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Exergo-Economic Fuel-Impact Analysis for Steam Turbines Sections in Power Plants

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Abstract

In this paper exergoeconomic fuel-impact models for steam turbines in power plants are proposed. They are applied to calculate the impact on the steam cycle when malfunctions are occurring during the operation of steam turbine sections. Concepts such as the exergetic consumption and the dissipation temperature are used to understand the proposed fuel-impact analysis. In order to validate these fuel-impact methods, well-known procedures, to simulate on- and off-design conditions of a steam power cycle, are used as references. Three different methods a) ASME PTC-6, b) existing fuel-impact formula, and c) proposed exergoeconomic Fuel–Impact formulation, are compared with respect to the simulator results. The proposed models allow evaluating fuel-impact cost with more accurate results than conventional procedures. An example of a 158 MW conventional power plant is presented herein. The malfunction costs occurring in the steam turbines are inferred from the results. One perspective of this analysis is to establish an on-line monitoring system into power plants that permits to opportunely detect steam turbine malfunctions, without simulators.

Key words: exergetic cost, unit exergetic cost, exergetic efficiency.

1. Introduction

Steam turbines in power plants are one of the most important components during the power generation processes, any malfunction occurring into them will increase the overall heat rate, that is to say an *increase in fuel for producing the same power*. Steam turbines malfunctions may occur mostly due to *induced* and/or *intrinsic* effects (Royo 1997). Induced malfunctions are due to out-of-guarantee operating conditions such as deviations in the inlet temperature and back pressure, as well as over-full throttle mass flow. Intrinsic malfunctions are due to internal mechanical worn-out such as: roughness, excess in clearances, end-packing losses, erosions, sediments, etc. The intrinsic malfunctions impact more strongly the (isentropic or exergetic) efficiency than the induced malfunctions. In this sense, exergetic efficiency (or exergetic consumption) can be one of the parameters that brings out the actual operating conditions of the steam turbine. Some power plants ignore the real impact on their steam turbines operating under malfunction conditions, what makes that heat rates become higher. For critical cases, operation of the plant under malfunction conditions could overcome the maintenance cost of the damaged component (s) due to fuel impact cost. Fuel Impact analysis will allow to the plant's managers to make decisions about opportune maintenances or overhauls, and thus getting a reduction in the energy consumption and emissions. Currently, there exist other procedures for applying fuel-impact analysis to steam turbines, one of them is the conventional ASME/ANSI PTC-6 (1996), and other one is the fuel-impact model which is based on "the Exergetic Cost Theory" presented by Valero et. al. (1994). These procedures are briefly described in the following paragraphs.

1.1 ASME performance test code (PTC)

Steam Cycle Heat-Rate is a conventional index of the power plants performance, and which is simply defined as the ratio of the heat input, $\dot{Q}_{boiler}$, to the work output, $\dot{W}_{Gen}$

$$HR_{cycle} = \frac{\dot{Q}_{boiler}}{\dot{W}_{Gen}} \qquad (1)$$

Any change occurring in the Steam Cycle Heat-Rate may be due to malfunctions in any component of the steam cycle (boiler, steam turbine sections, pumps, or heat exchangers). Currently, the performance test code ASME/ANSI PTC-6 (1996) is being used for evaluating the thermodynamic performance of steam turbines; this PTC also includes an analysis to determine Heat-Rate impact (ΔHR) due to changes in isentropic efficiency of steam turbines (Δη). The PTC's models are based on the work developed by Cotton and Westcott (1960), which includes models for evaluating Heat-Rate impacts due to isentropic efficiency changes (Δη) occurring in the steam turbine sections (i.e. High Pressure, *hp*; Intermediate Pressure, *ip*; and Low Pressure, *lp*). The Heat Rate Impact on the steam sections can be readily calculated as

$$\Delta HR\% = \frac{\Delta\eta_{hp}\%(UE_{hp})(\dot{m}_{hp})}{\overline{\dot{W}}_{Gen}} - \frac{\Delta\eta_{hp}\%(UE_{hp})(\dot{m}_{rhtr})}{\overline{\dot{Q}}_{Boiler}} \qquad (2)$$

$$\Delta HR\% = \frac{\Delta\eta_{ip}\%(UE_{ip})(LF)}{UE_{rh}}\left(1 - \frac{UE_{hp}\dot{m}_{hp}}{\overline{\dot{W}}_{Gen}}\right) \qquad (3)$$

$$\Delta HR\% = \Delta\eta_{lp}\%\left(1 - \frac{UE_{hp}\dot{m}_{hp}}{\overline{\dot{W}}_{Gen}}\right) \qquad (4)$$

where Δ represents the changes between state conditions (i.e. *actual and reference*) *at constant throttle flow*, *UE* stands for the Used Energy (enthalpy drop), in a Steam Turbine Section (*hp*, high pressure; *ip* Intermediate; and *rh*, Reheat section; respectively) and L.F. is the Loss Factor for correcting the Fuel-Impacts at Intermediate Pressure Steam Turbine. One feature of these models is that comparison between equations (1) and (3) is made *at constant throttle flow*.

1.2 Fuel impact based on exergy cost theory

Alternatively, Valero et al. (1994) presented a practical methodology (in the Exergetic Cost Theory) that calculates the exergetic costs[1] of the Fuels (F^*) and Products (P^*) for each stream in a (i-th) component or subsystem. It is achieved by simply applying a balance of costs between the fuels and the products of any component or subsystem

$$F_i^* = P_i^* \quad \text{or} \quad k_{P,i}^* \cdot P_i = k_{F,i}^* F_i \qquad (5)$$

where k_{F,i^*} and k_{P,i^*}, are the unit exergetic cost of fuels and products, respectively.
In addition, Valero et al. (1994) and Reini M., et. Al. (1995) have pointed out that any global Exergy Fuel Impact (dF_T) has its origin from an increase in the total production (dP_T) and/or an increase in the irreversibilities (dI_T), which can be written as

$$dF_T = dP_T + dI_T \qquad (6)$$

From equation (6), it is readily seen that if the production in the plant (P_T=const) is desired to be constant, then the fuel increase due to irreversibilities (malfunctions) inside the system simplifies to

$$dF_T\big|_{P_T=\text{const.}} = dI_T\big|_{P_T=\text{const.}} \qquad (7)$$

When a malfunction appears in a specific component or subsystem (i-th), on the other hand, it affects directly its local exergetic consumption (dk_i). And if it is also desired to maintain the local production constant, then the local fuel-impact can be derived from the definition of the unit exergy consumption as

$$k_i = \frac{1}{\eta_{ex,i}} = \frac{F_i}{P_i} \qquad dk_i = \left.\frac{dF_i}{P_i}\right|_{P_i\ =\text{const.}}$$

then $\quad dF_i = P_i\, dk_i = dI_i \qquad (8)$

Upon assuming that the marginal exergy cost of the irreversibilities in a component i, equals to its exergy fuel cost, while the other components do not undergo any malfunction, equation (8) becomes.

$$\left.\left(\frac{\partial F_T}{\partial I_i}\right)\right|_{\eta j\neq i} = k_{F,i}^* \qquad dF_T \cong k_{F,i}^* dI_i \qquad (9)$$

From the last assumptions, Valero et al. (1994) obtain an expression that helps to figure

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[1] Exergetic cost of a flow is defined as the exergy plus all the accumulated irreversibilities to get that flow.

out the Exergetic Fuel Impact (A) when a malfunction occurs in the *i-th* component. The coefficients $k_{f,i}^*$ and P_i are evaluated at reference condition, and dk_i is compared with respect to test and reference condition.

$$A\big|_{P_T=\text{const.},\ \eta_{j\neq i}} = dF_T = k^*_{F,i}P_i dk_i \qquad (10a)$$

Reini M., et. Al. (1995) presented (see reference) an exact analytical Fuel Impact Formula, equation (10b), it takes account also of global product variations:

$$\Delta F_T = \sum_{i=1}^{n}\left(\sum_{j=0}^{n} K_{P,j}{}^* \cdot \Delta k_{ji}\right)\cdot P_i^0 + \sum_{i=1}^{n} K_{p,i}{}^* \cdot \Delta P_{ext_i} \qquad (10b)$$

Later on, it is going to be explained that the comparison is made at *constant production of the plant*, equation (10a). It is worth pointing out that the calculations made by the model represent a hazardous analytic model that could bring calculation errors into the results.

2.- Proposed Exergoeconomic Fuel Impact Models

As it can be seen, the models explained by equations (2) and (4) are based on Heat Rate changes (ΔHR) at "constant throttle flow". In comparison, the fuel impact model presented in equation (10) makes the comparison between different conditions by assuming local and global "production constant". The following procedure will establish a unified criterion of comparison based on exergetic analysis when a malfunction appears in a subsystem (in this case steam turbine sections) of a Steam Cycle (as Overall System).

2.1 Specific exergy consumption of an overall system (steam cycle)

The exergy concept is useful to determine the local irreversibilities in a component, and it can be applied to diagnose and evaluate the efficiency of the components as well. The analysis of the proposed method derives from the well-accepted definition of *Total Specific Exergetic Consumption*, $Kb_{T,}$ of an Overall System,

$$Kb_T = \frac{F_T}{P_T} = \frac{\sum F_{T,i}}{\sum P_{T,i}} \qquad (11)$$

where F_T and P_T represent the *overall exergy supplied in Fuels*, and the *overall exergy in useful Products*, respectively. Whenever malfunctions occur in any *(i-th)* of the components, they will perturb the ratio of the *Total Specific Exergetic Consumption*. The perturbation can be written as:

$$\frac{dKb_T}{Kb_T} = \frac{\sum_{i=1}^{n} dF_{T,i}}{F_T} - \frac{\sum_{i=1}^{n} dP_{T,i}}{P_T} \qquad (12)$$

Overall Impact = Fuel changes + Production Changes

where the first term at the right-hand side of equation (12) represents the impact on $K_{b,T}$ due to a change on the *overall exergy inlet Fuels ($dF_{T,i}$)*, and the second term represents the impact due to *overall exergy outlet Products change (dP_T)*. It means that when only one of the (i-th) components goes through a malfunction (and the others do not), then a specific impact on the overall Fuels and Products will occur. In this paper, $K_{b,T}$ is applied to steam cycles and interpreted as the exergetic consumption of the cycle. Any perturbation of the $K_{b,T}$ can be evaluated economically as explained below.

2.2 Exergoeconomic fuel impact

Any change in the Total Specific Exergetic Consumption (dKb_T) of a steam cycle turns into an excess of exergy supplied as fuels to generate a unit of production (kJ/kWh). The exergoeconomic fuel-impact value is obtained from the change of the Total Specific Exergy Consumption, and it can be calculated as:

$$\text{Fuel Impact}_i[\$/\text{sec}] = 3600 \cdot FC\frac{\overline{P_T}}{\eta_{boiler}} dKb_{T,i} \qquad (13)$$

where Fuel Impact$_i$ represents the Fuel Impact Cost per unit time due to a malfunction occurring into the i-th component [$/sec]; FC is the Fuel-Cost [$/kJ]; $\overline{P_T}$ is the average (between reference and test) production [kW], η_{boiler} is the exergetic efficiency of the steam boiler; $dKb_{T,i}$ is the change in total exergetic fuel consumption (excess of Fuel per unit of Total Production) [kJ/kW hr]; and 3600 is a conversion factor [hr/sec]. From equation (13), it is seen that the main objective is to work out the change in total exergetic consumption $dKb_{T,i}$ due to malfunctions in the steam turbine sections.

2.3 Local malfunctions in a component (steam turbine)

An exergy balance of any steam turbine section, regarded as the (i-th) subsystem of the steam cycle, can be written as:

$$b_{i,in} - b_{i,out} = w_i + T_0 s_g \qquad (14)$$

A productive structure of the steam turbine [3] allows to define its local Fuel (F_i) and local Product (P_i) as:

$$F_i = \dot{m}_i\left(b_{i,in} - b_{i,out}\right) \text{ and } P_i = \dot{m}_i w_i \qquad (15)$$

Further, the local exergy consumption in the steam turbine can be given by:

$$k_{ex,i} = \frac{1}{\eta_{ex,i}} = \frac{F_i}{P_i} = \frac{b_{i,in} - b_{i,out}}{w_i}$$

$$= \frac{\left(h_{i,in} - T_0 s_{i,in}\right) - \left(h_{i,out} - T_0 s_{i,out}\right)}{\left(h_{i,in} - h_{i,out}\right)} \qquad (16)$$

When an intrinsic malfunction appears in the steam turbines, it affects directly the local exergy consumption ($dk_{ex,i}$), thereby occurring changes on Fuels (dF_i) and products (dP_i). In order to quantify these changes, Throttle Mass Flow (m_i=const.), and inlet thermodynamic state (*$b_{i,in}$=const.* because induced malfunctions are not considered) are considered constant, thus equations (15) and (16) become, respectively:

$$dF_i = \dot{m}_i\, d\left(b_{i,in} - db_{i,out}\right) = \dot{m}_i\left(-\,dh_{i,out} + T_0 ds_{i,out}\right)$$

$$= -\,\dot{m}_i\, dh_{i,out}\left(1 - T_0\frac{ds_{i,out}}{dh_{i,out}}\right) \qquad (17)$$

$$dP_i = \dot{m}_i\, dw_i = \dot{m}_i\, d(h_{i,in} - h_{i,out}) = -\,\dot{m}_i\, dh_{i,out}$$

$$= -\,\dot{m}_i\, dh_{i,out} \qquad (18)$$

Substituting then equation (18) into equation (17) yields,

$$dF_i = dP_i\left(1 - T_0\frac{ds_{i,out}}{dh_{i,out}}\right) \qquad (19)$$

In accordance with the Second Law analysis of Bejan (1994) and Royo et al (1997), the concept of the Dissipation Temperature (T_d) can be written as:

$$T_d[K] = \frac{dh_{i,out}}{ds_{i,out}} \qquad (20)$$

In the case of steam turbines, the Stodola´s Ellipse (Cooke, 1984) considers that for a constant throttle mass flow, the exhaust pressure remains approximately constant (p_{out}=const.), then under such conditions, dissipation temperature coincides with its exhaust temperature (T_{out}).

$$T_d = \left.\frac{dh_{i,out}}{ds_{i,out}}\right|_{p_{out}} = T_{i,out} \qquad (20a)$$

Substituting equation (20a) back into equation (19), it is possible to obtain an expression that relates the local fuel changes to local product change to the dissipation temperature,

$$dF_i = \left(1 - \frac{T_0}{T_d}\right) dP_i \qquad (21)$$

Derivating equation (15) and substituting then the result into equation (21), it is possible to express the influence of the change in local consumption and change in production as:

$$dk_{ex,i} = \left(1 - k_{ex,i} - \frac{T_0}{T_d}\right)\frac{dP_i}{P_i} \qquad (22)$$

The set of equations (12), (21) and (22) constitute the basis for carrying out a fuel-impact analysis in the steam turbine sections for a power plant.

2.4 Fuel -impact for high pressure steam turbine section (before reheating)

Any malfunction occurring in a High Pressure Steam Turbine (HP) before reheating will affect the overall production (shaft work) in the same proportion that occurs locally ($dP_T = dP_i$); while a reduction in the local Fuel will represent a drop in the operation of the reheater and thus a reduction in the overall Fuel (dF_i=dF_T). *Figure 1(a)*, shows the effect of change in the expansion line for a High Pressure Steam Turbine section. The fuel impact model that figures out the malfunctions due to HP steam turbine sections can be derived from substituting Equations. (21) and (22) back into equation (12), that is,

$$\left.\frac{dK_{b,T}}{K_{b,T}}\right|_{i-th\ malfuntion} = \frac{dF_i}{F_T} - \frac{dP_i}{P_T}$$

$$dKb_{T,HP} = \left(\frac{P_i}{P_T}\right)\left(\frac{1 - Kb_T - \dfrac{T_0}{T_{d,HP}}}{1 - k_{HP} - \dfrac{T_0}{T_{d,HP}}}\right)\left(dk_{HP}\right) \qquad (23)$$

where $dKb_{T,HP}$ represents the Overall Fuel Exergy Impact (kJ) per kWh of generation in a steam cycle.

2.5 Fuel-impact for an after reheating intermediate steam turbine section

In the Intermediate Pressure Steam Turbine, it is readily seen from the scheme of the *Figure1(b)* that the Total Fuel (F_T) of the Plant does not change when a malfunction appears, but a reduction in shaft work occurs (dp_{ip}). Nevertheless, this effect is attenuated by the recuperation of energy that is generated in the down -stream turbines which is defined as the

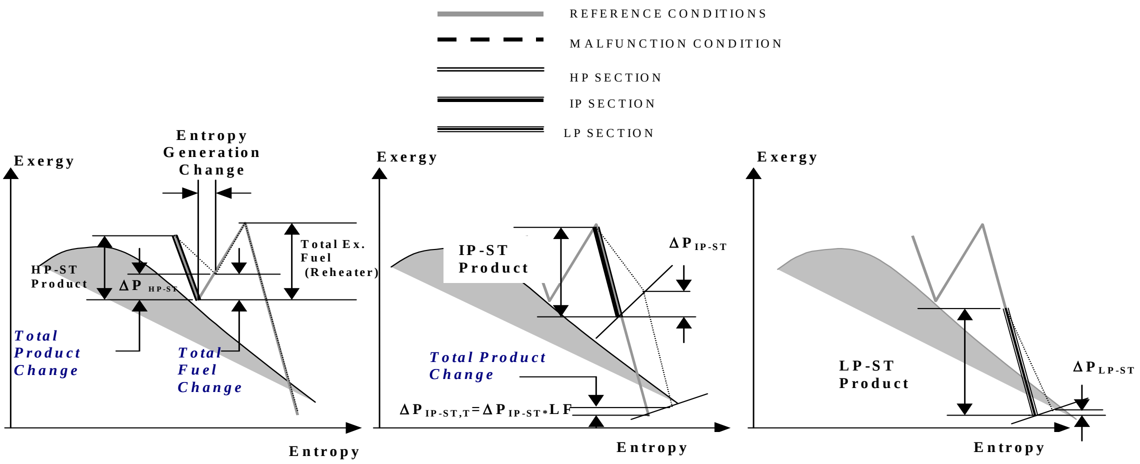


Figure 1. Schematic Representation of the Expansion Lines at Reference Condition and Malfunction Conditions, (a) High Pressure Section, (b) Intermediate Pressure Section, and (c) Low Pressure Section, respectively.

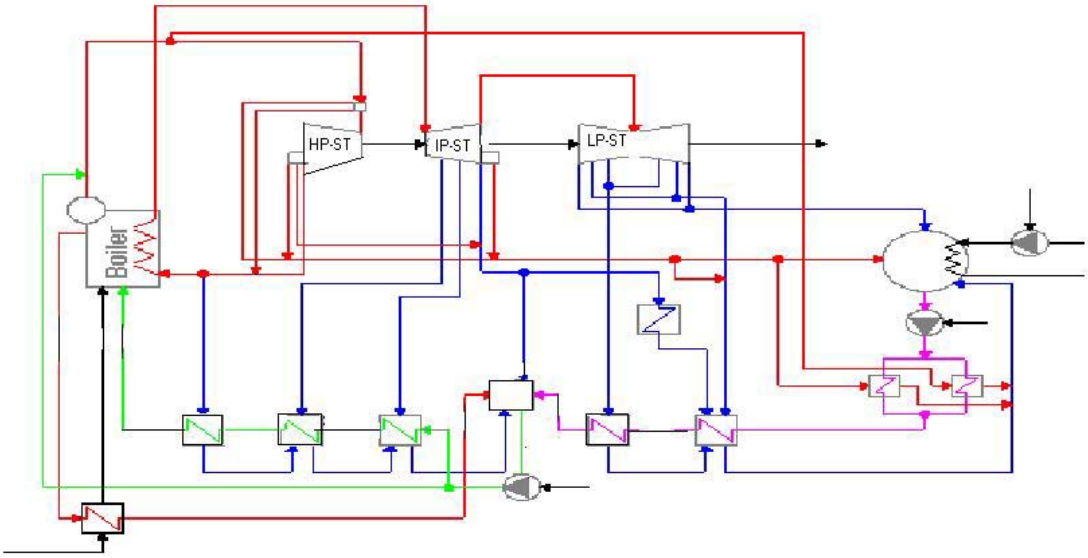


Figure 2. Diagram of a 158 MW Power Plant Steam Cycle Simulator

Loss Factor (L.F.) and that is broadly described in ASME/ANSI PTC-6 (1996). So, the Fuel (exergy) Impact for an IP turbine could be derived from substituting equations (21) and (22) back into equation (12),

$$\left.\frac{dK_{b,T}}{K_{b,T}}\right|_{i-\text{th malfuntion}} = -\frac{dP_i}{P_T}$$

$$dKb_{T,IP} \cong \left(\frac{P_{IP}}{P_T}\right)\left(\frac{LF}{1-k_{IP}-\frac{T_0}{T_{d,IP}}}\right)dk_{IP} \qquad (24)$$

where d Kb $_{T,IP}$ stands for the Overall Fuel Exergy Impact (kJ) per kWh of generation in a steam cycle.

2.6 Fuel -Impact for an After Reheat Low Pressure Steam Turbine Section

Provided that the Low Pressure Steam Turbine (LP-ST) discharges to a condenser, one could determine that the product losses in this section are equal to the change in the exergy of its expansion end point, (see *Figure 1c*), which can be written as:

$$\left.\frac{dK_{b,T}}{K_{b,T}}\right|_{i-\text{th malfuntion}} = -\frac{dP_i}{P_T}$$

$$dK_{b,T} \cong \left(\frac{P_{LP}}{P_T}\right)\left(\frac{1}{1-k_{LP}-\frac{T_0}{T_{d,LP}}}\right)dk_{LP} \qquad (25)$$

Finally, from the set of equations (23), (24) and (25), it is possible to obtain the exergoeconomic cost of the fuel-impact.

3. Study Case (Example)

A conventional Regenerative Steam Cycle Power Plant (158 MW) is presented in order to evaluate the proposed fuel impact models. *Figure 2* shows a diagram of the plant. The simulation of the model was carried out according to the following assumptions:

- Adiabatic Steam Turbines.
- Pressure Losses in pipes and ducts according to the manufacturer empirical models.
- Mass Flow Coefficients at throttle conditions for each steam turbine section, simulated according to Stodola´s Ellipse (Cooke, 1984).

$$\phi = \frac{\dot{m}}{A} / \sqrt{\frac{P_i}{\nu_i}} \qquad (26)$$

- Mass Flow extractions determined by modelling the performance in Heat Exchangers (NTU)
- Reference Efficiencies predicted by the procedure of Spencer et al. [4].
- Exhaust Losses at the last Section according to manufacturer information.
- No leaks or seals are considered.
- Mechanical and Electrical losses are considered.

Upon running the simulation program (simulator), it was possible to reproduce the operating conditions of the plant at different loads and operation manners. Besides, it was possible to determine a “real” value of the fuel-impact of the three steam turbine sections (HP, IP, LP) as well as to apply the exergy models expressed by the equations (23), (24) and (25) to determine the fuel-impacts. *Figure 1* shows an **Exergy-s** expansion line diagram of the steam turbine sections and the possible trajectory when a malfunction occurs in one of them (change the exergetic efficiency). In the conclusion section of this paper, the simulator will be helpful to compare fuel-impact values with other analytic models (*Figures 4-6*).

4. Results

Some tests in a power plant were accomplished with equipment from a certified laboratory by applying measurement procedures of a Performance Test Code. Data obtained in these tests are shown in the TABLE I.

* **Test 1**. In this test, the operation conditions of the power plant corresponded to a situation before an overhaul, where the components had been operating without maintenance for four years.

* **Test 2**. The operation conditions corresponded to a week after overhaul.

* **Test 3**. The operation conditions corresponded to six months after overhaul.

TABLE I. RESULTS FROM TESTS WITH VWO (VALVE WIDE OPEN).

STEAM TURBINE SECTION	MEASURED FIELD DATA	TEST 1, July 1998 (before overhaul)	TEST 2, August 1998 (after overhaul)	TEST 3, January 1999 (6 months after overhaul)
HIGH PRESSURE	Throttle Flow (kg/sec)*	135.89	132.61	133.93
	Inlet Pressure (bar)	123.143	126.93	128.77
	Inlet Temperature (ºC)	529.9	536.3	534.7
	Outlet Pressure (bar)	33.38	33.69	33.66
	Outlet Temperature (ºC)	348.2	347.2	349.7
INTERMEDIATE-PRESSURE	Throttle Flow (kg/sec)	120.29	116.46	118.23
	Inlet Pressure (bar)	29.75	29.88	29.98
	Inlet Temperature (ºC)	524.5	531.5	521.8
	Outlet Pressure (bar)	3.69	3.67	3.68
	Outlet Temperature (ºC)	260.3	261.1	254.0
LOW – PRESSURE	Throttle Flow (kg/sec)	106.70	102.39	104.57
	Inlet Pressure (bar)	3.69	3.67	3.68
	Inlet Temperature (ºC)	260.3	261.1	254.0
	Outlet Pressure (bar)	0.105	0.081	0.119
	Quality**	0.9419	0.9326	0.9410
Overall Power	MW	152.164	152.859	150.366
Total Specific Exergy Consumption ($k_{b,T}$) at Steam Cycle	1.2185 reference value	1.2736	1.2380	1.2679
% Change Exergy Consumption at Steam Cycle		4.522%	1.600%	4.054%

The proposed exergy models expressed by the equations.(23), (24), and (25) were applied to a study case to determine fuel-impacts. Exergoeconomic fuel-impact costs were worked out for Test 1, 2 and 3. According to the results, *Figure 3* and TABLE II, the fuel-impact cost in the turbine is lowest just after the overhaul, but six months afterward, the fuel-impact cost increased due the internal malfunctions, which reduced the exergetic efficiency. The fuel-impact with low cost corresponds to the operation conditions established by the manufacturer, but in real conditions, an increment in the fuel-impact cost is related to the deviation from the “ideal” operating conditions. This deviation causes the increment in the day-to-day fuel consumption and the operating cost in the power plant.

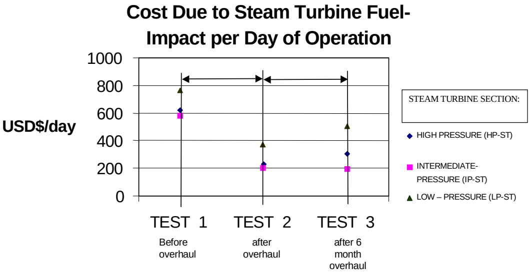


Figure 3. Cost due to the Fuel-Impact in the Steam Turbine per Day of Operation in Overall Plant (USD$/day).

TABLE II. FUEL IMPACT IN THE STEAM TURBINE PER DAY OF OPERATION AT STEAM CYCLE (KJ/DAY).

STEAM TURBINE SECTION	TEST 1, July 1998 (before overhaul)	TEST 2, August 1998 (after overhaul)	TEST 3, January 1999 (6 months after overhaul)
HIGH PRESSURE	1.098E+08	4.105E+07	5.472E+07
INTERMEDIATE-PRESSURE	1.047E+08	4.186E+07	3.901E+07
LOW – PRESSURE	1.346E+08	6.606E+07	8.552E+07

5. Conclusions and Perspectives

Three different models (listed below) were compared so as to determine the Fuel-Impact effects, assuming a 1% of loss of exergy efficiency in the steam turbine sections.

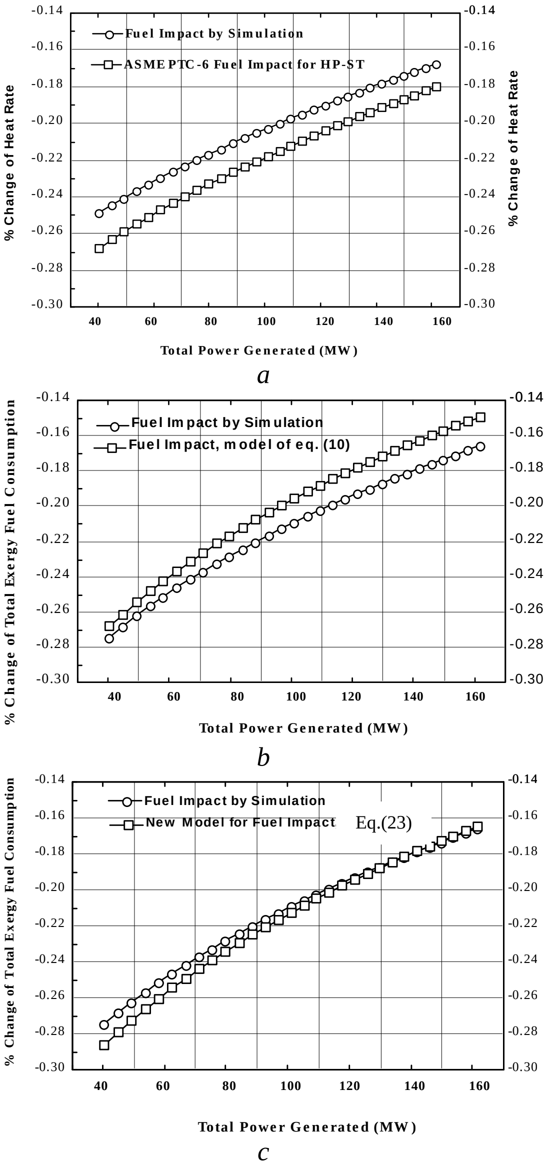
a) ASME PTC-6

b) Model of the equation (10)

c) Proposed model for HP, IP, and LP steam turbine sections, equations (23), (24) and (25), respectively.

Values obtained from these models were compared with the real values obtained through the simulator, as shown in *Figures 4, 5*, and *6*. Results reveal that the proposed model obtains for all cases an error lower than 0.15%.

Moreover, other procedures [2, 3] were also tested and an error in respect to the simulator higher than 2% was yielded. This means that the proposed Fuel Impact Models, equations. (23), (24), and (25), represent a more accurate way to determine the malfunction costs in the steam turbine sections during operating. It is worth noting that if the fuel impact value were "zero", that would mean that steam turbine section is operating at nominal condition. For a negative value of fuel impact, it would mean that an improvement inside the steam turbine occurs.



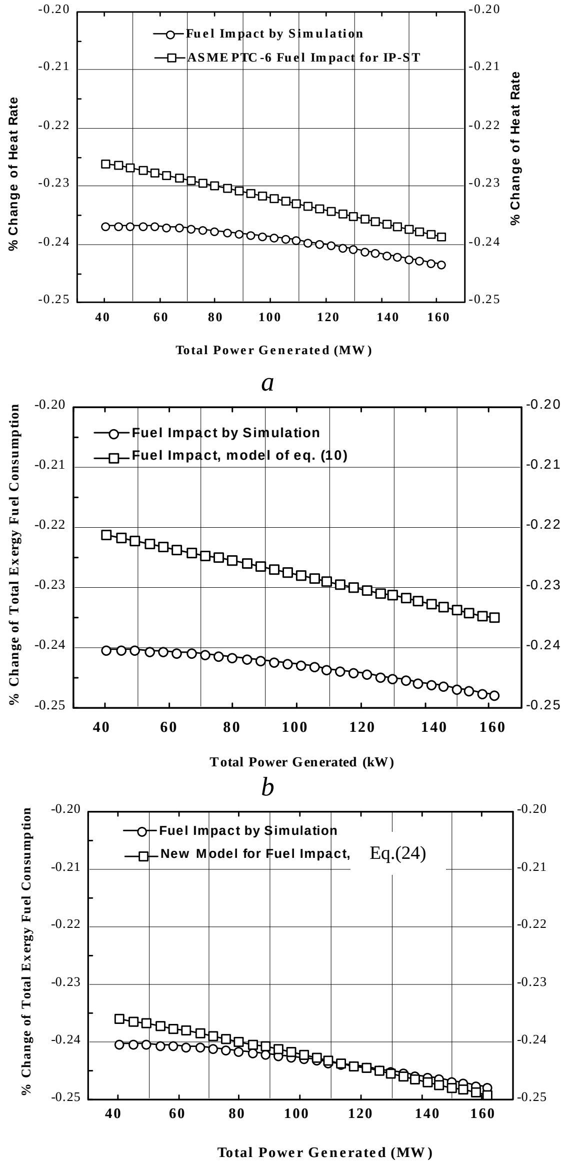
a

b

c

Figure 4. Comparison of the Fuel Impact Models in HP-ST (a)ASME/PTC-6, (b)Exergy Fuel Impact of the equation (10) ,and (c) Exergy Fuel Impact of the equation (23), when a 1% of Change of Exergy Efficiency Occurs.

The deviations that are observed in models ASME PTC-6 and equation (10) seems to be more notorious in the cases of the HP-ST and the IP-ST, the main cause it could assume by the induced effect of the malfunction in the reheater (for case HP-ST) and the LF (in the case of the IP-ST), nevertheless will be reason for a detailed analysis.



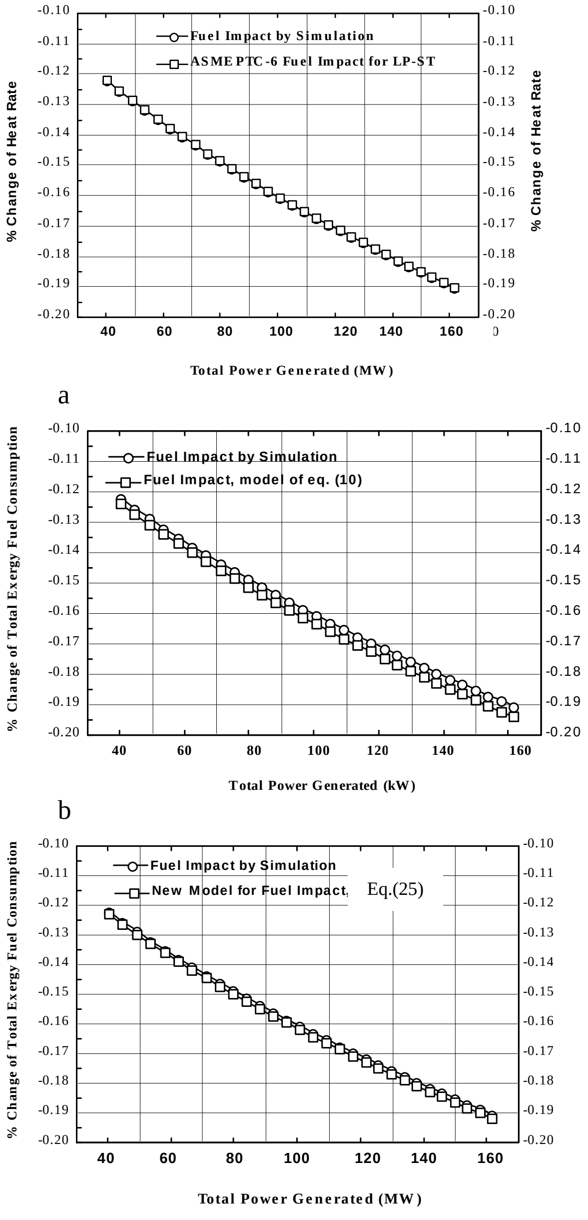
a

b

c

Figure 5. Comparison of the Fuel-Impact Models in IP-ST (a)ASME/PTC-6, (b) Exergy Fuel Impact of the equation (10) ,and (c) Exergy Fuel Impact of the equation (24), when a 1% of Change in the Exergy Efficiency Occurs.

To sum up, the exergoeconomic fuel-impact analysis provides important information to the power plant’s manager, before and after overhauling, and it is a useful tool during daily operating conditions. At present, the exergoeconomic fuel-impact model is being extended to study other equipments of the power plant (e.g. condenser, boiler, heat exchangers, etc.), in order to try to establish an on-line analysis in the power plant through INTRANET



a

b

c

Figure 6. Comparison of the Fuel Impact Models in LP-ST (a)ASME/PTC-6, (b)Exergy Fuel Impact of the equation (10) ,and (c) Exergy Fuel Impact of the equation (25), when a 1% of Change in the Exergy Efficiency Occurs.

Nomenclature

A	Exergy Fuel Impact
B	Exergy
F	Fuel
h	Enthalpy
hp,HP	High Pressure
HR	Heat Rate
I	Irreversibility

IP,ip	Intermediate Pressure
k	Exergy Consumption
k*	Unitary Exergetic Cost
L.F.	Loss factor
LP,lp	Low Pressure
m	Mass Flow
P	Product
Q	Heat Flow
r	Fuel Ratio
s_g	Entropy Generated
ST,st	Steam Turbine Section
T	Temperature
UE	Used Energy
W	Shaft Work

Greek Symbols

ΔHR	Cycle Heat Rate Impact
ϕ	Mass Flow Coefficient
η	Isentropic Efficiency
v	Specific Volume

Subscripts

Boiler	Inlet Heat to Steam Cycle from Boiler
d	Dissipation
Exh	Exhaust
Gen	Power Generation
i	i*th* component
R,r	Reference Conditions
Rh	Reheater
Cycle	Steam Cycle
T	Total
VWO	Valve Wide Open

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