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Full Length Article

Energy and exergy analyses of a fluidized bed coal combustor steam plant in textile industry

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ABSTRACT

In this study, the analyses of first and second laws of thermodynamic are presented for a 6.5 MW power plant located in Adana, Turkey. The system components, examined in the present study, are listed as a fluidized bed coal combustor (FBCC), a heat recovery steam generator (HRSG), an economizer (ECO), fans, pumps, a cyclone and a chimney. All of the system components are examined one by one and the energy and exergy analyses are carried out for all of the system components. The highest value of irreversibility is observed in the FBCC, about 93% of the entire system irreversibility tracked by HRSG and ECO with 3% and 1%, respectively. The high excess air value, which is the primary origin of irreversibility, causes the heat losses from the FBCC, due to the increment in mass flow rate of the combustion gas. Moreover, the high excess air value gives rise to occurrence of low combustion efficiency in FBCC which can be decreased through decreasing flow rate of air with decreasing oxygen. Secondly, changes in the energy and exergy efficiencies are examined employing different ambient temperature. As the ambient temperature increases, the second law efficiencies of FBCC and HRSG increases but efficiency of ECO decreases.

1. Introduction

One of the most prominent theme is energy in conjunction with consuming of fossil fuels and environmental contamination. Presently, the leading energy resource is fossil fuels and the world has finite resources of fossil fuels. It forms an emergency for energy misery in the future. However, consumption of fossil fuels is an important reason of environmental pollution. The mentioned two problems are examined to solve by two ways stated as Ref. [1]:

i. growing alternative energy resources and applications (especially renewable energy sources),
ii. progress in the energy efficiency of systems which use fossil fuels.

A cheap, fast and easy way to overcome develops the efficiency of systems. For this, the analysis of the performance, such as the losses and irreversibility analyses, is the core of the development actions. In this context, exergy term and exergy analysis have staminal. Exergy analysis is a useful appliance for design, analyses, and optimization of thermal systems. It is successfully applied to a wide variety of energy systems and beneficial information about the selection of proper component model and process procedure is provided by the application of exergy analyses in the scientific literature. Sizes and status of irreversibilities for the entire system may be recognized by exergy analysis, while potential improvements for energetic efficiency can be suggested [2–7].

There are several studies about thermodynamic analysis on fluidized bed coal combustor (FBCC) steam plant systems. Thermodynamic performance analysis of a FBCC power plant located in Turkey was performed by Eskin et al. [8]. They performed analyses for the system and subsystem one by one and created a model of the FBCC. According to the results, obtained from the developed and validated model, they identified component having the major irreversibility as FBCC. Furthermore, the first and second law efficiencies of the FBCC increased, when the ambient temperature enhanced. In another study of Eskin and Kılıc [9], the exergy analysis of a FBCC with different cooling tubes arrangements was investigated. The second law efficiency of the FBCC was examined changing the heat transfer coefficient in their study. Two important parameters which were defined in their study, called as the volume ratio and height ratio. They emphasized that increment in the height ratio caused the decrement of the effectiveness in FBCC. Moreover, as volume ratio decreased, effectiveness of the FBCC also decreased. Besides, height ratio had no major effect on

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Nomenclature

ex	specific exergy (kJ/kg)
$\dot{E}x_D$	exergy destruction (kW)
h	specific enthalpy (kJ/kg)
LHV	lower heating value of coal (kJ/kg)
$\dot{m}$	mass flow rate (kg/s)
P	pressure (Pa)
$\dot{Q}$	rate of heat transfer (W)
s	specific entropy (kJ/kg K)
T	temperature (K)
$\dot{W}$	rate of work (W)

Subscripts

AF	air fan
CH	chimney
comb.	combustion gas
CY	cyclone
destr.	destruction
ECO	economizer
FBCC	fluidized bed coal combustor
HRSG	heat recovery steam generator
P	pump
VF	ventilation fan
0	reference state

Greek symbols

η_I	first law efficiency
η_{II}	second law efficiency

the effectiveness of the FBCC for the high value of the volume ratio. Based on the studies of Eskin et al. [10], the effects of various parameters (steam pressure, excess air) on FBCC steam power plant were examined using the thermodynamic laws by a developed model. The model results had similarity with plant operational data in their study. They showed that when the excess air increased, efficiency of both energy and exergy decreased and the major irreversibility taken place on the FBCC component. Ozdemir et al. [11] investigated an exergoeconomic analysis of a FBCC power plant to optimize the energy for the power plant. Quantitative exergy cost balance was considered in the system and subsystem. In their study, the exergoeconomic analysis results were exhibited and the highest exergy destruction was occurred in FBCC and tracked by HRSG, VF, ECO, AF, CH and P. As a result, they demonstrated more information than exergy analysis to understand deeply the performance of the FBCC power plant. Aljundi [12] presented an experimental study, including the energy and exergy analyses of a power plant, located in Jordan. In his study, he evaluated the system components one by one. The major energy and exergy losses of power plant were determined. Furthermore, the system performance was investigated for the different ambient temperatures. He obtained that there is no efficacy of minor change in the ambient temperature on the power plant's performance. Kaushik et al. [13] expressed that the real useful energy losses could not be expressed by only first law of thermodynamics. The study was deal with the comparison of energy and exergy analysis of coal and gas power plants. They concluded that the major energy losses occurred in boiler and combustion chamber for coal power plant and gas power plant, respectively. Although there are some studies focused on the exergetic performance of coal combustion systems [14,15], there is still required information and studies performed with industrial data that is obtained from an existing industrial plant.

In this study, an elaborate exergy analysis was performed for an industrial fluidized bed coal combustor system used in an existing textile plant. The exergetic performance assessment for the system components were done in parts. Furthermore, the Grassmann diagrams, which provide quantitative data concerning the proportion of the exergy input to the FBCC system, were demostrated.

2. Steam power plant description

The system that is analyzed thermodynamically is called as fluidized-bed coal combustor (FBCC) steam plant. The plant, involving a FBCC, a HRSG, an ECO, a CY, two VF, an AF, a CH and two P, has a 6.5 MW capacity. The examined fluidized-bed coal combustor steam plant is established in Adana, in southern of Turkey. The schematic diagram of the investigated FBCC plant is represented in Fig. 1.

The FBCC, which is the major part of the steam plant system, has steam volume of 10 t/h, steam pressure of 10 bar with dimensions 3 m × 2 m cross-section and 12 m height. Two ventilation fans which are used as a distributor to provide the combustion air for the system, are called as primary and secondary air fan. Their capacities are with 8456 m^3/h (45 kW) and 1845 m^3/h (4 kW), respectively. The FBCC plant is employed using Şırnak Asphaltite as solid fuel and it's compounds are listed in Table 1. The solid fuel is received into the bed with a screw conveyor feeder. The FBCC component has vertical and horizontal heat exchangers, which are placed throughout the bed elevation and round the broader side of the bottom zone, respectively. The plant operating data are given in Table 2. The capacities of the feed water pump and aspiration fan which are used in the system are 11 kW and 15,000 m^3/h (37 kW), respectively. In the FBCC steam plant, the feed water is pumped inside the economizer and arrives at the HRSG in which steam is generated by the agency of the heat exchanger tubes located in the HRSG. The assumptions made here can be listed as;

i. a steady state plant case,
ii. the ideal gas principles are kept in view for air and combustion gas,
iii. the exergy of the ash is disregarded thanks to minor contribution,
iv. the vicissitudes in the kinetic and potential energy are paid no attention.

3. Analysis

The aim of this study is to carry out an energy and exergy analysis in order to grasp and show how the FBCC power plant works more effective and efficient. Energy and exergy balance equations generate the principal of thermodynamic relationship. Namely, the thermodynamic efficiency of the FBCC steam plant is identified with two methods which are energy and exergy efficiencies basis on first and second law of thermodynamic.

The inspection of the feed water and the steam production are provided by the HRSG which includes the saturated steam in its top zone and the saturated water in its bottom zone. Meanwhile the water grade remains stable in the HRSG. When the feed water enters in HRSG, the water temperature contained in the HRSG achieves the satiation temperature.

The thermodynamic tables are used to obtain properties of water, steam and combustion gases. Even, the reference surround-