant 01	Plant 03	Plant 01	Plant 03	Plant 01	Plant 03
Boiler Outlet	73.16	72,64	510.00	550,00	86.00	99,00	3416.26	3500,00	1418.00	1489,31
Turbine Inlet	72.75	71,63	510.00	540,00	86.00	99,00	3416.26	3476,00	1418.00	1473,58
1° extraction	7.69	1,34	419.02	388,19	40.00	33,25	3260.00	3200,00	1285.76	1168,02
2° extraction	3.42	5,79	308,00	321,27	5.91	20,02	3079.13	3074,00	874.36	1035,34
3° extraction	4.31	3,24	134.00	223,41	3.02	8,84	2725.94	288,00	645.94	843,47
4° extraction	4.59	5,40	113.28	158,34	1.59	2,77	2542.94	2780,00	518.43	650,15
5° extraction	-	0,065	-	99,63	-	1,00	-	2429,00	-	436,33
Condenser Inlet	52.73	55,553	37.25	37,08	0.063	0,063	2402.90	2263,00	89.61	82,95
Inlet Pump 1	64.50	64,436	37.08	37,36	0.063	0,063	155.96	155,96	0.93	0,93
Deaerator Inlet	64.50	64,436	117.60	114,53	5.84	8,34	493.81	481	50.76	48,01
Deaerator Outlet	68.23	71,069	151.00	168,7	5.81	8,34	636,51	713,40	89.00	113,50
Atemperator Outlet	1.65	3,901	150.80	168,4	5.81	8,34	636.51	712,00	88.84	112,59
Inlet Pump 2.	73.16	68,755	151.00	167,57	5.81	8,34	636.51	708,50	89.00	111,59
Boiler Inlet	73.16	68,755	197.60	235,00	86.00	99,00	845.71	1015,00	166.45	231,81

Table 2: Power, Fuel Consumption and Steam Flow.

Equip.	Power (MW)		Gas Volume (Nm^3/s)				Steam Rate (kg/s)	
	proj	oper	proj		oper		proj	oper
			BFG	COG	BFG	COG		
Plant. 01	66.00	68.00	60.95	0.00	50,48	1.78	73.85	74.353
Plant. 03	69.70	75.00	54.17	0.48	54.37	1.325	72.14	72.34

3 Exergoe conomic analysys

The exergoeconomic analysis is made by means of the First and Second Law of Thermodynamic. In the First Law analysis the values of the power, fuel consumption and efficiency of the component are determined, with the Second Law Analysis the irreversibility generated in the control volume of each component is calculated, to get the qualitative and quantitative view of the use of the exergy in each point of the plant. To complete the exergoeconomic analysis, balances of exergetic and monetary costs must be made, determining the costs of each flow in terms of the fuels of the system. Thus, information about the performance of the whole plant can be acquired. Tsatsaronis (1993) says exergoeconomic analysis has the following objectives:

a) to identify the localization, magnitude and the real sources of thermodynamic losses (exergy destroyed and exergetic losses);

b) calculate the associated cost of the exergetic losses and exergy destroyed in any component of the plant);

c) analyse the formation costs of each product, in the thermal systems that hold more than one product;

Tsatsaronis and Winhold (1985) divided the exergoeconomic analysis into four steps:

First step: exergetic analysis, identifying the localization, magnitude and source of each thermodynamic inefficiency.

This step, for this system, was previously done by Modesto et. al. (2002)

Second step: economic analysis in each component of the plant: providing the monetary costs associated with investment, operation, maintenance and cost of the fuel. The investment costs are considered fixed costs and the costs of maintenance, operation and fuel, variable costs.

CST arquives and manufacturing equipment data were used to evaluate the monetary costs of the equipment that make up the plant. The equipment costs must be added to the other costs, which are necessary for the complete operation of the plant, such as cost of installation, instrumentation, control, electrical and civil construction. The costs can be distributed as suggested by Bejan et al. (1995). The total cost can be amortized during the useful life of the plant. Amortization can be calculated using the formulation proposed by Bejan et. al. (1995).

A useful life period of 15 years and an annual interest rate of 12% were adopted. So as to use the cost balance equations, shown in the next section, it was considered that the plant operates for 8600 hours per year, calculating the equipment cost in (US$/s) for one year of operation.

Fuel cost calculation is done using an estimation with the natural gas market price. The use of this estimation is due to the fact that the COG and BFG gases do not have a defined commercial value. Considering that the price of each gas had been estimated regarding it LHV, thus, the BFG's and the COG costs were calculated based on the LHV's of each fuel, considering the natural gas price from GAS ENERGIA(2002). The values found are shown in Tab (3). In the make-up water cost case, used in the plant project condition 1, a value of 0.22US$/ton is considered (Guarinello et al. (2000)). Anyway, the make-up water consumption is very low.

Table 3 Price of Fuels Gases

	Lower Heat Value (kJ/m^3)	Price of gas (US$/m^3)
Natural Gas	37768	0.06335
BFG	3718	0.00625
COG	18275	0.03065

Third step: Calculus of the exergetic and monetary costs.

Exergetic costs; to calculate the exergetic costs and the monetary costs of each flow and of each component the "Theory of the Exergetic Cost" formulated by Lozano and Valero (1993) was used. The calculations of these costs are made by means equations of cost balances, both the exergetic and monetary costs, of all components, which makes up the system. The components can be separated or joined in control volumes where the equations of cost balance are applied. Equation (1) shows the cost balance equation in a generic control volume:

$$\sum k_i Ex_i - \sum k_e Ex_e = 0 \tag{1}$$

Where: "k" is the unitary exergetic cost and Ex is the total exergy of each flux, the sub index represents the inlet of the volume and "e" the exit of the volume.

Evaluating firstly plant 1 and taking as a reference Fig. (1), the Eq (1) is applied on each component shown in the figure. The equations of cost balance form a set of linear equations with the variable numbers larger than equation number. To obtain one equation system with the same number of variables and equations, to assume some extra relations is necessary to obtain a system with an unique solution.

These extra relations were performed, following the considerations proposed by Lozano and Valero (1993).

The exergetic costs of the inputs (in this case, fuel and the feeding water) can be considered unitary, so:

$$k_{comb} = k_{39} = 1 \tag{2}$$

Considering that all the irreversibility generated in the turbine must be "loaded" by the exergetic cost of electric power, what is obtained, considering that the costs of the steam, which enters and leaves the turbine are the same:

$$k_4 = k_5 = k_6 = k_7 = k_8 = k_9 = k_2 \tag{3}$$

In the valves, where only the division of the flows without generation of irreversibility exists, the flows that enter and leave the valves have the same exergetic cost.

Valve 20: $k_3 = k_2 = k_1$ (4)

Valve 21: $k_{36} = k_{37} = k_{35}$ (5)

Valve 22: $k_{40} = k_{18} = k_{17}$ (6)

Node 13: $k_{21} = k_{22} = k_{24} = k_3$ (7)

In the heat exchangers which pre-heat the boiler feeding water, it is considered that the exergetic cost of the steam is the same in the inlet and exit, thus all the irreversibility generated is "loaded" by the exergetic cost of the feeding water which left the heat exchanger, so:

$$\begin{cases} k_{22} = k_{25} \qquad k_8 = k_{28} \qquad k_{30} = k_{36} \\ k_{26} = k_{23} \qquad k_7 = k_{29} \end{cases} \tag{8}$$

Thus, equalizing the equation number with the variable number, a system of linear equations with unique solution was formed. This system was solved using the EES® software (2002)

It is necessary to determine the steam cost that is acquired from an external source, in this case the cost of this steam is considered to be the same cost obtained for the process steam from plant 1, in project conditions which was 6.27 US$/ton.

Using the same equations of exergetic balances costs, and the same kind of extra relations the exergetic costs for plant 3 were calculated.

So as to calculate the monetary costs of each energy current the same cost balances were carried out as the previous case, however this time the cost of the components of each control volume was considered, as shown in Eq (9)

$$\sum c_i Ex_i - \sum c_e Ex_e + \dot{Z}_k = 0 \tag{9}$$

Thus, the unitary monetary cost value (c_i) of each current, as well as of the electrical power and of the process steam in the project of plant 1, can be calculated.

The results for unitary and total exergetic and monetary costs to plants 1 and 3 are shown in the Tab (4) and (5)

Table 4: Unitary and total exergetic and monetary cost for plant 1

Localization	k		k_T (kW)		c (US$/GJ)		c_T (US$/hours)	
	proj	oper	proj	oper	proj	oper	proj	oper
Boiler Outlet	2,609	2,338	277471	252570	6,674	6,252	2555,280	2385,720
Turbine Inlet	2,609	2,338	275949	251202	6,674	6,252	2541,240	2372,760
1st extract	2,609	2,338	25001	5225	6,674	6,252	230,22	49,356
2ndextract	2,609	2,338	8008	7829	6,674	6,252	73,728	73,944
3rd extract	2,609	2,338	7313	7083	6,674	6,252	67,356	66,888
4th extract	2,609	2,338	6262	6066	6,674	6,252	57,672	57,312
Cond. Inlet	2,609	2,338	12102	12656	6,674	6,252	111,456	119,520
Inlet – Pump 01	2,609	2,338	157,8	152,8	6,674	6,252	1,453	1,444
Dea (Inlet)	6,367	5,842	21019	20457	19,1	18,27	226,980	230,328
Dea Outlet	4,982	4,448	30508	28891	17,01	15,85	374,760	370,440
Atemper. Outlet	4,748	3,779	679,5	1651	16,04	13,38	8,262	21,038
Inlet – Pump 02	4,748	3,779	31205	27888	16,04	13,38	379,440	355,428
Boiler Inlet	4,186	3,795	51456	44595	13,73	13,2	607,680	548,280
Process Steam	2,764	-	7541	-	7,131	-	70,020	-
Electric Power	3,473	3,306	219504	215072	11,42	11,14	2713,680	2727,000

Table 5: Unitary and total exergetic and monetary cost for plant 3

Localization	k		k_T (kW)		c (US$/GJ)		c_T (US$/hours)	
	proj	oper	proj	oper	proj	oper	proj	oper
Boiler Outlet	2,307	2,325	245186	247797	6,234	6,131	2384,640	2352,240
Turbine Inlet	2,307	2,325	239787	244344	6,234	6,131	2332,080	2319,480
1st extract	2,307	2,325	11618	334,1	6,234	6,131	113,004	3,171
2ndextract	2,307	2,325	9971	3904	6,234	6,131	96,984	37,044
3rd extract	2,307	2,325	9912	11283	6,234	6,131	96,408	107,100
4th extract	2,307	2,325	4353	4872	6,234	6,131	42,336	46,260
5th extract	2,307	2,325	4872	5444	6,234	6,131	47,376	51,696
Cond. Inlet	2,307	2,325	10,26	16,55	6,234	6,131	0,100	0,157
Inlet – Pump 01	2,307	2,325	9523	10641	6,234	6,131	92,628	101,016
Dea (Inlet)	4,882	5,293	14543	16267	16,32	17,03	174,996	188,424
Dea Outlet	3,706	3,846	26626	30413	13,78	13,46	159,804	174,528
Atemperator Outlet	3,597	3,773	546,3	573	12,97	13,18	7,092	7,207
Inlet – Pump 02	3,597	3,773	28358	30098	12,97	13,18	368,280	378,360
Boiler Inlet	3,086	3,629	50640	37113	10,9	13,68	644,040	503,280
Electric Power	2,854	2,911	191286	210008	10,11	9,911	2538,000	2675,880

Table (6) shows MWh values for electrical energy calculated for plant 1 and for plant 3.

Table 6 Electrical energy cost.

Localization	Energy Cost (US$/MWh	
	proj	oper
Plant 1	41,12	40,11
Plant 3	36,41	35,68

Fourth Step: Exergoeconomic analysis of each component

To evaluate each component, three exergoeconomics indices proposed by Tsatsatonis and Winhold (1985) were calculated: cost difference, relative cost difference and the exergoeconomic factor:

Cost difference: $\Delta c_k = c_{P,k} - c_{F,k}$ (10)

Relative Cost Diff.: $r_k = c_{P,k} - c_{F,k} / c_{F,k}$ (11)

Exergoeconomic Factor: $f = \dfrac{\dot{Z}_k}{\dot{Z}_k + c_{F,k}\left(\dot{E}_{D,k} + \dot{E}_{L,k}\right)}$ (12)

Where, the values of $c_{P.k}$ and $c_{F,k}$ are calculated for each component, using the relations proposed by Tsatsaronis and Winhold (1985). $\dot{Z}_k$ is the amortized cost, considering the investment and maintenance cost of the component. $\dot{E}_{D,k}$ and $\dot{E}_{L,k}$ are the exergy destroyed and the exergy losses.

The cost difference for one component shows the degree each subsystem contributes to the final cost of the products. The relative cost difference, expresses the same idea, but in a more elaborate form, because it calculates the increase of the cost in relation to the input of the component. The exergoeconomic factor indicates the percentage, with which the cost of the component $(\dot{Z}_k)$ influences the relative cost difference. Based on the exergoeconomic factor, it is observed that exergy losses and destroyed exergy are evaluated as having the same cost as the exergetic input of the component considered. Tsatsaronis and Moran (1997) affirm that if the value of (f_k) is high, it means that the cost of the equipment is responsible for the greater part of the product cost of this component, making it advantageous to investigate the decrease of investment capital of the component, eventually admitting analysing a decrease in it efficiency.

However, a low value of (f_k) means that the greater part of the cost of the product is due to exergetic losses. The greater the cost associated to the irreversibilities of a certain component, the higher the priority to investigate the possibility of decreasing the irreversibilities of this component by the increase of the investment capital. The index values for plants 1 and 3 are shown in Tab. (7) and (8)

Table 7 Exergoeconomic index for plant 1

Component	Δc_k		r_k		f_k (%)	
	proj	oper	proj	proj	oper	proj
Boiler	5,332	4,884	12,690	12,730	68,680	73,750
Turbine	4,747	4,888	0,711	0,782	45,510	43,180
AEJ	18,530	71,370	2,777	11,420	7,100	7,200
GC	17,140	21,710	3,115	4,132	8,450	8,350
HTR1	8,921	8,366	1,337	1,338	12,890	12,970
HTR2	3,645	3,358	0,583	0,567	29,660	29,560
HTR3	1,731	2,147	0,263	0,304	30,330	67,860
Dea	4,422	3,618	0,352	0,296	72,110	71,580
Pump 01	342,900	237,900	116,000	88,140	94,910	95,330
Pump 02	21,690	74,830	0,207	0,728	28,320	29,700

Table 8 Exergoeconomic index for plant 3

Component	Δc_k		r_k		f_k (%)	
	oper	proj	oper	oper	proj	oper
Boiler	4,974	4,896	13,790	12,530	76,810	73,290
Turbine	3,881	3,779	0,622	0,616	58,800	56,480
AEJ	2,024	8,676	0,325	1,415	9,300	8,540
GC	16,570	5,071	0,622	0,377	96,030	97,960
HTR1	6,346	6,152	1,018	1,003	17,400	16,190
HTR2	1,960	2,974	0,311	0,480	39,290	37,260
HTR3	0,200	2,961	0,032	0,483	59,960	71,520
HTR4	1,927	91,160	0,309	14,870	69,000	93,490
Dea	3,657	3,390	0,370	0,346	67,150	65,150
Pump 01	582,600	299,500	216,800	112,900	95,790	95,510
Pump 02	4,637	40,860	0,047	0,878	23,310	39,000

4. Conclusion

Considering firstly Plant 1, the exergoeconomic analysis found that the alterations carried out in the layout of the plant improved the thermal performance of it in all the indices analyzed.

Comparing the conditions of the project and operation, there was a 17,17% decrease in the consumption of the BFG, a 3% increase in the electric power generated, a 10.5% decrease in the total irreversibility generated and a 7.2% increase in the global efficiency of the unit. Following the same improvement tendency in the indices, the calculation of the exergetic costs shows a decrease of 4,8% in the exergetic cost of electric power and a 2,45 % decrease in the monetary cost of the MWh generated.

This gain of quality in the use of energy is due to the availability of steam from CDQ (Coke Dry Quench) and also by the availability of the COG as fuel. This steam is used to pre-heated the water feed in the HTR3, thus decreasing and/or eliminating the use of one of the turbine extractions, increasing the power generated. The COG gas has a LHV 14 times larger than BFG, thus with a small amount of COG the consumption of BFG can decrease, improving all performance indices.

In terms of plant 3, the difference between the project and operation conditions is the decrease and/or elimination of the use of the turbine extractions, which pre-heat the feed water to boiler in the last two heat exchangers (HTR3 and HTR4). This modification involves a 176% increase of COG consumption; a 7.6% increase of electric power and 9.1% increase in the irreversibility generated, while the global efficiency decreased 0.6%. The index of costs shows that exergetic cost of electric power increased 2,0% and a decrease of 2,0% for monetary cost of MWh.

The main objective of the modification is the increase of generation of electric power without the decrease of plant efficiency. This objective can be reached due to the availability of the COG, because even with the increase of the generated electric power and irreversibility, the increase of the total volume of fuel represented an insignificant increase of the exergetic and monetary cost. Analyzing the components of each plant by means of the exergoeconomic index: $(\Delta c_k,\ r_k,\ f_k)$ it can be seen that the behavior of the components is similar in both plants. Analyzing the (Δc_k) values it can be observed that the pump 1 has the higher value, but the HTR4 in plant 3 operation condition also has a high value of (Δc_k), due to the fact that closed turbine extraction decreases the value of the exergetic input $(c_{f,(HTR4)})$ and increases the value of cost difference $(\Delta c_{k(HTR4)})$. The same fact occurred with the AEJ and GC components in the operation conditions of plant 1.

When the relative cost difference (r_k) was analyzed, considering the cost variation with the input involved with each equipment, it was noted that apart from the component cited previously, the boiler also has a high value of (r_k), which shows the importance of this equipment in the composition of total plant costs. Finally, the exergoeconomic factor (f_k) indicates the weight of equipment cost in the relative cost difference. The component which has the larger values of (r_k), and therefore contributes more towards the increase of the cost of the plant is the condensed pump, GC and AEJ under the operation conditions of plant 1, HTR4 under the operation conditions of plant 3, the deaerator and the boiler in all cases. In the conditions analyzed, these components has a high value of (f_k), indicating that a decrease in the capital cost, with a decrease of efficiency, could contribute to the decrease of the global cost of the plant. The AEJ and GC components have a low (f_k) value, indicating that an increase in the capital cost of the component could increase the efficiency and decrease the global costs.

Crossing the information of the exergoeconomic factor with the results of the exergetic analysis, it can be verified that a component such as the pump 1, AEJ, GC and HTR4 each contribute with less than 1% of the irreversibility generated in the plant, while the boiler contributes with more than 75% of the total irreversibility generated. Thus, modifications made to the boiler produce a greater effect in the global cost of the plant than in the other components, thus, the exergoeconomic analysis allows a diagnosis of the project and operation of the plant so as to indicate the best way to improve the efficiency and decrease the costs of the plant products.

The exergoeconomic analysis carried out here was on metallurgical gases. A more precise analysis should take into account the cost estimate of each gas as they are gases which present different characteristics. Especially in relation to LHV values. Fig. (3) shows a price estimate for MWh of electric energy generated in relation to the price percentage of natural gas. This estimate is carried out so as to estimate the price of combustion gases used in the power system. This was done so as to best quantify the cost of these metallurgical gases.

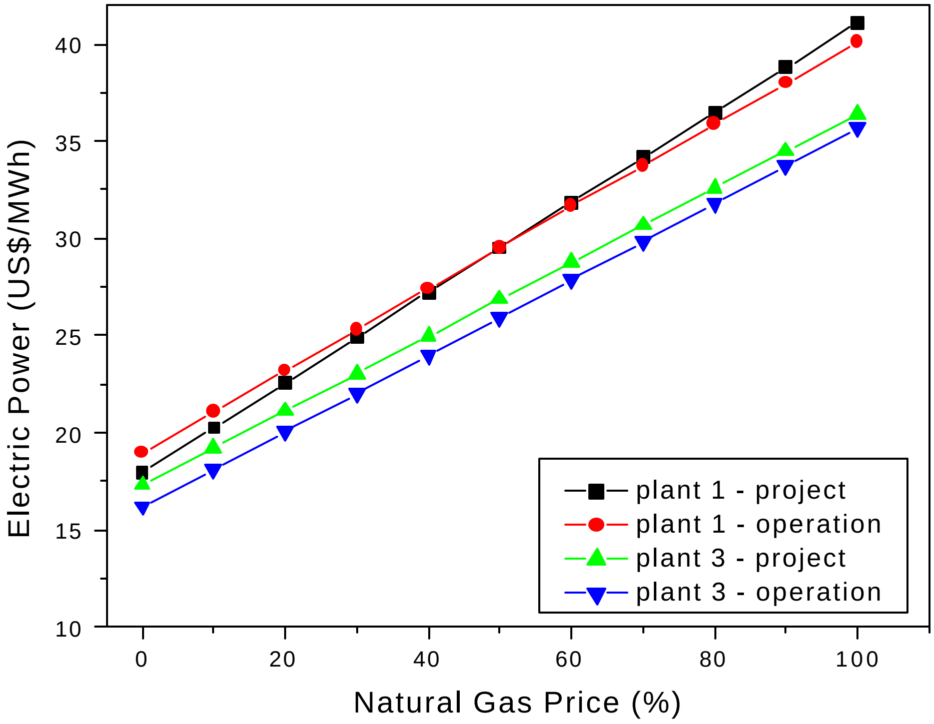

Figure 3 Price variation of the MWh generated in function of the fuel prices

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