Energy 52 (2013) 96–109

Contents lists available at SciVerse ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Investigating the effect of several thermodynamic parameters on exergy destruction in components of a tri-generation cycle

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ARTICLE INFO

Article history:
Received 28 May 2012
Received in revised form
6 November 2012
Accepted 4 January 2013
Available online 6 March 2013

Keywords:
Tri-generation cycle
Advanced exergy analysis
Endogenous exergy destruction
Exogenous exergy destruction
Fuel consumption
Exergy loss

ABSTRACT

Multiple energy generating cycles such as tri-generation cycles, which produce heat and cold in addition to power through burning of a primary fuel, have increasingly been used in recent decades. On the other hand, advanced exergy analysis of thermodynamic systems by splitting exergy destruction into endogenous and exogenous parts identifies internal irreversibilities of each of the components and the effect of these irreversibilities on the performance of other components. Therefore, main sources of exergy destruction in cycles can be highlighted and useful recommendations in order to improve the performance of thermodynamic cycles can be presented. In the present work, a tri-generation cycle with 100 MW power production, 70 MW heat and 9 MW cooling capacity is considered. For this tri-generation cycle, effects of various thermodynamic parameters on the amount of endogenous and exogenous exergy destructions, exergy loss and the amount of fuel consumption, are investigated. The results indicate that, increasing compressor pressure ratio, pre-heater outlet temperature and excess air leads to better combustion and lower exergy loss and fuel consumption. Increasing the mass flow rate of steam generator, while keeping the cycle outlet temperature constant and considering cooling capacity variable, lead to increase the first- and second-law efficiencies of the cycle.

1. Introduction

In recent years, tri-generation cycles are being implemented in industrial and domestic units. Power, heat and cold generating systems with various production capacities are utilized because of their ability to produce various forms of energy, high energetic and exergetic efficiency and less harmful effects on environment. Therefore, optimizing the performance of these systems becomes important to have more efficient system, better combustion process and consequently lower fuel consumption.

Hernandez and Sanchez [1] compared co- and tri-generation cycles and stated that utilizing tri-generation cycle leads to 10% energy saving and cost. The results showed that, humidity and ambient temperature have important role in performance and fuel consumption of the cycle. Meunier [2] studied the CO_2 emission produced from co- and tri-generation cycles. He found that the CO_2 emission reduction, which was in the range of 10–50%, highly depends on the efficiency of these cycles and their working conditions. Temir and Bilge [3] analyzed a tri-generation cycle from thermoeconomic point of view. Their results indicated that, gas engines are too expensive to use only for electricity production and also, it is impossible to achieve lower irreversibilities by utilizing an absorption chiller unit with higher efficiency. Khaliq and Kaushik [4] analyzed a gas turbine co-generation system. They investigated effects of process steam pressure and pinch point temperature used in the design of heat recovery steam generator, by considering energetic and exergetic efficiencies. Their results indicated that, first- and second-law efficiencies decrease with an increase in pinch point temperature. But on the other hand, second-law efficiency increases significantly with increase in process steam pressure, but first-law efficiency decreases with increase in process steam pressure.

Khaliq [5] in another paper investigated effects of various thermodynamic parameters on components exergy destruction of a tri-generation cycle and then performance of the whole cycle was analyzed based on first- and second-law viewpoints. They showed that the exergy destructions in combustion chamber and heat recovery steam generator were decreased significantly with an increase in pressure ratio. On the other hand, the first-law efficiency of co- and tri-generation cycles was decreased by increasing the pressure ratio. Ameri and Ahmadi [6] investigated the influence of ambient temperature on exergy destruction in heat recovery steam generator. The results showed that exergy destruction in heat recovery steam generator is minimized at ambient temperature equal to 19 °C. Sadrameli and Goswami [7] simulated a combined power

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http://dx.doi.org/10.1016/j.energy.2013.01.007

Nomenclature

$\dot{E}$	exergy (MW)
$\dot{m}$	mass flow rate (kg/s)
P	pressure (bar)
Q	heat transferred (MW)
r	compressor pressure ratio
$\dot{S}$	entropy generation rate
$\dot{s}_{gen}$	specific entropy generation rate
T	temperature (K)
$\dot{W}$	power (MW)
Δ	difference
ε	exergetic efficiency
η	thermal efficiency
λ	air/fuel ratio
χ	ratio of endogenous exergy destruction to total exergy destruction

Abbreviation

ABS	absorber
AC	air compressor
APH	air pre-heater
CC	combustion chamber
COND	condenser
EVAP	evaporator
GEN	generator
GT	gas turbine
SG	steam generator
THR	throttling valve

Superscripts

CH	chemical
EN	endogenous
EX	exogenous
ID	ideal
PH	physical
RS	real state

Subscripts

a	air
D	destruction
F	Fuel (exergy)
g	gas
gen	generator
k	Kth component
L	loss
others	other components
P	product
s	isentropic
tot	total
0	thermodynamic environment

and cooling cycle to define the optimum operating conditions for the considered system. Wang et al. [8] had an exergy analysis and parametric optimization for different co-generation power plants in cement industry. The results showed that the exergy losses in turbine, condenser, and heat recovery vapor generator are relatively large. They concluded that reducing the exergy losses of these components could improve the performance of the co-generation system. Compared with other systems, the Kalina cycle could achieve the best performance in cement plant.

Exergetic analysis of thermodynamic systems can be helpful to improve performance of the system. In addition, new exergetic concepts such as endogenous and exogenous exergy destructions provide useful data in identifying irreversibilities and ineffectiveness of a thermodynamic system. In this case, by varying thermodynamic parameters which affect the performance of the cycle, exergy destruction in components can be reduced and their efficiency can be enhanced. Kelly [9] presented the general concept of endogenous and exogenous exergy destructions and defined four different calculation methods in analyzing a simple power production cycle and a simple compression refrigeration system. Kelly et al. [10] in another paper studied the performance of simple compression refrigeration systems with different working fluids. They used method of splitting exergy destruction into endogenous and exogenous parts to investigate the potential of improvement of every component.

Morosuk and Tsatsaronis [11,12] analyzed an absorption refrigeration cycle using these concepts. Their results indicate that optimization efforts should be focused on generator before other components, optimizing the performing condition of this component improves the same in other components. Another interesting points is, improving evaporator's condition leads to increase in exergy destruction in other components of the cycle. Razmara and Khoshbakhti [13] investigated the combustion process in a simple gas turbine and co-generation cycle based upon general concept of endogenous and exogenous exergy destructions. Additionally, the effect of utilizing different mixture ratios of natural gas and diesel fuels on the amount of endogenous and exogenous exergy destructions was investigated.

From the mentioned literature survey, it can be concluded that, tri-generation cycles have many advantages over simple and even co-generation cycles such as higher efficiency, less fuel consumption and less damage to environment. Therefore, optimizing its performance by changing effective thermodynamic parameters should be considered to have more efficient system. In present work, effect of various thermodynamic parameters such as pressure ratio, pre-heater inlet temperature, steam generator mass flow rate and evaporator working temperature, on the performance of a tri-generation cycle with 100 MW power production, 70 MW heat and 9 MW cooling capacity, using first- and second-law of thermodynamic, have been investigated. Besides, these effects are analyzed by new exergetic concepts, endogenous and exogenous exergy destructions, to define the effects of changing parameters on performance of the cycle more precisely.

2. Exergy analysis methodology

2.1. Conventional exergy analysis

In every conventional energy system, the exergy balance for the Kth component in steady state condition can be written as

$$\dot{E}_{F,k} = \dot{E}_{P,k} + \dot{E}_{D,k} \tag{1}$$

In the exergy analysis of a specific component, system boundaries that are used for all components are considered to be at T_0, the reference environment temperature. Therefore, there are no exergy losses associated with the Kth component. Exergy loss is assumed at the level of overall system. Thus, for whole thermodynamic system, the exergy balance is

$$\dot{E}_{F,\text{tot}} = \dot{E}_{P,\text{tot}} + \sum_k \dot{E}_{D,k} + \dot{E}_{L,\text{tot}} \tag{2}$$