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Comparative energetic and exergetic performance analyses for coal-fired thermal power plants in Turkey

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ABSTRACT

The purpose of this study is to analyze comparatively the performance of nine thermal power plants under control governmental bodies in Turkey, from energetic and exergetic viewpoint. The considered power plants are mostly conventional reheat steam power plant fed by low quality coal. Firstly, thermodynamic models of the plants are developed based on first and second law of thermodynamics. Secondly, some energetic simulation results of the developed models are compared with the design values of the power plants in order to demonstrate the reliability. Thirdly, design point performance analyses based on energetic and exergetic performance criteria such as thermal efficiency, exergy efficiency, exergy loss, exergetic performance coefficient are performed for all considered plants in order to make comprehensive evaluations. Finally, by means of these analyses, the main sources of thermodynamic inefficiencies as well as reasonable comparison of each plant to others are identified and discussed. As a result, the outcomes of this study can provide a basis used for plant performance improvement for the considered coal-fired thermal power plants.

1. Introduction

The amount of energy consumption is one of the most important indicator showing the development stages of countries and living standards of communities. Population increment, urbanization, industrializing, and technologic development result directly in increasing energy consumption. As a parallel, this rapid growing trend brings about the crucial environmental problems such as contamination and greenhouse effect. Currently, 80% of electricity in the world is approximately produced from fossil fuels (coal, petroleum, fuel-oil, natural gas) fired thermal power plants (TPPs), whereas 20% of the electricity is compensated from different sources such as hydraulic, nuclear, wind, solar, geothermal and biogas [1].

In Turkey, although the share of TPPs generating electricity is approximately 61% within the total installed power, its ratio at the compensation of electricity demand is about 80% (39.5% natural gas, 32.6% coal and 7.9% fuel-oil) [2]. Nowadays, 50% of the amount of electricity generated from TPPs is depended on imported fuel sources, especially natural gas. If the importing increment continuous as the rate of the last decade, it is expected that the imported fuel share will be 76% at 2020 [3]. It is obvious that the main solution of this problem is efficiently utilization of the domestic fuel sources. For Turkey, coal is an essential domestic source that the predicted reserve is 8 billion metric tons, ranking Turkey seventh largest in the world [4]. Accordingly, enhancing the performances of coal-fired TPPs is a crucial objective in terms of economic, energy policy, national security, fuel reserve, and environmental concerns. In relation to this issue, a study revealing the performance conditions of existing coal-fired TPPS will be the first step for determining efficient ways of better performance.

Generally, performances of thermal power plants are evaluated through energetic performance criteria based on First Law of Thermodynamics, which are electrical power and thermal efficiency. In recent decades, exergetic performance analysis based on Second Law of Thermodynamics has found as useful method in the design, evaluation, optimization and improvement of thermal power plants [5–8]. Exergetic performance analyses can not only determine magnitudes, location and causes of irreversibilities in the plants, but also provide more meaningful assessment of plant individual components' efficiency [9,10]. These points of exergetic performance analyses are the basic differences from energetic

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Nomenclature

$\dot{E}x$	exergy transfer rate (kW)
$\dot{e}x$	specific exergy (kJ kg^{-1})
$\dot{E}x_D$	exergy destruction rate (kW)
h	enthalpy (kJ kg^{-1})
LHV	lower heat value (kJ kg^{-1})
$\dot{m}$	mass flow rate (kg s^{-1})
s	entropy (kJ kg^{-1} K^{-1})
T	temperature (K or °C)
$\dot{W}$	electrical power output (kW)
$\dot{Q}$	heat transfer rate (kW)
Greek letters	
η	efficiency
ζ	exergetic performance coefficient
Subscripts	
B	boiler
C	condenser
fw	feed water
in	inlet
out	outlet
P	pump
rh	reheat
s	steam
sh	superheat
T	turbine
th	thermal

performance analyses. Therefore, it can be said that performing exergetic and energetic analyses together can give a complete depiction of system characteristics. Such a comprehensive analysis will be a more convenient approach for performance evaluation and determination of the steps towards to improvement direction.

In the literature, there exist a number of papers concerning energetic and exergetic performances of coal-fired thermal power plants [11–20]. For instance, Bhatt and Rajkumar [11] presented different ways of enhancing the performance of the coal-fired thermal power plants. Aljundi [12] determined the location of the most energy and exergy losses for Al-Hussein thermal power plant in Jordan through the energy and exergy analyses and, investigated the effects of variation of the reference ambient conditions on exergetic performance. Oktay [13] analyzed the irreversibilities, exergy efficiency and improvement factors of plant components (boiler, steam turbines, pumps, etc.) for a fluidized bed 2 × 160 MW thermal power plant in Turkey. Srinivas [14] attempted an analysis for a Rankine cycle based thermal power plant with feed water heaters from both first law and second law point. He investigated the effect of number of feed water heaters and other operating parameters on the performance by generalizing the procedure. Kopac and Hilalci [15] calculated heat losses from energy analysis and analyzed exergy losses of the plant at different ambient temperatures from exergy analysis. Rosen [16] made a thermodynamic comparison of coal-fired and nuclear electrical generating stations using energy and exergy analyses. Rosen and Raymond [17] carried out energy and exergy analyses for a coal-fired steam power plant and evaluated possible modifications to improve the efficiency of the plant. Dincer and Al-Muslim [18] conducted a thermodynamic analysis for a Rankine cycle reheat steam power plant. In these studies, the analyses were carried out for a single power plant. Moreover, it is seen from these studies contents that different definitions for a specific performance criterion are used. For example, lower heating values of fuels are used in the definition of thermal efficiency while some of them use the higher heating values. In addition, it is observed that the definition of exergy efficiency for components is different. Furthermore, since companies designing power plant use generally gross electricity power instead of net electricity power in the thermal efficiency calculation, it is possible that there are important difference between the analysis results in the literature and information of the companies. In fact, there is confusion on this subject and the difficulties related to definitions of performance criteria were emphasized by some researchers [21–23]. They examined and discussed the views regarding efficiency, loss and exergy based performance measures.

Keeping in view the facts stated above, it can be expected that performing an analysis based on the same definition of performance criteria will be meaningful for performance comparisons, assessments and improvement for thermal power plants. Additionally, considering both of energetic and exergetic performance criteria together can guide the ways of efficient and effective usage of coal resources because of taking into account the quality and quantity of the energy used to generate electricity power in TPPs. For these reasons, the purpose of this study presented here is to carry out energetic and exergetic performance analyses, at the design conditions, for the existing nine coal-fired thermal power plants under control governmental bodies in Turkey in order to identify the needed improvement. For performing this aim, thermodynamic models for the considered power plants are developed on the basis of mass, energy and exergy balance equations. The thermodynamic models are simulated and the simulation results are compared with values at design conditions of the TPPs for model validation. Then, the defined energetic and exergetic performances are determined for the all plants. In the direction of the comprehensive analysis results, the requirements for performance improvement are evaluated.

2. Characteristics of the considered coal-fired thermal power plants

The coal-fired thermal power plants under control governmental bodies in Turkey have been considered in this study. For these coal-fired TPPs, the technical data are summarized in Table 1. The installed capacity of the considered coal-fired thermal power plant is about 6426 MW. The average age of these power plants is above 15 years. All of these plants were established as sub-critical steam conditions. The power plants use generally low quality coal (lignite). The main steam pressure and temperature conditions for these power plants are the range of 127.5–172 bar and 530–545 °C, respectively. The feed water to boiler is heated up to 215–257 °C in a 5–8 stage feed-water preheating systems.

3. Analysis methodology

3.1. Modeling approach

In order to analyze the energetic and exergetic performances, thermodynamic models are developed using zero-dimensional approach for each investigated coal-fired thermal power plant in the scope of this study. One unit of each power plant is considered in the modeling process. In the model development, the continuous