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Exergy analysis and multiobjective optimization of a biomass gasification based multigeneration system

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ABSTRACT

Biomass gasification is a process of converting biomass to a combustible gas suitable for use in boilers, engines and turbines to produce combined cooling, heat and power. This paper presents a detailed model of a biomass gasification system and designs a multigeneration energy system which uses the biomass gasification process for generating combined cooling, heat and electricity. Energy and exergy analyses are first applied to evaluate the performance of the designed system. Next, minimizing total cost rate and maximizing exergy efficiency of the system are considered as two objective functions and a multiobjective optimization approach based on differential evolution algorithm and local unimodal sampling technique is developed to calculate the optimal values of the multigeneration system parameters. A parametric study is then carried out and Pareto front curve is used to determine the trend of objective functions and assess the performance of the system. Furthermore, a sensitivity analysis is employed to evaluate effects of design parameters on the objective functions. Simulation results are compared with two other multiobjective optimization algorithms and effectiveness of the proposed method is verified using various performance indicators.

Introduction

Biomass is an alternative energy source that unlike a fossil fuel is carbon neutral, widely available and helps reduce waste and global warming. Since biomass is a renewable energy resource and environmental friendly, it can be used to replace or reduce dependency on fossil fuels [1]. Hence, hybrid energy systems based on renewable energies such as biomass for multigeneration purposes are important for effective energy production and environmental protection.

Biomass based energy systems have been studied over many years by numerous researchers for various industrial applications. Recently, a number of studies have been reported on biomass based trigeneration and multigeneration systems.

Authors in Ref. [2] have designed a multigeneration system fuelled by gasified biomass and natural gas. They concluded that renewable energy is the source for reducing CO2 and environmental impact. Performance assessment and optimization of an integrated biomass energy system for multigeneration purposes have been conducted in Ref. [3] wherein results have shown that the energy and exergy efficiencies of

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the overall system are higher than the efficiencies of an individual biomass system. Energy and exergy analyses of a biomass based multigeneration system using an organic Rankine cycle (ORC) have been performed in Ref. [4] wherein simulation results have shown that maximum exergy efficiency of the ORC increases from 13% to 28% from single generation to multigeneration. Authors in Ref. [5] have developed thermodynamic, energy and exergy analyses on a biomass based integrated system wherein they have investigated effects of design parameters on system operation. Simulation results reported in Ref. [5] illustrate that increasing the operation temperature of fuel cell results in more exergy destruction of system in fuel cell and combustion chamber. Authors in Ref. [6] have developed energy and exergy of a combined cooling, heat and power (CCHP) system based on solar and biomass. Simulation results for the system used in Ref. [6] which includes absorption chiller, heater, desalination system, biomass burner and solar collector show that energy and exergy efficiencies are 61 and 7% respectively. Reference [7] has presented an integrated system based on biomass energy wherein effects of various system parameters on energy and exergy efficiencies have been examined. Simulation results presented in Ref. [7] show that energy and exergy efficiencies are 66.5% and 39.7% respectively. Authors in Ref. [8] have proposed an optimization model for biomass gasification based Building Combined Cooling, Heating and Power (BCHP) system. They have also calculated the most optimal scheme in terms of cost, energy consumption, steel consumption and dioxide carbon emission. Authors in Ref. [9] have focused on modeling, simulation and economic analysis of small scale biomass CCHP system. Results presented in Ref. [9] show that the maximum efficiency and best electricity price for the proposed system are as 85% and 87 £/MWH. A CCHP system that includes a biomass gasifier, a double effect absorption refrigeration cycle, a HRSG and a solid oxide fuel cell has been designed in Ref. [10] and its performance has been and compared with a CHP system. Authors of [10] have shown using exergy and energy analysis that maximum exergy efficiency and CO_2 emission of the CCHP system are respectively significantly higher and lower than that of the CHP system. Results of studies presented in Ref. [11] for a system that consists of three subsystems, i.e. a biomass gasification plant, a hydrogen liquefaction unit, and a solid oxide fuel cell/gas turbine (SOFC/GT) has shown that SOFC/GT system compare with propulsion systems provides considerable higher exergy efficiency. Authors of [12] have studied energy and exergy analysis of an integrated coal based gasification system for hydrogen production and electric power generation wherein they have concluded that energy and exergy efficiencies are 41% and 36.5% respectively. A hybrid energy system for hydrogen production and electric power generation has been modeled in Ref. [13]. The model includes photo voltaic array, wind turbines, electrolyzer, polymer electrolyte membrane fuel cell, hydrogen tank and converter. Energy and exergy analysis of the hybrid system have shown that average energy and exergy efficiencies for the PV array are 13.31% and 14.26% respectively while for electrolyzer equipment are 59.68% and 60.26% and for wind turbine are 46% and 50.12%. Energy analysis of a solar based biomass gasification system for hydrogen production has been presented in Ref. [14] wherein three gasification processes have been studied. In the first gasification process, a gasification reactor along with a conventional water gas shift section and a pressure swing absorber has been selected. In the second gasification process, a gasification reactor followed by an integrated membrane water gas shift reactor has been considered. In the third gasification process, supercritical gasification reactor followed by two flash separators and a pressure swing absorber has been selected. Results of conducted simulations have shown that the optimal solar share of the second process is higher than that of the first process. Moreover, solar integration was not possible in the third process. Authors of [15] have presented exergy, energy and exergoeconomic analysis of a biomass based hydrogen production system. Their analysis have shown that based on the parameters used in their study, cost of hydrogen produced by circulating fluidized bed gasifier system is in the range of 1.59 $/kg to 5.37 $/kg. An energy production system which consists of a biomass gasification as well as a fuel cell system has been studied in Ref. [16] wherein energy and exergy analysis have shown that effect of steam biomass ratio on the hydrogen production efficiency is significant. A solar thermal system has been used in Ref. [17] as an energy source to supply the electrolyzer of coupled hydrogen and solar energy system wherein detailed model of the fuel cell and the thermal solar system have been studied. A multigeneration system that consists of geothermal and solar for generating electrical power, cooling, heating, hydrogen and hot water for buildings has been presented in Ref. [18] wherein energy and exergy analysis have shown that according to the internal parameters used in the study, the net cost of the optimized system is 476,000$ and the levelized cost of electricity is 0.089$/kWh.

Energy and exergy analysis of a geothermal power based multigeneration energy production system conducted in Ref. [19] have shown that when geothermal water temperature rises, electrical power generation as well as hydrogen production increase but hydrogen production cost decreases.

Reference [20] has developed a model for designing, optimizing and simulation of an energy system based on biomass gasification which includes five configurations for power, heating and cooling production. Results presented in Ref. [21] show that exergy efficiency of the system is in the range of 18.9%–23.2%. Energy and exergy analysis of a biomass based energy system which includes cooling, heating and power cogeneration have been presented in Ref. [22]. Energy, exergy and economic analyses of the system show that exergy efficiency is 28% and total destructed exergy of biomass burner and ORC evaporator are 55% and 38% respectively.

Multigeneration systems based on renewable energies, such as biomass, potentially provide numerous benefits such as higher efficiencies, lower greenhouse gas emissions, lower operating costs and better use of resources. However, there are many design parameters which have significant effects on the system performance from economic, thermodynamic and environmental aspects. Hence, from the engineering application point of view, it is necessary to apply optimization techniques to find the best values for the design parameters in order to improve the system performance. The optimization process for a multigeneration energy system with many design parameters is a complicated and challenging task.