ADVANCED EXERGY ANALYSIS OF THE STEAM TURBINE OPERATIONS OPTIMISATION

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ABSTRACT

Petkim Petrochemical Inc. is one of the most important companies in Turkey. The Petkim Complex consists of 14 production plants and 7 utility plants to supply the production plants. Petrochemical processing has a high energy requirement, especially plants with the complex technology that is used at the Petkim Complex. This means that Petkim is a large energy consumer, with a total consumption of 913.000 TEO in 2009.

Following privatization of Petkim in 2008, an energy management system was introduced and several energy saving studies were initiated. In 2012, after implementation of energy saving projects, the energy consumption at Petkim was 813.000 TOE. This means that from 2009 to 2012, there was a reduction of 100.000 TEO, which is equal to a financial saving 50.8 M USD, and represents a saving 232.000 tons CO_2e.

To enable the Power Plant efficiencies in Petkim complex to be improved, the advanced exergetic analysis of the system were studied on some what-if scenarios which were studied by using simulation and optimisation software. In this article, how steam turbine operations were optimized will be explained in detail and the results of the advanced exergetic analysis will be given.

INTRODUCTION

The energy requirement of industry is supplied mainly by fossil and nuclear fuels. According to New Policies Scenario, global primary energy demand rises by over one-third in the period to 2035. Oil demand reaches 99.7 mb/d in 2035, up from 87.4 mb/d in 2011. Coal demand rises by 21% and natural gas by a remarkable 50%. Renewables are deployed rapidly, particularly in the power sector, where their share of generation increases from around 20% today to 31%. Growth in nuclear power is revised down relative to our previous projections, in large part due to policy moves following Fukushima Daiichi. These trends call for $37 trillion of investment in the world's energy supply infrastructure to 2035. All those projections show that energy demand is growing up by coming years besides policy makers confronted with the twin challenges of ensuring reliable and affordable energy supplies and dealing with climate change have consistently identified energy efficiency as an essential means of moving to a more sustainable energy future. Energy and economic analysis point to the same conclusion: improving energy efficiency in energy-importing countries reduces import needs or slows their growth; measures can be implemented quickly compared with often lengthy projects to expand production; it is among the cheapest of the large-scale carbon dioxide (CO_2) abatement options; and it can play a role in spurring economic growth and reducing energy bills, both of particular importance during this period of economic uncertainty and persistently high energy prices [1].

For this reason, the studies on alternative energy resources and new techniques in order to utilize the energy resources more efficiently have increased. The optimization of energy conversion systems becomes one of the most important subjects in the industry. Engineers and scientists dealing with the design and operation of an energy conversion system want to improve or optimize it by maximizing efficiency, and minimizing product cost and environmental impact associated with this plant [2]. In order to optimize such systems, firstly the real mechanism should be understood according to which thermodynamic inefficiencies, costs, and environmental impacts are formed within the system.

In 2011 all major energy-consuming countries introduced new legislation on energy efficiency, making provisions for a 16% reduction in energy intensity by 2015 in China, new fuel-economy standards in the United States and a cut of 20% in energy demand in the European Union in 2020. Japan also aims to achieve a 10% reduction in electricity demand by 2030 in its new energy strategy. Implementation of those policies and of those under discussion in many other countries, at the level assumed in our New Policies Scenario, would result in annual improvements in energy intensity of 1.8% over 2010-2035, a very significant increase compared with 1.0% per year achieved over 1980-2010. In the absence of those gains, global energy demand in 2010 would have been 35% higher, almost equivalent to the combined energy use of the United States and China. According to the New Policies Scenario of WEO 2012, efficiency accounts for about 70% of the reduction in projected global energy demand in 2035, compared with the Current Policies Scenario [3].

The performance of energy conversion systems is reduced by the presence of irreversibilities. Entropy is used as a quantitative measure of irreversibilities associated with a process, and can also be used to determine the performance of process and its equipment. For this purpose a technique called exergy analysis is used. Exergy analysis is a thermodynamic tool for assessing and improving the efficiency of processes and their equipment, and for increasing environmental and economic performance. The exergy analysis is used to identify the location, the magnitude, and the causes of thermodynamic inefficiencies in systems, which are exergy loss and exergy destruction [2]. The sum of exergy destruction and exergy loss within an energy conversion system represents the real thermodynamic inefficiencies of this system. The exergy loss in a component is caused by the transfer of thermal exergy to the environment. When the boundaries for the component analysis are drawn at the ambient temperature, the exergy loss is zero and the thermodynamic inefficiencies consist exclusively of exergy destruction [3].

The exergy destruction is caused chemical reaction, heat transfer, mixing of matter at different compositions or states, unrestrained expansion, and friction. At any given state of technological development, some exergy destruction within a system component will always be unavoidable due to physical and economic constraints [4].

A conventional exergetic analysis does not evaluate the mutual independencies among the system components nor the potential for improving a component [2]. This can be achieved by an advanced analysis, in which the exergy destruction in each component is split into endogenous and exogenous parts; also avoidable and unavoidable parts, and a combination of these two splitting approaches. Such an approach can provide an energy conversion system with valuable detailed information in order improve the overall efficiency of a system.

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After investments of plants in Petkim, power generation and utility operations in the petrochemical complex had had a complicated structure. Optimisation of the big sized and complicated power generation operations was getting higher importance. It was really too important to monitor and to optimise the energy consumption and power generation operations in order to perform energy saving studies. By optimising energy consumption of the complex continuously it is possible to save 2 – 5 % of energy consumption of the complex.

In this study advanced exergy analysis of the steam turbines which are running in the power plant of a petrochemical complex, operations optimisation was performed. At the initial state two backpressure turbines having 64 MW power output each, and two condensing turbines having 20 and 22 MW power outputs were running in the power plant. After making some what – if scenarios by using HSPO (Heat – Steam – Power – Optimisation software), one of the backpressure steam turbine was shut down. What – if study and the exergy analysis results will be examined in coming section.

POWER PLANT

Petkim has its own Power Plant to generate steam at different pressure and temperature levels and electricity to use its processes. There are 4 steam boilers having 350 tons/h capacity to generate XHS (extra high pressure steam) and two backpressure turbines to generate HS (high pressure steam), MS (medium pressure steam), and LS (low pressure steam) and electricity and two condensing turbines for electricity generation using LS. Depending on the complex demand steam and electricity generation is changed. 420.000 TOE fuel is consumed annually to produce 4.400.000 tons XHS and 920.000 MW electricity in the Power Plant. Steam and power system have a dynamic structure and it brings on to optimize the generation and consumption of the complex.

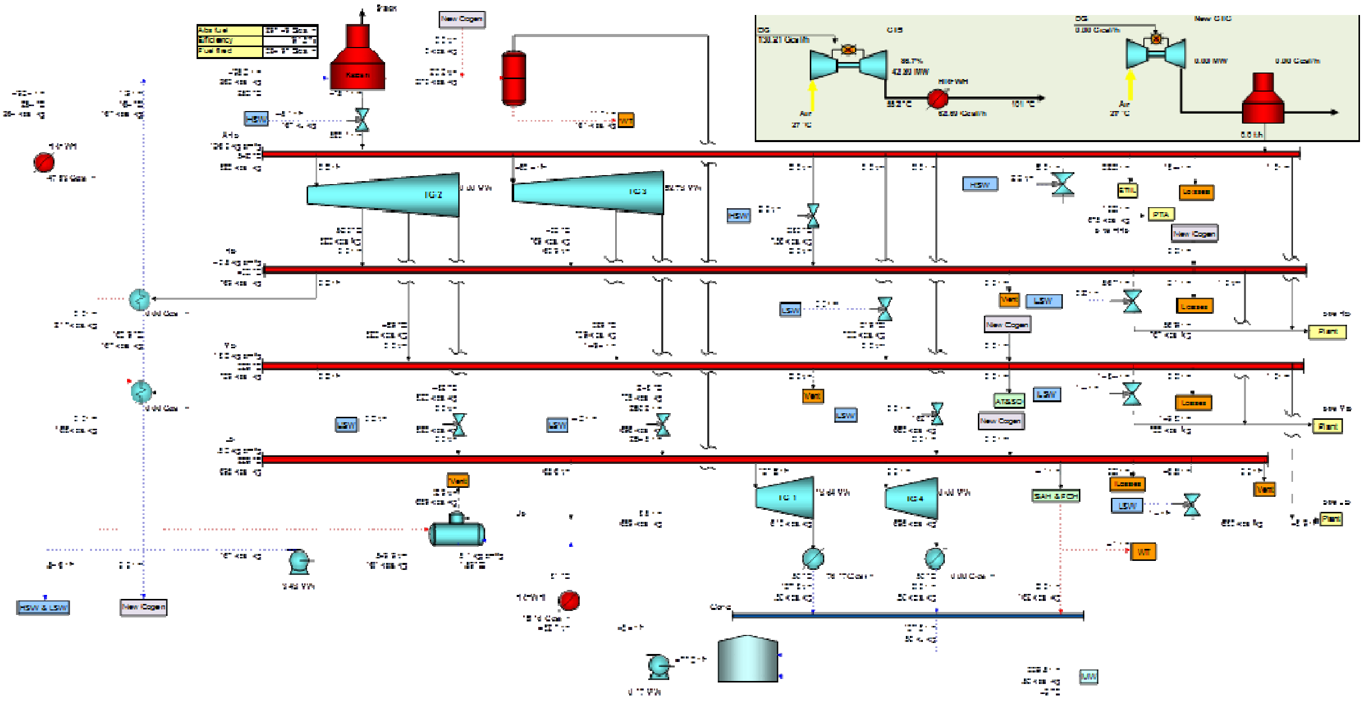

Figure 1. General Scheme of the Steam and Power Generation

Fuel oil, natural gas, fuel gas, aromatic oil, hydrogen and ethylene oxide plant vent gas are used as primary energy sources to produce XHS and electricity in Petkim Power Plant. It has 4 steam boilers (B1, B2, B3, and B4) having maximum capacity of 350 tons/h XHS; two backpressure turbines (TG2, and TG3) having 64 MWh capacity for each; two condensing turbines having capacity of 20 MWh (TG1) and 22 MWh (TG4); and one gas turbine (TG5) having capacity of 58 MWh, (Figure 1). 500 t/h steam and 130 MWh electricity is used by plants. There are five main steam levels which are using by plants in the complex given in Table 1.

Table 1. Steam Levels Generated by Power Plant

STEAM LEVELS	**PRESSURE (kg/cm^2g)**	**TEMPERATURE (^0C)**
XHS	134	540
HHS	84	310
HS	42	390
MS	18	300
LS	5.5	190

WHAT – IF STUDY

Electricity is generated by passing XHS trough backpressure turbines and HS, MS, and LS which are used in processes are taken from different sections of each turbine. For supplying the complex demand for steam and electricity at least three boilers, two backpressure turbines and two condensing turbines had been running. Depending on the complex demand steam and electricity generation is changed. By performing what – if scenario by using HSPO software, it was seen that instead of two running backpressure turbines at lower loads, one backpressure turbine at higher loads and one condensing turbine could be supply the complex demand. All analysis showed that three boilers, one backpressure turbine, and one condensing turbine could be supplied the complex demand for steam and electricity without any disturbances on the system and complex.

Table 2. What – if Scenario Complex Application Results

		TG2	**TG3**	**Total**	**Difference**
XHS Consumption of Turbines (tons/h)	Before Application	279	188	467	**-11(tons/h)**
	After Application	456	0	456	
Power Generation (MW)	Before Application	26	15	41	**+12 (MW)**
	After Application	53	0	53	

At the beginning the capacity of the backpressure turbines were 35 – 45% and this caused big losses in efficiency. To prevent this, one of the back pressure turbine was stopped and other backpressure turbine was loaded twice than before. At this condition the running backpressure turbine is run 80 – 90% of its capacity. The what – if scenario was studied in software firstly and then it was applied in the complex gave results that XHS consumption was decreased by 11 tons/h and the electricity generation was increased by 12 MWh as seen in Table 2.

EXERGY ANALYSIS

Exergy of a thermodynamic system is the maximum theoretical useful work (shaft work or electrical work) obtainable as the system is brought into complete thermodynamic equilibrium with the thermodynamic environment while the system interacts with this environment only. [5] A conventional exergy analysis can highlight the main components having high thermodynamic inefficiencies, but cannot consider the interactions among components or the true potential for the improvement of each component. By splitting the exergy destruction into endogenous/exogenous and avoidable/unavoidable parts, the advanced exergy analysis is capable of providing additional information to conventional exergy analysis for improving the design and operation of energy conversion systems [6].

Like mass, energy, and entropy, exergy is an extensive property, so it too can be transferred into or out of a control volume where streams of matter enter and exit. The general form of such exergy transfer can be expressed as:

$$\frac{dE_{cv}}{dt} = \sum_j \left(1 - \frac{T_0}{T_j}\right) Q_j - \left(W_{cv} - p_0 \frac{dV_{cv}}{dt}\right) + \sum_i \dot{m}_i e_i - \sum_e \dot{m}_e e_e - \dot{E}_D \tag{1}$$

The first term denotes rate of exergy change, the term $\dot{E}_D$ denotes rate of exergy destruction and the rest of the terms on the right side of the equation denote rates of exergy transfer.

In the absence of nuclear, magnetic, electrical, and surface tension effects the total exergy of a system E can be expressed as:

$$E = E^{PH} + E^{KN} + E^{PT} + E^{CH} \tag{2}$$

where E^{PH} is physical exergy, E^{KN} is kinetic exergy, E^{PT} is potential exergy, and E^{CH} is chemical exergy.

The physical exergy can be expressed as:

$$E^{PH} = (U - U_0) + p_0(V - V_0) - T_0(S - S_0) \tag{3}$$

Where U, V, and S denote, respectively, the internal energy, volume, and entropy of the specified state, and U_0, V_0, and S_0 are the values of the same properties when the system is at the restricted dead state.

The chemical exergy per mole of mixture is,

$$\bar{e}^{CH} = \sum x_k \bar{e}_k^{CH} + \bar{R}T_0 \sum x_k ln x_k \tag{4}$$

and x_k is the mole fraction of gas k in the environmental gas phase and $\bar{e}_k^{CH}$ is the chemical exergy per mole of kth component.

Exergy rate balance at steady – state can be expressed as:

$$\dot{E}_i = \dot{E}_e + \dot{E}_D + \dot{E}_L \tag{5}$$

where $\dot{E}_i$ denotes exergy rate at the inlet, $\dot{E}_e$ denotes exergy rate at the outlet, $\dot{E}_D$ denotes exergy destruction, and $\dot{E}_L$ denotes exergy loss.

The exergetic efficiency ε is the ratio between product and fuel and is expressed as [7]:

$$\varepsilon = \frac{\dot{E}_P}{\dot{E}_F} = 1 - \frac{\dot{E}_D + \dot{E}_L}{\dot{E}_F} \tag{6}$$

RESULTS

In this paper the advanced exergy analysis of the steam turbine operations optimisation were studied. Firstly the what – if analysis of the turbine operations were examined and then the action which was defined in the what – if scenario was applied to Power Generation in the complex. According to the scenario applied one of the bakpressure turbine TG2 and one of the condensing turbine TG4 had been shut down. Before the application HS only was taken from TG2 and this amount of HS could be supplied to complex HS demand. So, before application there was no HS section data to calculate exergy and efficiency of the HS section of TG3. After application HS is started to be taken from TG3. Before and after application of the scenario the exergetic efficiency of the backpressure turbines and condensing turbines had been calculated and all results are given in Table 3. It is clear that for backpressure turbine operation all efficiencies of the turbine sections was incresed at least 5%.

Table 3. Exegy and Efficiency Results of the Steam Turbines Operation

	Before Application		After Application	
	Exergy (kW)	Efficiency %	Exergy (kW)	Efficiency %
TG1	13591.9	70.3	24838.4	52.7
TG2-HS	4122.3	85.3		
TG2-MS	9031.6	80.6		
TG2-LS	33139.9	79.0		
TG3-HS			5457.8	80.3
TG3-MS	10228.5	77.1	21600.7	82.5
TG3-LS	30456.6	68.1	51781.6	75.4
TG4	16091.9	43.8		

NOMENCLATURE

Symbol	Quantity	SI Unit
XHS	Extra High Pressure Steam	tons/h
HHS	High High Pressure Steam	tons/h
HS	High Pressure Steam	tons/h
MS	Medium Pressure Steam	tons/h
LS	Low Pressure Steam	tons/h
TOE	Tonnes Oil Equivalent	-
HSPO	Heat – Staem – Power – Optimisation	- -
B1, B2, B3, B4	Boilers	
TG2, TG3	Backpressure Turbines	-
TG1, TG4	Condensing Turbines	-
TG5	Gas Turbine	-
E_D	Rate of Exergy Destruction	
E	The Total Exergy of A System	kj/kmol
E^{PH}	Physical Exergy	kj/kmol
E^{KN}	Kinetic Exergy	kj/kmol
E^{PT}	Potential Exergy	kj/kmol
E^{CH}	Chemical Exergy	kj/kmol
U	The Internal Energy	kj/kmol
V	Volume	m^3
S	Entropy	kj/kmolK
U_0	The Internal Energy at the Restricted Dead State	kj/kmol
V_0	Volume at the Restricted Dead State	m^3
S_0	Entropy at the Restricted Dead State	kj/kmolK
$\bar{e}^{CH}$	The Chemical Exergy Per Mole of Mixture	kj/kmol
x_k	The Mole Fraction Of Gas k in the Environmental Gas Phase	-
$\bar{e}_k^{CH}$	The Chemical Exergy Per Mole of kth Component	kj/kmol
$\dot{E}_i$	Exergy Rate at the Inlet	MW
$\dot{E}_e$	Exergy Rate at the Outlet	MW
$\dot{E}_D$	Exergy Destruction	MW
$\dot{E}_L$	Exergy Loss	
ε	The Exergetic Efficiency	MW

$\dot{E}_P$	Exergy Rate of Product	MW
$\dot{E}_F$	Exergy Rate of Fuel	MW

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