BIOMASS BASED POWER PLANTS – EVALUATION OF NOVEL REACTORS AND PROCESS DESIGNS

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Summary

The combination of gasification and fuel cells is a promising option for the efficient generation of electrical power from dry biomass. In this contribution, we focus on the model based design of such systems and a system wide evaluation of novel reactor concepts. Results indicate that high temperature gas cleaning units and high temperature PEMFC can overcome the limiting heat integration in low temperature fuel cell systems. Combined power plants applying a low temperature PEMFC and a high temperature SOFC are shown to offer highest efficiencies and attractive system designs.

Keywords

Biomass, Fuel Cells, Plant Design, Renewable Energy.

Introduction

Biomass has a high potential to substitute fossil fuels for energy supply, thereby reducing greenhouse gas emissions and dependency on non-renewable resources. One option to produce electrical energy from biomass with a high efficiency is by gasification, subsequent gas clean-up and finally electrochemical conversion of the cleaned gases in fuel cells. The Max Planck Society together with the Fraunhofer Society initiated a joint project entitled “ProBio” with the aim to develop a concept for a decentralised power plant based on this idea.

This project focusses on two aspects: the development of new reactor units for gas clean-up and combination of classical and novel reactors in a system design. In this contribution, we focus on the evaluation of the new reactor concepts based on a system wide analysis and on the design of efficient systems.

Novel reactor concepts

Four reactors are developed within the ProBio project.

The Moving Bed Reactor (MBR) removes tar and dust from the gas stream and operates at similar temperatures as the gasifier. Because the catalytically active bed particles are degraded in this process, they are continuously removed from the MBR and regenerated. This unit is supposed to replace the scrubber in classical systems.

The Cyclic Water Gas Shift Reactor[1,2] (CWGSR) uses the gasifier product gases to reduce a fixed bed of iron oxide and subsequently applies steam to re-oxidise the iron. During the oxidation phase, a mixture of hydrogen and water is produced that contains no carbon monoxide. This gas can be utilised in PEM fuel cells. Thus, the CWGSR replaces the carbon monoxide removal sequence of shift reactors in a classical system.

The Electrochemical Preferential Oxidation[3] (ECPrOx) unit is a modified PEM fuel cell which can oxidise carbon monoxide. The reactor only works efficiently under autonomously oscillating conditions, where it removes carbon monoxide from the gas stream and produces a certain amount of electrical energy. This reactor could replace the units for deep removal of carbon monoxide such as pressure swing adsorption (PSA) columns.

An interesting alternative for the classical PEM fuel cell is the high temperature (HT)-PEMFC. It tolerates several percent of carbon monoxide in its feed gas and delivers heat above the boiling point of water which is attractive for the heat integration of the system.

Approach

The system design is carried out with the help of a model library. Each reactor unit is described as a spatially lumped system with several input variables such as the entering gas flow, the most important control variables,

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and output variables such as the gas outflows, the electrical power demand or production and the heat flows required or produced by the unit. These unit models are then used to assemble complete systems.
Each system under a given set of control variables is subject to several feasibility checks. Feasibility is given if no carbonisation occurs in any of the units, if the heat integration of the complete system is possible and if all restrictions with respect to acceptable carbon monoxide concentrations are fullfilled. Heat integration is checked via pinch-analysis in which no additional heat may be supplied to the system.

Results

The model library is applied to evaluate the system wide benefit of the application of the novel reactors. For example, the performance of a low temperature system with a scrubber, two shift reactors, a preferential oxidation unit and a PEMFC can be seen in Fig. 1 in dependence of the air number and steam number in the gasifier. It is severely limited by the heat integration constraint (upper green line in Fig. 1). A mixed gasification with air and steam is required in order to fulfill this constraint, and only a relatively low electrical efficiency can be achieved.

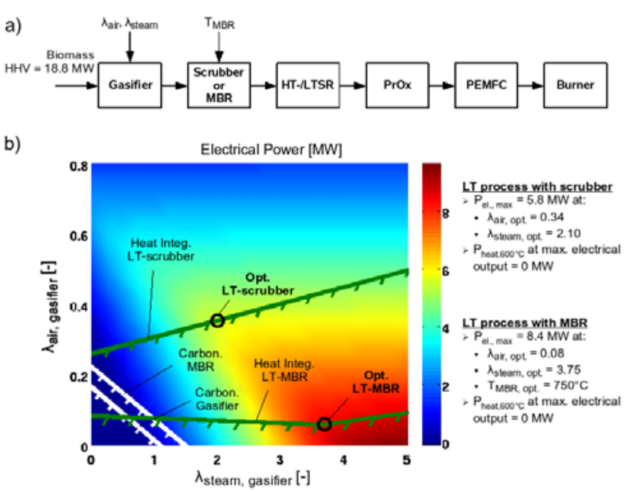

Fig. 1: Electrical power output of low temperature processes with scrubber or moving bed reactor over gasification parameters. Green and white lines indicate the boundaries of feasible regions due to carbonisation or heat integration.

Applying the high temperature MBR instead of the scrubber significantly relaxes this constraint (lower green line in Fig. 1). Thus, operating conditions with attractive efficiencies become feasible. Furthermore, this system requires less heat exchanger area then the system with the scrubber. Similar advantages can be seen when the MBR is applied in a high temperature system with an SOFC.

Other reactors are evaluated in a similar manner. Calculations show that the HT-PEMFC brings another strong advantage with respect to heat integration, so that this constraint is not limiting and the system can be operated at the highest possible efficiency.

Other results show that the CWGSR as a unit for carbon monoxide removal does not yield a significant advantage for the low temperature fuel cell system in terms of efficiency. However, it offers the possibility to design a very efficient and attractive class of fuel cell plants by combining low and high temperature fuel cells in a single system (Fig. 2). In the configuration shown, the CWGSR operates as a gas splitter, which separates a hydrogen-rich portion from the gas stream and feeds it to the PEMFC. The remaining gas is utilised in the SOFC. The SOFC provides the heat for the evaporation of steam for the gasifier. Due to the different types of fuel cells applied, this system provides electrical base load and high-graded heat via the SOFC and electrical peak load via the PEMFC. These three products can be balanced by manipulating the amount of hydrogen that is separated and utilised in the PEMFC.

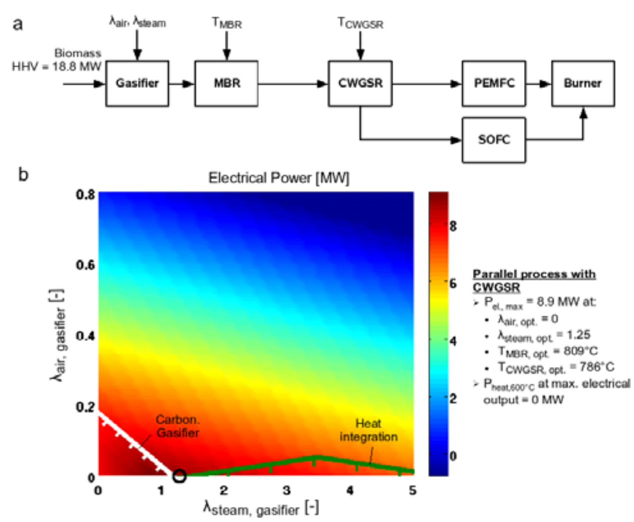

Fig. 2: Parallel plant design with CWGSR as a gas splitter: Electrical power output depending on gasification parameters

In this contribution, we discuss the benefits of the novel reactor concepts and propose attractive system designs.

References

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