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# Exergy analysis of a circulating fluidized bed boiler cogeneration power plant

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ABSTRACT

In this study, energy and exergy analysis of a cogeneration power plant have been performed. The steam which is produced by the cogeneration power plant is used for salt production and most important part of the cogeneration power plant is the circulation fluidized bed boiler. Energy and exergy efficiency of the circulation fluidized bed boiler were found as 84.65% and 29.43%, respectively. Exergy destruction of the circulation fluidized bed boiler was calculated as 21789.39 kW and 85.89% of exergy destruction in the plant. The automation system of the cogeneration power plant is insufficient. Exergy efficiency of the plant was calculated as 20%. Also, some design parameters increasing energy losses were determined.


## 1. Introduction

The combined heat and power systems, which are called as cogeneration power systems, are very effective systems which generate both power and thermal energy. A single fuel source is used in these systems. Also, different fuel combinations such as coal based synthetic natural gas have been used in these effective systems [1]. Waste heat released from the system used to generating power is used efficiently. Thus, the cycle efficiency of the system is increased. Different approach and analysis are applied for complex systems for improving the efficiency and decreasing the production cost. For example, exergy and exergoeconomic analysis of combined heat and power system were considered in order to provide cost-based information and suggests possible locations for combined heat and power system improvement [2]. Also these analyses are used for determining waste energy and exergy values. For instance, 50.88% of total exergy input was found as lost in a study, which focused on exergy assessment of a cogeneration system [3] or theoretical analysis of systems which produces electric from the waste heat can be found in the literature [4]. Results obtained from exergy analysis can be used for determining insufficient system components or subsystems [5]. Also, exergy analysis of complex thermal systems such as cogeneration power plant presents very important parameters. One of these parameters is exergy destruction. Exergy analysis of combined cycle cogeneration plant showed exergy destruction of the subsystems [6]. In addition, these systems reduce air emissions. Some of these emissions are $NO_x$ (Nitrous Oxides), $SO_2$ (Sulfur Dioxide), particles in the combustion products and $CO_2$ (Carbon Dioxide) [7]. The most important component of the system analyzed in this study is circulation fluidized bed boiler. Fluidized bed combustion of solid fuels represents a burning procedure of these fuels in a granulated form of some adequate dimensions inside of an air flow from below to above such that the fuel particles in the air mass until their complete combustion [8]. Fluidized beds can be used for different purposes in physical and chemical processes [9]. There are many applications of fluidized beds and they are used for energy conversion, petrochemical processes, mineral processing, chemical and pharmaceutical, physical processing which are heat exchanger and treatment, coating of particles, flue gas cleaning and drying [10]. In generally, fluidized beds are used for energy conversion and evaluated as fuels different coal wastes or coals having low combustion efficiency with biomass and these resources can be used by considering efficient and environmental responsibilities. Biomass is used as fuel in the fluidized bed boilers for energy conversion. Cedar wood, wood sawdust, olive oil residue, rice husk and straw, pine sawdust, spruce wood pellet, coffee ground, larch wood, grapevine pruning waste, jute stick, sugar-cane bagasse, corn cob, peach stone, wheat straw, cotton sterm, swraw, camphor wood, veech wood, switchgrass, etc. can be used as fuel in fluidized

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**Nomenclature**

| | |
|---|---|
| $a$ | mass fraction of hydrogen |
| $b$ | mass fraction of carbon |
| $Cp$ | specific heat capacity (kJ/kg K) |
| CFBB | circulation fluidized bed boiler |
| ESP | electrostatic precipitator |
| $\dot{E}x$ | exergy rate (kW) |
| $\dot{E}$ | energy rate (kW) |
| $ex$ | specific exergy (kJ/kg) |
| $F$ | mass of fuel (kg) |
| $h$ | enthalpy (kJ/kg) |
| $K$ | coefficient |
| $LHV$ | low heating value (kJ/kg) |
| $M$ | molar mass (kg/kmol) |
| $\dot{m}$ | mass flow rate (kg/s) |
| $O$ | mass of oxidant (kg) |
| $\overline{R}$ | universal gas constant (kJ/kmol K) |
| $\dot{S}$ | entropy (kJ/s K) |
| $s$ | specific entropy (kJ/kg K) |
| $T$ | temperature (K) |
| $\dot{W}$ | work rate (kW) |
| $x$ | mole fraction |
| $X$ | mass fraction |

*Greek letters*

| | |
|---|---|
| $\lambda$ | fuel–air ratio |
| $\gamma$ | chemical exergy/energy ratio |
| $\eta$ | energy efficiency |
| $\eta_{ex}$ | exergy efficiency |
| $\overline{\varepsilon}^{o}$ | standard chemical exergy (kJ/kmol) |
| $\phi$ | equivalence ratio |

*Subscripts*

| | |
|---|---|
| $cv$ | control volume |
| $comb$ | combustion |
| $D$ | destruction |
| $ex$ | exergy |
| $gen$ | generation |
| $out$ | output |
| $i$ | stream no |
| $in$ | inlet |
| $k$ | $k$th content |
| $s$ | surface |
| $st$ | stoichiometric conditions |
| $\infty$ | reference environment |

*Superscripts*

| | |
|---|---|
| $ch$ | chemical |
| $ph$ | physical |
| – | molar unit |
| 0 | standard environmental state |

bed boilers [11]. For example, researchers have studied on availability as fuel of rice husk and valuable results were obtained by them [12]. Also, biomass obtained from forest and agriculture is used for both electric and heat production [13].

In the literature, studies about fluidized bed boilers and cogeneration power systems can be found. One of those studies is the energy and exergy analysis of the systems. A steam power plant involves fluidized bed coal combustor and energy and exergy analysis of it was performed [14]. The exergy analysis can be used for technical feasibility. Results obtained from the exergy analysis of bubbling fluidized bed co-combustion by using biomass and low-grade coal mixtures were used for technical feasibility study [15]. The performance of fluidized bed boilers is a very important parameter, because the mass transfer, energy conversion, heat transfer, chemical reactions, momentum transfer and many phenomena occur in the fluidized bed boiler. Specially, when different coal mixtures or biomass were used as fuel, performance of the fluidized bed boiler was used for comparing [16]. Different approaches for comparison analysis can be found in the literature. For example, a simulation study was performed for comparing between fixed bed and fluidized bed membrane reactor configurations [17]. The combustion process is the main phenomena in the fluidized bed boiler. The studies about combustion efficiency and the parameters that affect the efficiency present valuable results. In the one of combustion analysis studies, the effects of different parameters such as excess air ratio, bed operational velocity, coal particle diameter and combustor load on combustion efficiency was investigated [18]. Also, there are studies to model circulating fluidized bed boiler for determining hydrodynamics, heat transfer and combustion aspects in the literature [19]. In this perspective, there are many studies about the heat transfer process in different types of fluidized bed combustors as well as the important operation conditions affecting the process [20]. Different topologies, methodologies and algorithms have been used for optimization analysis of fluidized bed. In one of these studies, an artificial neural network topology using coupled response surface methodology and genetic algorithm was used for optimization of fluidized bed drying system [21]. Examples published in the recent years can be given for cogeneration power plant. For example, mathematic models which were proposed for novel water-power cogeneration plant were based and performance of the system was studied at different parameters [22]. In a cogeneration system, new concept was development. Two renewable system which are biomass and solar energy sources, were used in the system. Also, fluidized bed combustor was used for biomass combustion [23]. A synthetic natural gas and power cogeneration technology were considered for determining techno economic performance [24]. Also, performance optimization and feasibility study of small combined cycles for cogeneration heat and power generation from biomass can be found in the literature [25]. In the recent years, hybrid systems utilizing biomass and solar energy are widely used. Energy, exergy and economic analysis of a cogeneration and trigeneration hybrid system were studied [26]. Thermodynamic performance of a novel electricity heating cogeneration system was studied and the analysis was carried out for specific condition and variable conditions [27]. A parameter optimization for each cogeneration system was achieved by means of genetic algorithm to reach the maximum exergy efficiency. The optimum performances for different cogeneration systems was compared under the same conditions [28]. In this study, fluidized bed in the cogeneration power plant is used for energy conversion and type of fluidized bed boiler is circulation fluidized bed boiler (CFBB). A circulating fluidized bed boiler burns unburned fuel in the flue gas and it burns fuel in a fast fluidized bed regime. Combined heat and power system produces both electricity and thermal energy which is in the form of steam or hot water [6]. The power plant considering in this study generates both electricity and steam. The steam is used for salt production. The company produces salt for different industries and purposes. Prod-