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Numerical Investigation of Integrated Biomass Gasification and Plannar Solid Oxide Fuel Cell

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ABSTRACT: Current study aims to numerically investigate steady state performance of integrated cycle consisting of biomass gasification process and planar type solid oxide fuel cell (SOFC) for different biomass moisture contents and amount of air as gasification agent in the gasifier. Single stage lumped gasifier is analyzed by use of a modified thermodynamic equilibrium model, while the steady-state intermediate temperature solid oxide fuel cell model developed here is one-dimensional which allows for monitoring the temperature gradients along the cell length under different operating conditions. Complete electrochemical model, species mass balances and energy conservation equation beside the kinetics describing internal methane steam reforming and water-gas shift reactions organize the structure of fuel cell model. Developed model for two main parts of the integrated cycle are validated against the available experimental and numerical data. Results indicate that the low heating value of the product syngas with 30% moisture content decreases with decreasing the modified equivalence ratio and increasing the biomass moisture content from 10 to 50%. Based on the obtained results, the cell electric power mitigates by increasing the biomass moisture content.

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1- Introduction

Biomass gasification is a process that converts solid renewable material into combustible gas mixture namely syngas (synthesis gas). This gas mixture now can be used in modern conversion devices such as gas turbine, engine and SOFC. Regarding the high temperature range of 800 ºC - 1300 ºC for completion of biomass gasification process [1], integration of SOFC with biomass gasification systems have been considered to be very promising technologies of the future. Møller and Rokni [2] proposed and simulated a hybrid system consisting of a fixed bed two-stage gasifier, tubular SOFC and MGT (micro gas turbine). Colpan et al. [3] explored the effect of the gasification agent on the performance of allothermal biomass gasification and SOFC integrated system. Wongchanapai et al. [4] investigated the effect of operating parameters such as steam to biomass ratio, SOFC input temperature, fuel consumption factor and the SOFC output recycling coefficient on the performance of the biomass gasification/SOFC system.

This study aims to propose an integrated cycle based on SOFC and auto-thermal biomass gasification system. The steady-state performance of the integrated system has been investigated and an extensive parametric analysis is adopted. The proposed model enables us to investigate the effect of the amount of air and moisture content of fuel entering the gasifier on the important cycle outputs.

2- Mathematical Modeling

The considered gasifier is of the fixed bed downdraft type in which the feedstock and gasifying agent both move in the same direction. The gases have to pass through the high temperature zone, so the amount of tar is significantly lower than that of updraft gasifier. The gasification includes a set of complex chemical reactions which require the use of mathematical models for their analysis, and two main approaches, namely, thermodynamic equilibrium and kinetic rate modelling, have been used to model this complicated phenomenon [5]. At chemical equilibrium, the system is at its most stable condition in which the entropy of system is maximized or the Gibbs free energy is minimized. In current study, from two general approaches of equilibrium models; namely stochiometric and non-stochiometric, the former is selected [6].

The SOFC thermodynamic voltage can be determined by Nernst equation which is called reversible cell voltage or open-circuit potential [7]:

$$E^{REV} = \frac{\Delta G^0}{2F} - \frac{RT}{2F} \ln \left[\frac{P^{fc}_{H_2O}}{P^{fc}_{H_2} \cdot \left(\frac{P^{ac}_{O_2}}{100000}\right)^{0.5}} \right] \quad (1)$$

Reversible voltage is the maximum voltage that can be achieved by a fuel cell under specific operating conditions. The SOFC output voltage can be expressed by:

$$E_{cell} = E^{REV} - \left(\eta_{ohm} + \eta_{act,ct} + \eta_{act,an} + \eta_{conc,ct} + \eta_{conc,an}\right) \quad (2)$$

where η_{ohm} is ohmic loss, $\eta_{act,ct}$, $\eta_{act,an}$, $\eta_{conc,ct}$ and $\eta_{conc,an}$ are the cathode and anode activation and concentration overpotentials, respectively. Two main output parameters of the SOFC model; the electric power for single cell and fuel efficiency and cooled gas efficiency of the biomass gasification process are described

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mathematically using following equations:

$$P_{SOFC} = j_{avg} E_{cell} \quad (3)$$

$$\eta_{SOFC} = \frac{j_{avg} E_{cell} LW}{\left(X^0_{CH_4} LHV^0_{CH_4} + X^0_{H_2} LHV^0_{H_2} + X^0_{CO} LHV^0_{CO}\right)\dot{N}^0_f} \quad (4)$$

$$\eta_{CG} = \frac{LHV_{gas}}{LHV_{Biomass}} \quad (5)$$

3- Results and Discussion

The effect of the amount of the air (ER_m) entering the gasifier on specious production and the SOFC performance for moisture content at 30% are depicted in Figures 1 and 2. As depicted in Fig. 2, the increased ER_m at constant moisture content produces mixtures richer in CH_4 and H_2 and poorer in CO. The effect of ER_m on the power produced by the cell and electric efficiency of the cell are presented in Fig. 2. The variation of biogas composition and *LHV* at different moisture content (*MC*) of the biomass are depicted in Figures 3 and 4 respectively. As demonstrated at Fig. 3, increasing of the moisture content of the biomass causes the increasing of the methane and hydrogen mole fraction. The effect of moisture content of the biomass on the electric performance of the SOFC is depicted in Fig. 4.

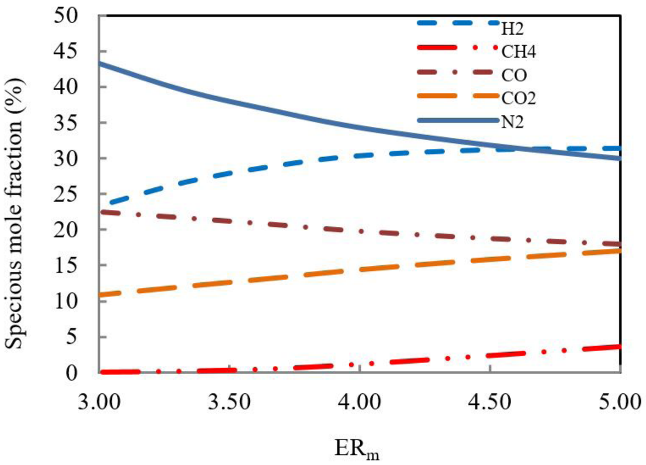

Figure 1. Biogas composition V.S. ER_m

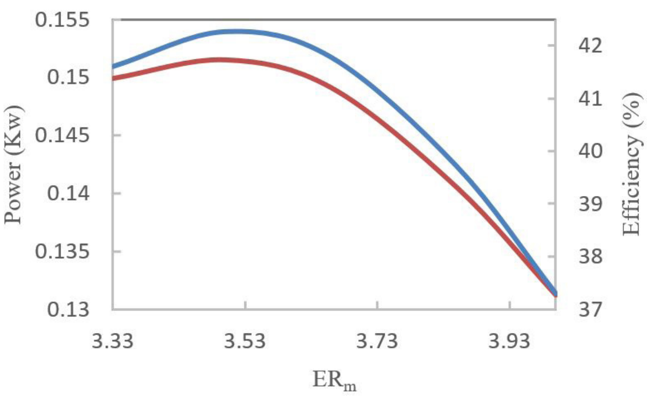

Figure 2. SOFC power and efficiency V.S. ER_m

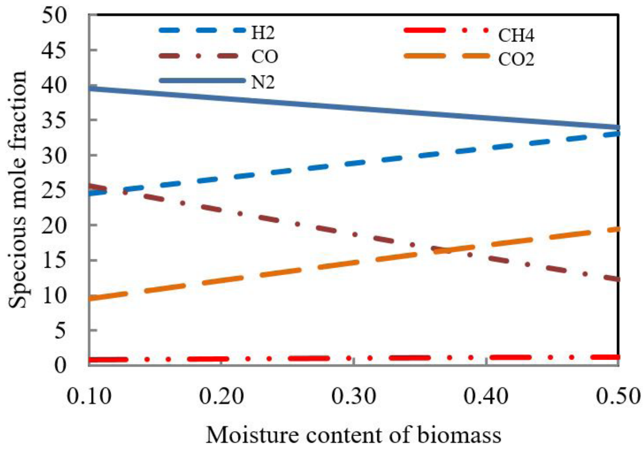

Figure 3. Biogas composition V.S. MC

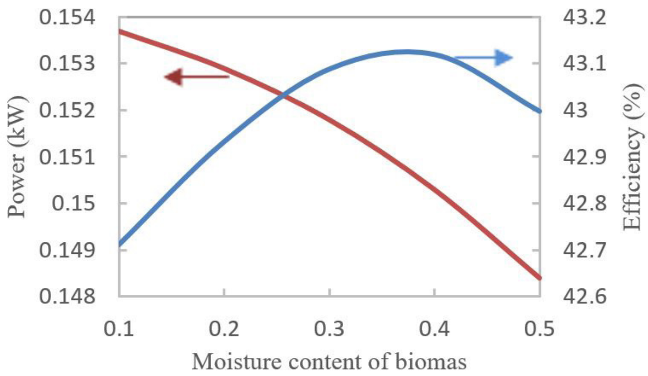

Figure 4. SOFC power and efficiency V.S. MC

4- Conclusion

The integration of biomass gasification with a direct internal reforming planar SOFC was assessed. Several simulations were conducted to investigate the effects of the gasification agent (air) and moisture content of biomass on the cycle output parameters. It was revealed that the increased ER_m at constant moisture content of biomass produces a mixture rich in CH_4 and H_2 and poor in CO; hence, the gasifier produced a mixture with higher *LHV* efficiently. The temperature difference along the cell length, operating temperature, and the cell operating electric power and efficiency decreased with increasing ER_m. On the other hand, investigation of the moisture content of biomass at fixed ER_m revealed that increasing moisture content increases the amount of H_2 and decreases the CO mole fraction in the produced syngas. In this case, the *LHV* of the biogas decreased with increasing moisture content inefficiently. PEN structure temperature of the SOFC decreased with increasing moisture content, while the cell electric efficiency despite of the decreasing electric power of the cell increased with increasing moisture content of biomass.

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