Energy Conversion and Management 181 (2019) 463–475

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Thermodynamic and thermoeconomic analysis of basic and modified power generation systems fueled by biogas

Towhid Gholizadeh[a], Mohammad Vajdi[a,*], Farzad Mohammadkhani[b]

[a] Department of mechanical engineering, Faculty of Engineering, University of Mohaghegh Ardabili, Ardabil, Iran
[b] Faculty of Mechanical Engineering, University of Tabriz, Tabriz, Iran

ARTICLE INFO

Keywords:
Biogas
Gas turbine
Organic Rankine cycle (ORC)
Thermodynamic analysis
Thermoeconomic analysis

ABSTRACT

Biogas has been used practically as an attractive renewable energy source for various combined power plants as a recent advancement in technologies. Feasibility investigation of a modified organic Rankine cycle coupled with a gas turbine cycle fueled by biogas (60% methane + 40% carbon dioxide) as a heat source is carried out in this study. Thermodynamic and thermoeconomic analysis are employed as the most powerful tools to estimate performance and cost of the system and the results are compared with the basis coupled system. Also, to investigate how the proposed systems perform under any external disturbances, a thorough sensitivity study around the basic operating input parameters was carried out. The results of the second law analysis demonstrated that among all components and for both proposed systems, the combustion chamber had the highest value of exergy destruction rate, followed by the recovery heat exchanger. The proposed combined system could produce net output electricity of 1368 kW, resulting in the thermal efficiency, exergy efficiency and overall product cost of 41.83%, 38.91%, and 17.2 $/GJ, respectively. Moreover, it is found that the thermal and exergy efficiencies of both systems could be maximized with respect to the air compressor pressure ratio and steam turbine inlet pressure, while the overall product cost of the cycles can be minimized with air compressor pressure ratio and gas turbine inlet temperature.

1. Introduction

Biogas is established as a well-known fuel for many industrial and domestic applications, motivating factories to develop liquid biofuels as a practical substitute for petroleum fuels. Especially, producing biogas by anaerobic digestion, where organic materials are broken down by microbiological activity, is a promising substitute to fossil fuels. This phenomenon occurs at the bottom of ponds in the absence of air. However, all biomass is not suitable for anaerobic digestion, such as lignocellulosic biomass because of its complex structure which leads to a challenge in designing appropriate digester [1]. Human-made technologies are developed to produce biogas by two common methods, namely human/animal waste fermentation and methane capturing from municipal waste landfill regions. However, due to the small number of feces and available plant matters in domestic systems, less gas is produced through this process making it less attractive. The required temperature for biogas production is crucial since most bacteria operate at temperature of 35 °C. In cold weather where the temperature drops below 5, approximately 20% of the generated gas is used for heating the digester.

Many countries have initiated their programs for large-scale exploitation from biogas resources. This requires many investigations and scholar's efforts to model recovery process from municipal and industrial waste for producing electricity or other forms of commodities. In 2016, Hosseini et al. [2] integrated a Gas Turbine Cycle (GTC) and an Organic Rankine Cycle (ORC) to extract more power by the waste heat of the GTC. They used biogas instead of methane as a fuel and presented a complete investigation of thermal design and parametric study for 1.4 MW net power. Barzegaravval et al. [3] performed an exergoeconomic evaluation for a biogas-based GTC and studied the influence of fuel composition and size of the system on the exergy and economic critical parameters. They computed net electricity cost of 0.05–0.18 $/kWh for their investigated case and reported about 1% rise in total cost of the system with decreasing methane content from 0.95 to 0.6. Mehr et al. [4] used biogas for different configurations of the Solid Oxide Fuel Cell (SOFC) and compared their performance thermodynamically and thermoeconomically. They reported that increasing the anode recycling ratio or decreasing the cathode recycling ratio will increase the unit product cost of the system. They also demonstrated the fact that biogas-based SOFC with anode and cathode recycling is

* Corresponding author.
E-mail address: Vajdi@uma.ac.ir (M. Vajdi).

https://doi.org/10.1016/j.enconman.2018.12.011
Received 29 August 2018; Accepted 1 December 2018