Energy Reports 4 (2018) 243–251

Contents lists available at ScienceDirect

Energy Reports

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

Research paper

Exergy and economic analyses of replacing feedwater heaters in a Rankine cycle with parabolic trough collectors

Amin Mohammadi [a], Mohammad Hossein Ahmadi [b,*], Mokhtar Bidi [a], Mahyar Ghazvini [c], Tingzhen Ming [d,*]

[a] *Faculty of Mechanical & Energy Engineering, Shahid Beheshti University, A.C., Tehran, Iran*
[b] *Faculty of Mechanical Engineering, Shahrood University of Technology, Shahrood, Iran*
[c] *Renewable Energy and Environmental Engineering Dep. University of Tehran, Tehran, Iran*
[d] *School of Civil Engineering and Architecture, Wuhan University of Technology, Wuhan, PR China*

HIGHLIGHTS

- Exergy and economic analyses are performed on a solar implemented Rankine cycle.
- A thermal storage system is added to the cycle to enable it for 24 hour operation.
- Total power generated of the system increases by 8.14% compared to base case.
- Exergy analysis revealed that boiler has the highest rate of exergy destruction.
- Payback time of the proposed system is equal to 1.5 year.

ARTICLE INFO

Article history:
Received 19 December 2017
Accepted 7 March 2018

Keywords:
Parabolic trough collector
Rankine cycle
Energy analysis
Exergy analysis
Economic analysis

ABSTRACT

Fossil fuels are exhaustible and their consumption causes environmental problems. As a result, renewable energy resources, specifically solar energy, should be utilized more to overcome the aforementioned issues. The biggest problem with renewable energy utilization is that their capital cost is very high. To tackle this problem, renewable energies should be coupled with conventional energy systems to lower the initial investment. In this paper, a parabolic trough collector is coupled with a conventional Rankine cycle to increase output power of the system by replacing its closed feedwater heaters. Also, to be able to use the system during the nights, a thermal storage system is added to the cycle. A complete energy, exergy and economic analyses are performed on the system and the results are compared with the base case condition. The results show that by using the proposed system, net generated power of the plant increases by 8.14%. Also, exergy analysis shows that in both cases boiler has the highest rate of exergy destruction. In general, due to huge amount of losses in the collector, exergy efficiency of the system decreases. Finally, economic analysis shows that simple payback time of the system equals to 1.5 years which is very low.

1. Introduction

In order to evaluate the energy systems, exergy analysis is a great method which discloses the inefficient thermodynamic processes. In recent years, exergy analysis has turned into a fundamental issue in presenting a superior comprehension of the processes, to evaluate the inefficiency's sources and to discriminate quality of energy consumption (Dincer and Al-Muslim, 2001; Jin et al., 1997; Kotas, 2013). In order to determine the type, location and genuine size of exergy losses (or destruction), it is notable that exergy can be utilized. Therefore, a crucial role in progressing approaches and in presenting guidelines for more efficient utilization of energy has been played by the exergy.in the existing power plants (Jin et al., 1997). Additionally, the origin of the exergy loss is another imperative issue for enhancing existing systems. Consequently, a conspicuous picture, instead of only the magnitude of exergy loss in each section, is required. Moreover, the utilization of exergy analysis in evaluating the thermal power plants is predominantly acceptable. In order to examine the effect of reheat temperature and pressure on the performance of regenerative cycle, an analysis of the second law on a steam turbine power cycle has been performed by Sciubba

---

* Corresponding authors.
E-mail addresses: mhosein.ahmadi@shahroodut.ac.ir, mohammadhosein.ahmadi@gmail.com (M.H. Ahmadi), tzming@whut.edu.cn (T. Ming).

https://doi.org/10.1016/j.egyr.2018.03.001

Nomenclature

$\dot{Ex}$	Exergy flow rate (kW)
$\dot{Ex}^{D}$	Exergy destruction
$\dot{Ex}^{Q}$	Exergy associated with heat
$\dot{Ex}^{W}$	Exergy associated with work
ex	Specific exergy (kJ/kg)
ex_i^{ch}	Standard chemical exergy of *i*th component
h	Specific enthalpy (kJ/kg)
LHV	Lower heating value of fuel (kJ/kg)
$\dot{m}$	Mass flow rate (kg/s)
P	Pressure (bar)
$\dot{Q}$	Heat transferred (kW)
R	Gas constant (kJ/kg K)
s	Specific entropy (kJ/kg K)
T	Temperature (K)
T_r	Heat transfer temperature
$\dot{W}$	Work rate (kW)
y	Mole fraction
Y	Share of exergy destruction

Greek symbols

ψ	Exergy efficiency
ξ	Chemical exergy/Energy ratio

Subscripts

0	Reference environment condition
ch	Chemical
cond	Condenser
c.v.	Control volume
FWH	Feed water heater
in	Inlet stream
ph	Physical
out	Outlet stream
ST	Steam turbine

and Su (1986). An analysis of the optimal performance on a combined Carnot cycle (two single Carnot cycles in cascade), containing internal irreversibilities for steady-state operation has been carried out by Şahin and Kodal (1995). Furthermore, the maximum power and efficiency have been analytically achieved and the influences of irreversibility parameters on maximum power output have been demonstrated.

Rosen and Dincer (2001) presented exergy analysis as the exceptional method for determining on optimization of the cycle regarding the input information. Additionally, the boiler's energy and exergy analyses in a steam power plant have been performed by Amir (2012). According to the results, reducing the fraction of combustion excess air from 0.4 to 0.15 leads to 0.19% and 0.37% increase in energy and exergy efficiencies, respectively. Furthermore, the mentioned efficiencies respectively enhance to 0.84% and 2.3% by decreasing the temperature of the exhaust gases leaving the chimney from 137 °C to 90 °C. Also, with a specific end goal of developing an optimization plan, the energy and exergy analyses for every part of a heat recovery steam generator in combined-cycle power plant have been provided by Kaviri et al. (2013). Drum pressure and arrangement of heat exchangers in the heat recovery steam generator with respect to high and low-pressure parts were the examined parameters in the research. Additionally, the exergy analysis of an existing 27 MW binary geothermal power plant in which isobutene operates as the working fluid and liquid-dominated heat source at 160 °C has been carried out by Kanoglu and Bolatturk (2008). According to the results, the exergy and energy efficiencies were 33.5% and 10.2%, respectively. Also, an exergoeconomic analysis on a steam power plant has been performed by Bolatturk et al. (2015) in Turkey. By considering both design and off-design conditions of a steam power plant, Ray et al. (2010) presented exergy analysis of the power plant. As the results indicated, a superior principle to reflect the degradation of the system is the second law of thermodynamics. The location where the most exergy destruction occurs is combustion chamber as the result of chemical reaction circumstance. Furthermore, the investigation of the combustion processes and its exergy analysis have been provided by Taniguchi et al. (2005). The simulation of gas turbine power plant in Mahshahr and its optimization with respect to economic and exergy have been presented by Almasi (2011). Kaviri et al. (2012) modeled a dual pressure combined cycle power plant equipped with a duct burner and optimized the plant based on exergy and economic objective functions. According to the results, the performance of the plant has been considerably affected by compressor pressure ratio, gas turbine inlet temperature and pinch point temperatures.

In addition to the benefits of exergetic performance analysis in determining the magnitudes, location and causes of irreversibilities in the plants, it provides more considerable evaluation of the individual elements efficiency of the plant (Kaushik et al., 2011). A review of energy and exergy analyses for distinct power plants has been presented by Reddy et al. (2010). Also, an analysis of the second law founded on the exergy concept for a solar thermal power system has been provided by Kaushik et al. (2000). In order to demonstrate the different thermodynamic and thermal losses, related exergy and energy flow diagrams have been drawn. According to the results, the maximum energy loss happens at the condenser of the heat engine part, while the main exergy loss happens at the collector–receiver assembly. Additionally, analyses of energy and exergy for the distinct elements of a presented theoretical direct steam generation solar thermal power plant have been carried out by Gupta and Kaushik (2010). As the results indicated, the main energy loss occurs in the condenser followed by the solar collector field, whereas the main exergy loss takes place in the solar collector field and the exergy loss in other elements of the plant is insignificant. Also, a thermodynamic assessment in various designs of coupling parabolic-trough solar power plants and desalination facilities in a dry location have been presented by Palenzuela et al. (2011). Blanco-Marigorta et al. (2011) performed an investigation of two distinct cooling technologies and an exergy analysis for the power cycle of a 50 MW$_e$ solar thermal power plant. Furthermore, the impact of ambient temperature on the exergy efficiency of Catalagzi power plant in Turkey has been investigated by Kopac and Hilalci (2007). According to the results, the maximum exergy losses take place in the boiler, while the main energy losses occurs in the condenser. They also discovered that an increment in ambient temperature reduces the exergy efficiency of all the components of a power plant except the condenser. In this study, the condenser pressure at various ambient temperature has been assumed to be constant, while is not consistent in the actual situation. Farhad et al. (2008) designed a method to reduce irreversibility of the feedwater heaters network in steam power plants based on pinch and exergy analyses. Applying this method leads to increase the exergy efficiency of the system components and the total system. Popov (2011) used Fresnel collectors to directly increase temperature of boiler's feedwater and therefore eliminating feedwater heaters. Four different scenarios were considered to couple the Fresnel collector with the fossil fuel power plant and the best one was selected. Reddy et al. (2012) coupled Fresnel collectors with a combined cycle power plant and performed energy and exergy analyses on it. They showed that by using the proposed system, net output power of the system increases by