**Proceedings of the 3rd European Fuel Cell Technology & Applications**
**"Piero Lunghi Conference"**
**EFC09**
**December 15 - 18, 2009, Rome, Italy**

# EFC09-17074

# THERMODYNAMIC ANALYSIS AND HEAT INTEGRATION OF WOOD GASIFIER - SOFC SYSTEMS

**Matteo Morandin**†
Energy Systems
Department of Mechanical Engineering
University of Padova
Padova, Italy 35131
Email: matteo.morandin@unipd.it

**Matthias Dubuis**
**Stefan Diethelm**
**François Maréchal**
Industrial Energy Laboratory (LENI)
Ecole Polytechnique Fédérale de Lausanne (EPFL)
Lausanne, Switzerland 1015
Email: stefan.diethelm@epfl.ch, matthias.dubuis@epfl.ch
francois.marechal@epfl.ch

Biomass integrated gasification fuel cell (BIGFC) systems benefit from the combination of a gasifier that produce syngas from biomass, a distributed and renewable energy source, with high temperature fuel cells which generate electricity from syngas with good efficiency even at partial loads. Intermediate gas cleaning and processing stages are however necessary to avoid reductions in fuel cell performance and reliability that contaminants in the producer gas (mainly heavy hydrocarbons, alkali metals and sulfur species) may cause.

Thermodynamic optimization of different BIGFC systems is here presented. A good review can be found in the literature about the same topic [1]. Different configurations were generated starting from the superstructure shown in Fig. 1 by the virtual activation of possible technological alternatives. The aim was to find the set of design parameters along with the system structure that maximize efficiency (the ratio between the net power production over the biomass chemical energy input flow). Results give indications about the maximum potential for power generation and about how the choice of technological alternatives can influence this potential.

System configurations were optimized following the approach proposed in the literature by different authors [2, 3]. The basic idea is that design parameters of a given set of basic components (base configuration) can be modified regardless to the definition of the heat exchangers network (HEN synthesis problem). Feasibility of heat transfer between the whole set of system cold and hot streams can be subsequently verified according to Pinch Analysis rules.

A brief description of the system superstructure is given. 20 kg/hr of woody biomass (average composition with 50%wt of water) enters an air dryer (AD) in which the humidity is reduced to a desired value. Wood is then gasified either in a fast internally circulated fluidized bed gasifier (FB) with steam injection or with a two-stages Viking gasifier (VK) with air injection. The producer gas [800°-1000° C] exits the gasifier and part of its flow rate is diverted to a combustion for system thermal balance. The other part of the gas is sent to the hot gas cleaning section in which a combination of a cyclone (CYC) and a ceramic filter (CF) allows to remove particles. Gasification is modeled considering Boduard and Methane Pyrolisis reactions and with an adjusted equilibrium approach. TAR generation is modeled considering an average amount of four species (Toluene, Phenol, Pyrene, Naphtalene) and TAR contents in the producer gas are fixed to 5 mg/Nm$^3$ for FB and 1 mg/Nm$^3$ for VK. TAR are removed either in endothermic Steam reforming (SMR) or authermal reformer (ATR). The cleaned syngas [700°-830° C] is then injected in the SOFC . Both anode and cathode recirculations are considered. SOFC thermal management is done by cooling the recycling streams and by removing isothermically the excess

† Address all correspondence to this author.

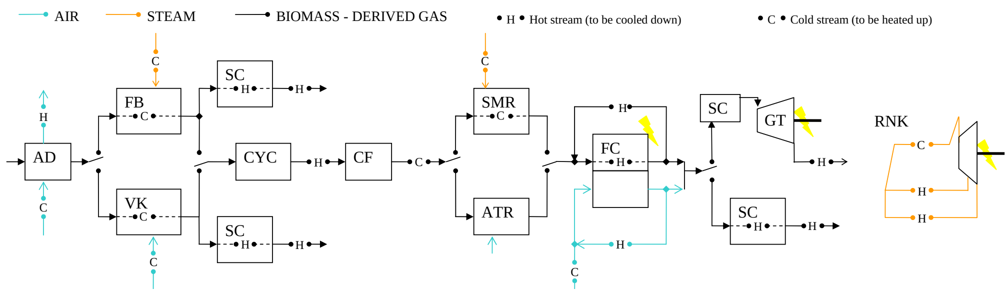


Figure 1. SYSTEM SUPERSTRUCTURE CONSIDERED IN THE ANALYSIS

of heat from the SOFC (this strategies allow to avoid high excess of air). Dependig on the SOFC internal fuel utilization FU [0.5-0.9], a certain amount of unreacted fuel is still present in the depleted anode stream and therefore stoichiometric combustion (SC) and gas turbine (GT) convert this amount in additional heat and power. In the case GT is selected SOFC operates in pressurized conditions (at pressure P [2-8 bar]) in hydrid configuration. A Rankine cycle (RNK) is also considered as a possible additional energy conversion system as an alternative to GT.

A two levels optimization strategy was used to maximize systems thermodynamic efficiency. In the first level a genetic algorithm is used to select optimal values for operating parameters of system components. In the second level a deterministic algorithm is used to evaluate the system mass flow rates (the part of the gas that is used for the power generation, the part diverted to the combustion and the steam mass flow rates of the Rankine cycle when selected) in order to maximize heat and power integration according to Pinch Analysis rules ($\Delta T_{min} = 10°C$).

Resulting cold and hot composite curves give indications about how the thermal streams inside the system should be matched to reach the system maximum efficiency. As an example hot and cold composite curves for the base configuration including the fluidized bed gasifier, steam reforming and the only fuel cell as power generating device (FB-SMR-FC) is presented in Fig. 2.

Efficiency (lower heating value basis) of the optimized configurations goes from 45% to 54% in the case only fuel cell is the power generating component. When adding a Rankine bottoming cycle, efficiency can reach values around 60% to 65%. When passing to the more advanced pressurized hybrid system (fuel cell plus gas turbine), efficiency can even reach values around 73%. The combination of fludized bed gasfier and steam reforming allows to increase hydrogen content in the syngas and more efficienct internal heat recovery configurations are generated compared to the cases in which Viking gasifier and Autothermal reforming are adopted.

To sum up, the approach of separating the definition of the system base configuration (the set of components responsible for chemical and energy conversions of the biomass into electricity)

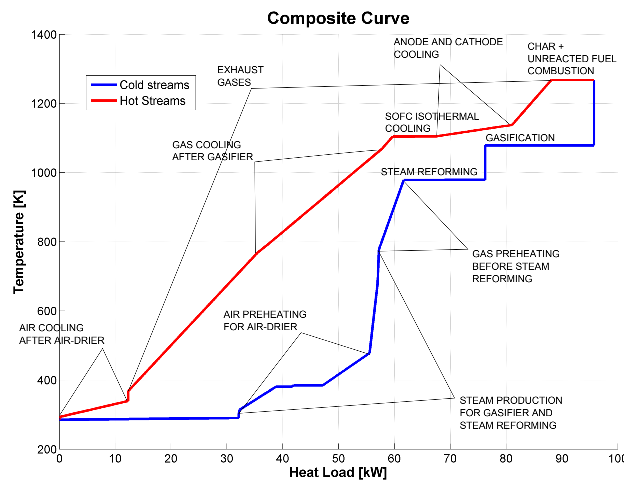


Figure 2. FB-SMR-FC: HOT AND COLD COMPOSITE CURVES

from the definition of the heat-exchangers network responsible for the internal heat recovery appeared to be an effective method for the systematic generation and optimization of different configurations of BIGFC systems. Results will be useful to proceed with an extensive thermoeconomic analysis.

## REFERENCES


[1] Seitarides, T., Athanasiou, C., and Zabaniotou, A., 2008. "Modular biomass gasification-based solid oxide fuel cells (SOFC) for sustainable development". *Renewable and Sustainable Energy Reviews*, ***12***(5), pp. 1251–1276.

[2] Marechal, F., and Kalitventzeff, B., 1997. "Effect modelling and optimization, a new methodology for combined energy and environment synthesis of industrial processes". *Applied thermal engineering*, ***17***(8-10), pp. 981–992.

[3] Lazzaretto, A., and Segato, F., 2002. "A thermodynamic approach to the definition of the HAT cycle plant structure". *Energy Conversion and Management*, ***43***(9-12), pp. 1377–1391.