Available online at www.sciencedirect.com

ScienceDirect

http://www.elsevier.com/locate/biombioe

BIOMASS & BIOENERGY

Effect of operating parameters on performance of an integrated biomass gasifier, solid oxide fuel cells and micro gas turbine system

Junxi Jia [a,*], *Abuliti Abudula* [b], *Liming Wei* [c], *Baozhi Sun* [a], *Yue Shi* [a]

[a] College of Power and Energy Engineering, Harbin Engineering University, Harbin 150001, China
[b] North Japan Research Institute for Sustainable Energy, Hirosaki University, Aomori 030-0813, Japan
[c] School of Electric and Electronic Information Engineering, Jilin Jianzhu University, Changchun 130118, China

ARTICLE INFO

Article history:
Received 13 October 2014
Received in revised form
5 February 2015
Accepted 6 February 2015
Available online 27 February 2015

Keywords:
Biomass gasification
Solid oxide fuel cell
Chemical equilibrium
Kinetics model
Combined heat and power

ABSTRACT

An integrated power system of biomass gasification with solid oxide fuel cells (SOFC) and micro gas turbine has been investigated by thermodynamic model. A zero-dimensional electrochemical model of SOFC and one-dimensional chemical kinetics model of downdraft biomass gasifier have been developed to analyze overall performance of the power system. Effects of various parameters such as moisture content in biomass, equivalence ratio and mass flow rate of dry biomass on the overall performance of system have been studied by energy analysis.

It is found that char in the biomass tends to be converted with decreasing of moisture content and increasing of equivalence ratio due to higher temperature in reduction zone of gasifier. Electric and combined heat and power efficiencies of the power system increase with decreasing of moisture content and increasing of equivalence ratio, the electrical efficiency of this system could reach a level of approximately 56%.Regarding entire conversion of char in gasifier and acceptable electrical efficiency above 45%, operating condition in this study is suggested to be in the range of moisture content less than 0.2, equivalence ratio more than 0.46 and mass flow rate of biomass less than 20 $kg\ h^{-1}$.

1. Introduction

Biomass is supposed to be one of the most common renewable sources used for power generation [1]. Biomass gasification (BG) technology has been used to produce syngas and electricity, from laboratory scale test to some demonstration scale plants. Although low energy density and seasonal availability of biomass lead to both the high transport cost and high capital cost of biomass plants, it has potential of being commercialized to produce hydrogen in the future [2]. Solid oxide fuel cell (SOFC) is considered one of the most important energy technologies for its high efficiency and low environmental impact. It is ideal for syngas conversion due to its high operation temperature [3–5].

Integration of BG with SOFC has received more attention as a potential substitute for fossil fuels in electric power production since it combines the merits of renewable energy sources and hydrogen energy systems.

* *Corresponding author.*
E-mail address: jiajunxi99@sohu.com (J. Jia).
http://dx.doi.org/10.1016/j.biombioe.2015.02.004
0961-9534/

Thermodynamic analysis of BG and SOFC hybrid systems have been reported by many researchers [6–14]. These studies mainly focus on effect of operating conditions on overall performance of the power systems.

Athanasiou et al. [8] and Cordiner et al. [9] investigated an integrated process of biomass gasification and solid oxide fuel cells system, the overall electrical efficiency could reach very high level of more than 40%.Fryda et al. [10] assessed the combination of BG with SOFCs and micro gas turbine (MGT). Their results show that an electrical efficiency of 40.6% could be achieved at elevated pressures. A hybrid plant consisting of gasification system, solid oxide fuel cells and organic Rankine cycle has been presented by Pierobon et al. [11]. The results show that efficiencies over 54% can be achieved. Colpan et al. [12] studied the effect of gasification agent (air, enriched oxygen and steam) on the performance of an integrated SOFC and BG system. The results show that using steam as the gasification agent yields the highest electrical efficiency of 41.8%.Rokni et al. [13] reported a hybrid plant producing combined heat and power (CHP) from BG, SOFC and a MGT. An electrical efficiency of 58.2% has been reported resulting from optimization efforts.

Recently, Campitelli et al. [14] have invested the effect of operating conditions on BG-SOFC systems performance. The influence of H_2 utilization of SOFC and moisture content in biomass have been analyzed in details. In their work, a zero-dimensional chemical equilibrium model was used in gasifier. The authors did not take into account any char conversion in the reduction zone of gasifier.

Most of gasification models adopted to analyze the performance of BG, SOFC, and GT system mentioned above [6–14] are based on thermodynamic equilibrium as those reported in Refs. [15–18]. These equilibrium models are developed by the thermodynamic parameters based on minimization of Gibbs free energy. Although these pure equilibrium models are relatively easy to be applied with fast convergence, they have certain limitations such as considering sufficient residence time, high reaction temperature, and fast reaction rates. The dying, pyrolysis and oxidant process is assumed to be lumped together in a single reaction. The gas compositions and temperature remains essential uniform in gasifier rather than variable with the height of the gasifier. All the char is assumed to be completely consumed before leaving the gasifier, which could not take place in actual gasification process.

Since few of chemical kinetic model of gasifier is available for analysis of an integrated BG, SOFC, and GT system, in this paper kinetics model of downdraft biomass gasifier is presented in order to overcome the limitations of the equilibrium model. The gas composition, reaction temperature, and unreacted char are predicted along height of the reduction zone. Effect of process parameters, such as moisture content, equivalence ratio and mass flow rate of dry biomass on char flow rate and overall performance of BG, SOFC and GT system is examined. Energy analysis is applied by thermodynamic model. Regarding entire char conversion and acceptable system efficiency, the suggested operating conditions are proposed.

2. System description

A schematic of an integrated biomass gasification, SOFC and GT system is shown in Fig. 1. Biomass enters a dryer and its moisture content is reduced to a level acceptable by gasifier. Air, oxygen and steam may be used as gasification agents. In this work air enters a downdraft gasifier. The syngas produced by gasification is cleaned up after entering a hot gas cleaning unit according to the tolerance limits of SOFC. Then, the cleaned syngas enters the SOFC, where electricity is produced. The depleted fuel and air enter a combustor to burn. The high temperature and pressure effluent from the combustor is expanded through GT to generate mechanical power, which is used to generate electrical power. The GT exhaust is used to increase the temperature of air supplied by compressor to the

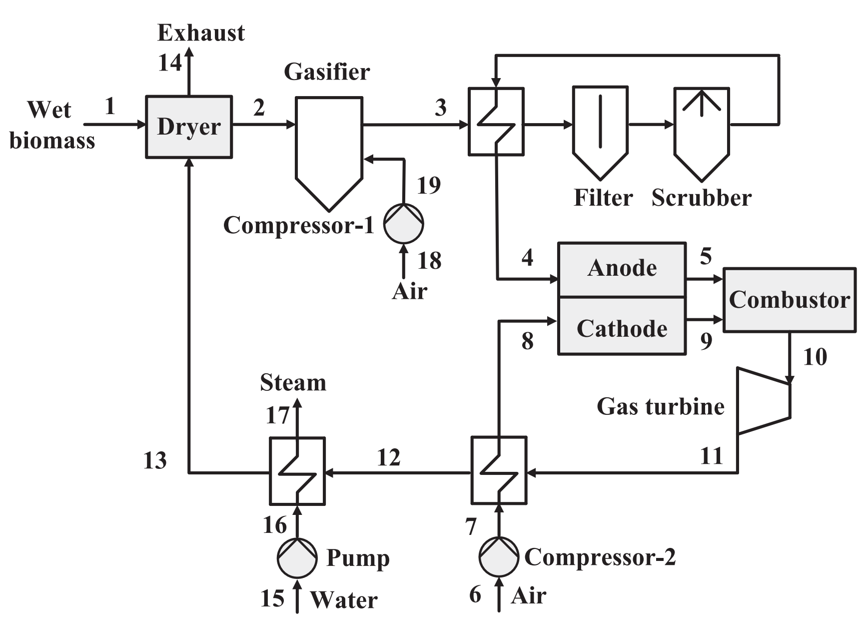

Fig. 1 – Integrated biomass gasifier, SOFCs and GT system.