Energy 194 (2020) 116843

Contents lists available at ScienceDirect

Energy

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

Thermodynamic analysis of a biomass-fired lab-scale power plant

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ARTICLE INFO

Article history:
Received 12 October 2019
Received in revised form
14 December 2019
Accepted 24 December 2019
Available online 24 December 2019

Keywords:
Thermodynamic analysis
Biomass
Combustion
Environmental impact
Power plant

ABSTRACT

In this study, thermodynamic analysis and environmental impact of a lab-scale biomass-fired open cycle power plant have been performed. The performance of the plant including combustion and generated power efficiencies was studied based on first and second laws of thermodynamics. The combustion temperature and mass fraction of pollutants resulted from direct burning of biomass were also estimated theoretically using a mathematical model developed by the authors. It was found that the measured temperature of combustion of biomass mixture reached 818 °C, which agrees with theoretical result. The estimated energy and exergy efficiencies of the plant were 12 and 16.4%. The heat addition process in the boiler through the burner was the major source of irreversibility in the lab-scale plant; due to non-adiabatic heat transfer in the un-insulated burner where most exergy destruction and energy loss took place. The environmental impact of biomass combustion showed insignificant contents of sulfur and nitrogen oxides pollutants, which enhances the use of biomass as alternative fuel.

1. Introduction

As the energy demand is increasing rapidly nowadays, the search for alternative and renewable energy sources becomes extremely important since fossil fuels are running out around the world and emit huge amounts of dangerous emissions [1]. Biomass-fired systems are among the alternative systems that depend on biomass as renewable energy sources. Biomass, which includes all organic and inorganic matters, is basically an organic mixture that consists of hemicellulose, lignin and cellulose content [2]. When burning biomass fuel, low CO_2 levels are obtained in comparison with conventional fossil fuels since biomass is carbon-natural matter [2]. The reasonable heating value and the cheap prices of biomass fuels encourage using it in co-firing coal power plants for electricity generation applications [3]. They have found that biomass co-firing with coal can mitigate coal usage and decrease emissions significantly. Utilization of biomass can be done using many techniques that include direct combustion, fermentation and anaerobic digestion where typically the moisture content plays a significant role in defining the utilization method [4]. For example, Anaerobic digestion method is used when the moisture content exceeds 80% of the total mass [5,6]. Direct combustion of biomass fuels produces temperatures up to 818 °C. On the other hand, converting biomass to biogas using gasification method is considered for methanol production. The relatively low heating value and the instability of biomass production quantities are the main limitations that need to be treated in future in order to enhance biomass firing efficiency and allowing more environmental operation [1]. Many endeavors and studies in the literature have focused on investigating biomass production and firing systems. Large percentage of the investigations focuses on using biomass as an assistant fuel in energy power plants. Gholamian et al. [5] presented a new cogeneration system which includes gas turbine and gasifier to compare the maximum exergy efficiency and CO_2 emissions for two types of biomass (wood and paper). They found that using wood is more efficient than using paper in terms of the energy output while CO_2 emission is almost the same for both biomass fuels. Ahmadi et al. [6] studied biomass combustion in organic Rankine cycle for Hydrogen and hot water production. They also performed parametric study to evaluate the effect of different system parameters on the energy and exergy efficiencies. They found that shifting the operation toward the multi-generation

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https://doi.org/10.1016/j.energy.2019.116843
0360-5442/