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Effect of ambient temperature on the efficiency of the regenerative and reheat Çatalağzı power plant in Turkey

Mehmet Kopac *, Ayhan Hilalci

Mechanical Engineering Department, Zonguldak Karaelmas University, Zonguldak 67100, Turkey

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Abstract

In this study, the energy and exergy analysis have been applied to the Çatalağzı power plant in Zonguldak, Turkey. The fuel used in this power plant was low calorific value coal middlings with particle size below 0.5 mm. The heat loss of each components were determined by energy analysis and the irreversibility rates (or exergy destruction rates) of whole plant were obtained for different ambient temperatures by the exergy analysis. The ambient temperature was selected within the range of 5–35 °C. The percentage efficiency defects of each components (or the ratios of the irreversibility rates to the fuel exergy rate) and the rational efficiency, the exergy efficiencies of the boiler, the turbine, the pump, the heaters and the condenser were determined for different ambient temperatures.

It was found that the efficiency defect of boiler had strong effects on the total efficiency defect and the rational efficiency of the plant. The ambient temperature had high effect on the changes of the irreversibility of boiler (or efficiency defect of boiler) but it had low effect on outer components of the plant.

Keywords: Energy; Exergy; Efficiency defect; Rational efficiency; Steam power plant

1. Introduction

The general energy supply and environmental situation requires an improved utilization of energy sources. Therefore, the complexity of power-generating units has increased considerably. Plant owners are increasingly demanding a strictly guaranteed performance. This requires thermodynamic calculations of high accuracy. As a result, the expenditure for thermodynamic calculation during design and optimization has grown tremendously [1].

The most commonly-used method for evaluating the efficiency of an energy-conversion process is the first-law analysis. However, there is increasing interest in the combined utilisation of the first and second laws of thermodynamics, using such concepts as exergy (availability, available energy), entropy generation and irreversibility (exergy destruction) in order to evaluate the efficiency with which the available energy is consumed. Exergetic analysis allows thermodynamic evaluation of energy conservation, because it provides the tool for a clear distinction between energy losses to the environment and internal irreversibilities in the process. A thermal power plant is a good example of the utilisation of exergy analysis. According to energy (first-law) analysis, energy losses associated with the condenser are carried into the environment by the cooling water and are significant because they represent about half of the energy input to the plant. An exergy (second-law) analysis, however, shows that virtually none of the exergy (resource which went into the power plant) is lost in that water. The real loss is primarily back in the boiler where entropy was produced. Thus, it is not reasonable to attempt to take advantage of the energy lost in the condenser [2]. Recently, exergy analysis has become a key aspect in

* Corresponding author. Tel.: +90 372 257 5126; fax: +90 372 257 4023.
E-mail addresses: mehmet_kopac@hotmail.com, kopacm@karaelmas.edu.tr (M. Kopac).

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Nomenclature

c	mass fraction of C in the coal (–)
$\bar{c}_p^h$	mean isobaric enthalpy capacity (kJ/kmol K)
$\bar{c}_p^\varepsilon$	mean isobaric exergy capacity (kJ/kmol K)
$\dot{E}$	total exergy rate (kW)
$\dot{E}_f$	fuel exergy rate (kW)
$\dot{E}_d$	irreversibility rate (kW)
$\dot{E}_o$	chemical exergy rate (kW)
$\dot{E}_Q$	rate of heat exergy (kW)
$\dot{E}_{ph}$	physical exergy rate (kW)
g_o	Gibbs free energy (kJ/kg)
h	specific enthalpy (kJ/kg), mass fraction of H_2 in the coal (–)
$\dot{H}$	enthalpy rate (kW)
$(LHV)^\circ$	lower heat value (kJ/kg)
$\dot{m}$	mass flow rate (kg/s)
n	mass fraction of N_2 in the coal (–)
$\dot{n}$	molar flow rate (kmol/s)
o	mass fraction of O_2 in the coal (–)
P	pressure (kPa)
$\dot{Q}$	heat rate (kW)
$\bar{R}$	universal gas constant (kJ/kmol K)
s	specific entropy (kJ/kg K), mass fraction of S in the coal (–)
T	temperature (K)
$\dot{V}$	volumetric flow rate (m^3/h)
$\dot{W}$	power (kW)
w	mass fraction of H_2O in the coal (–)
x	mole fraction of gas mixture (–)

Greek letters

$\bar{\varepsilon}$	molar specific exergy (kJ/kmol)
ε	specific exergy (kJ/kg)
φ_{dry}	dry coal constant (–)
δ	efficiency defect (–)
ψ	rational efficiency (–)
η_ε	exergy efficiency (–)
η_{em}	efficiency of electrical motor for pump (–)
η_m	mechanical efficiency of pump (–)

Subscripts

b	boiler
c	condenser
d	destruction
dry	dry
em	electrical motor
el	electrical
f	fuel
he	heater
i	inlet, number of component
j	exit
m	mixture, mechanical
o	environmental state, chemical
out	output
ph	physical
pl	plant
PR	product
s	surface, sulphur
t	turbine

providing a better understanding of the process, to quantify sources of inefficiency, to distinguish quality of energy (or heat) used [1,3–13].

Exergy is defined as the maximum theoretical useful work (or maximum reversible work) obtained as a system interacts with an equilibrium state. Exergy is generally not conserved as energy but destructed in the system. Exergy destruction is the measure of irreversibility that is the source of performance loss. Therefore, an exergy analysis assessing the magnitude of exergy destruction identifies the location, the magnitude and the source of thermodynamic inefficiencies in a thermal system [14].

The objective of this paper is to determine the effect of the ambient temperature on the irreversible losses in boiler, turbine, condenser, feed water heaters, pipe and pump and on the rational efficiency in an existing regenerative reheat power plant and to compare each irreversibility types. Çatalağzı power plant in Zonguldak, Turkey was considered for this purpose.

2. Exergy analysis

2.1. The exergy concept

Exergy is the amount of work obtained when a piece of matter is brought to a state of thermodynamic equilibrium with the common components of its surroundings by means of reversible processes. This a broad definition of exergy; thermodynamic equilibrium includes not only pressure and temperature but also chemical equilibrium with the substances of the environment.

It is important to observe that unlike energy, exergy is exempt from the law of conservation. Irreversibilities associated with actual processes cause exergy destruction.

2.2. Chemical processes including combustion

Before the exergy analysis, mass and energy balances on the system are required to determine the flow rates and