



Sensitivity analysis of exergy destruction in a real combined cycle power plant based on advanced exergy method



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ABSTRACT

The advanced exergy analysis extends engineering knowledge beyond the respective conventional methods by improving the design and operation of energy conversion systems. In advanced exergy analysis, the exergy destruction is splitting into endogenous/exogenous and avoidable/unavoidable parts. In this study, an advanced exergy analysis of a real combined cycle power plant (CCPP) with supplementary firing is done. The endogenous/exogenous irreversibilities of each component as well as their combination with avoidable/unavoidable irreversibilities are determined. A parametric study is presented discussing the sensitivity of various performance indicators to the turbine inlet temperature (TIT), and compressor pressure ratio (r_c). It is observed that the thermal and exergy efficiencies increase when TIT and r_c rise. Results show that combustion chamber (CC) concentrates most of the exergy destruction (more than 62%), dominantly in unavoidable endogenous form which is decreased by 11.89% and 13.12% while the avoidable endogenous exergy destruction increase and is multiplied by the factors of 1.3 and 8.6 with increasing TIT and r_c , respectively. In addition, TIT growth strongly increases the endogenous avoidable exergy destruction in high pressure superheater (HP.SUP), CC and low pressure evaporator (LP.EVAP). It, also, increases the exogenous avoidable exergy destruction of HP.SUP and low pressure steam turbine (LP.ST) and leads to the high decrement in the endogenous exergy destruction of the preheater (PRE) by about 98.8%. Furthermore, r_c growth extremely rises the endogenous avoidable exergy destruction of gas turbine (GT), CC and high pressure evaporator (HP.EVAP); it also increases the exogenous exergy destruction in LP.EVAP, GT, air compressor (AC) and PRE and causes the most increment in endogenous exergy destruction of GT by about 28.4%. Therefore, an increase in TIT and r_c has positive effect on most of the component's potential improvements to have a CCPP with higher efficiency and lower exergy destruction.

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1. Introduction

Due to the importance of energy saving and its cost, efforts have been directed towards increasing the efficiency of cycles and decreasing their losses with conventional and advanced exergy analyses. Conventional exergy analysis can identify the location, the magnitude, and the sources of thermodynamic inefficiencies in a thermal system, and thus provide information to improve the overall efficiency of a system or to compare the performance of various systems. In addition, an exergy analysis can highlight the areas of improvement of a system. CCPP is one of the energy conversion systems generating power in a wide field. Throughout the last decades, conventional exergy analysis with parametric studies have been discussed and applied to a wide variety of CCPPs.

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Fiaschi and Manfrida [1] investigated pressure ratio and temperature approach on the performance of the semi-closed CCPP. Bassily [2] applied the gas reheat with recuperation to the regular triple-pressure steam-reheat combined cycle. He discussed the effects of varying TIT on the net power, cycle efficiency and amount of irreversibilities etc. Ahmadi et al. [3] analyzed TIT changes and r_c effects on efficiency and exergy destruction of heat recovery steam generator (HRSG), CCPP, total power of cycle and their costs. Results showed increasing of r_c , increased efficiencies and decreased exergy destructions. Moreover, TIT growth increased the net total power plant while decreased the HRSG efficiency. Tajik Mansouri et al. [4] presented the effect of HRSG pressure levels on exergy efficiency of CCPP. They found that the stack gas exergy and the exergy destruction rate of cycle decreased, and the energetic efficiency of the cycle increased with increasing the number of pressure levels of HRSG. Ganje Kaviri et al. [5] studied a dual pressure CCPP that observed TIT, r_c and pinch point temperatures to be significant design parameters any change in them

Nomenclature

CCPP	combined cycle power plant
HRSG	heat recovery steam generator
TIT	turbine inlet temperature (°C)
$\dot{E}$	exergy flow rate (MW)
e	specific exergy (kJ kg ⁻¹)
LHV	lower heating value (kJ kg ⁻¹)
r_c	compressor pressure ratio
r_p	pump pressure ratio
h	enthalpy (kJ kg ⁻¹)
HP	high pressure
LP	low pressure
HR	heat rate (MJ MW h ⁻¹)
HPR	heat to power ratio
P	pressure (bar)
T	temperature (°C)
$\dot{W}$	power (MW)
$\dot{m}$	mass flow rate (kg s ⁻¹)
$\dot{Q}$	heat rate (MW)

Abbreviations

AC	air compressor
BFP	boiler feed pump
CC	combustion chamber
CEP	condensate extraction pump
COND	condenser
DB	duct burner
DEAR	dearator
ECO	economizer
EVAP	evaporator
GEN	generator
GT	gas turbine
PRE	preheater
ST	steam turbine
SUP	super heater

Greek letters

η_{ex}	exergetic efficiency
η_{th}	thermal efficiency
η_{is}	isentropic efficiency
Δ	difference
λ	excess air fraction
ξ	coefficient of fuel chemical exergy

Superscripts

AV	avoidable
EN	endogenous
EX	exogenous
UN	unavoidable

Subscripts

AP	approach point
D	destruction
exh	exhaust
F	fuel
f	natural gas fuel
in	inlet stream
k	kth component
L	loss
min	minimum
net	net
out	outlet stream
P	product
PP	pinch point
R	real condition
T	theoretical condition
tot	total
UN	unavoidable condition

leads to a drastic change in thermodynamic results. Ghazi et al. [6] carried out the sensitivity analysis of change in design parameters such as high and low drum pressures, steam mass flow rate, PP temperature and duct burner fuel mass flow rate ($\dot{m}_{DB}$), with change in fuel in HRSG of CCPP. Sanjay and Prasad [7] showed that the maximum cycle efficiency occurs at lower value of intercooling pressure ratio while the maximum plant work output happens at higher value of it, in intercooled combustion-turbine based CCPP.

However, conventional analysis does not provide information about components interaction (i.e. endogenous/exogenous) and real potential for improvement (i.e. unavoidable/avoidable) of an energy conversion system. Tsatsaronis [8,9] not only evaluated the weaknesses of the conventional exergy analysis, but also discussed the advanced exergy, exergoeconomic and exergoenvironmental analyses being solutions to those weaknesses. Advanced exergy analysis is an approach that explains and calculates the different parts of exergy destruction (endogenous/exogenous and unavoidable/avoidable) in each component of an energy system. Tsatsaronis and Mang-Ho [10] were the first researchers who presented the concepts of unavoidable and avoidable exergy destruction of them. Kelly et al. [11,12] defined several methods by using a simple refrigeration cycle and a simple gas turbine (GT) cycle, to calculate the endogenous (i.e. the part of exergy destruction within the kth component caused by the irreversibilities of that component) and exogenous (i.e. the part of exergy destruction within the kth component caused by the irreversibilities of the remaining components) exergy destruction values. Morosuk and Tsatsaronis

[13] explained exergy balance approach, in detail, which used for chemically reacting systems such as a GT cycle.

For CCPP in advanced level, Czesla et al. [14] investigated avoidable and unavoidable exergy destruction of an externally fired combined cycle component. In addition, they presented some results and aspects of design and improvement of the system. Petrakopoulou et al. [15] analyzed a three pressure level of CCPP with one reheat stage, using conventional and advanced exergy, and reported a wide range of potential improvement and interaction among components. Petrakopoulou et al. [16] investigated advanced exergy analysis to a CCPP. It was observed that the plant can be improved potentially by enhancing the performance of the CC, GT, AC and the low-pressure steam turbine. Soltani et al. [17] modeled an externally fired CCPP integrated with a biomass gasification unit. They showed that the unavoidable part of exergy destruction, in most of the components, is higher than the avoidable part. In addition, exploding biomass energy for electricity produced is more efficiently. In [18,19] a real CCPP, in Turkey, was analyzed with advanced exergy analysis. Like above mentioned articles, the relationship between the components, real potential improve and possible recommendation to increase the system efficiency are determined.

To the best of our knowledge, no parametric study of different parameters on advanced exergy destruction of CCPP has previously been developed. In this paper, an advanced exergy analysis is applied to a real dual pressure of CCPP with supplementary firing located in north of Iran called Neka. With the application of

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