Abstract

Co-utilization of biomass and natural gas: a new route for power productin from biomass

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Electricity production from biomass can occur through external combustion or internal combustion. External combustion offers only limited conversion efficiencies (25-30%) while efficient internal combustion requires a problematic, severe and costly gas cleaning.

A new alternative route for power production is proposed in which biomass energy is used to partially reform natural gas in gas turbines. As a result, part of the natural gas fuel supply can be replaced by biomass while keeping the biomass combustion gases separated from the internal gas turbine parts and benefiting from high chemical conversion efficiency.

Part of the natural gas is to be diverted and mixed with superheated steam to be fed to a reformer. Biomass is fired externally to provide the reaction heat for the endothermic reactions to partially reform natural gas into a H_2 and CO rich syngas mixture. Biomass energy is stored chemically in the syngas-natural gas mixture and is then fed to the gas turbine. In this way, biomass energy is fired externally but introduced into the Gas Turbine internally.

The concept was simulated using the process-simulation tool ASPEN+. It was used first to identify the favourable conditions for application of the concept on advanced gas turbine power plants. Sequentially, several types of gas turbine power plants have been simulated to act as a reference. Next, the modifications required to allow co-firing of biomass in the proposed manner were included in the cycle simulations. The simulated cycles were checked for violations of the thermodynamic main laws in order to guarantee their feasibility.

The concept of biomass co-utilization was first applied to a generic Steam Injection Gas Turbine. After verifying its feasibility, it was found that the adapted cycle performed at the same level as the reference STIG cycle.

The concept was then applied to Combined Cycles, the most commercially installed type of natural gas fired power plant. In order to maintain cycle efficiency and feasibility, the simulations demonstrated the need for a condenser and a saturation tower. The saturation tower allows a more gradual evaporation of the water needed for the reforming reactions, ensuring the Composite Curves remain uncrossed. When comparing the reference and the modified cycle, the biomass marginal efficiency is somewhat (<5%) lower than its reference Combined Cycle counterpart. This is mainly due to the nature of (woody) biomass which is burned atmospherically. As such, the part of natural gas that is replaced is not pressurized, nor will it be expanded in the turbine. A similar conclusion was drawn from the (more detailed) simulation of the existing (reference and modified) Drogenbos Combined Cycle 500MWe power plant.

As a future first pilot plant, a small-scale fuel flexible gas turbine would be ideal. As such, the microturbine (MGT) available at the laboratories of the Vrije Universiteit Brussel, was selected and simulated. Measurements of part-load performance and variable inlet air temperature lead to a more sophisticated model, capable of predicting off design performance and behaviour of the microturbine as biomass was introduced in the proposed manner.

Because the partially reformed mixture contains a considerable amount of redundant water, the effect of steam injection on the behaviour of the MGT needed investigation. It was concluded that steam injection had a beneficial effect on the electrical efficiency without posing additional risks to the microturbine.

The steam-injected MGT simulation was then used as a reference for the biomass co-utilizing (wet) MGT cycle. The efficiency of both wet MGT cycles (the ‘micro-STIG’ and the biomass co-utilizing MGT) were nearly equal in accordance with the previously found results for the STIG cycle. In off design, biomass co-utilizing mode, no problems are expected with the compressor or turbine performance. The increased volume flow of the partially reformed mixture, as well as its different chemical composition, should be however investigated experimentally.

As a next step towards applying the proposed concept, the syngas-mixture obtained through partial reforming was combusted in a lab-scale atmospheric, transparent microturbine type combustor. The combustion regime of the mixture was compared to that of natural gas under similar conditions. Special attention was given to possible effects of the change in chemical composition on the combustion regime, namely: flammability limits, flame shape and anchor, flame stability, emissions and wall liner temperatures. The flame shape and position of the pure premixed flame differ significantly when switching from natural gas to the hydrogen-containing mixture. No problems concerning wall liner temperature or combustion stability are expected.

Subsequently a slightly modified, pressurized MGT combustor was isolated and setup to burn (wet and dry) syngas mixtures. The large volume flow of the syngas mixtures required increasing the fuel injector nozzles in order to keep the associated pressure drop within limits. Furthermore, additional fuel feed lines were required to allow a switch from natural gas to syngas. A diaphragm positioned after the combustor allowed to simulate the backpressure of the turbine and take the effects of pressurization into account. In this actual MGT combustor, a small fraction of the fuel is used for a pilot flame. This pilot flame, used continuously during normal operation to stabilize the premixed flame, keeps the flame shape and position comparable to that of the natural gas premix and pilot flame. The separated, pressurized MGT combustor switched fuel feed from pure NG to pure (wet) syngas and was operated safely at full load for the remainder of the test run.

Finally an actual MGT was equipped with the slightly modified combustor for a final test as pilot plant for the biomass co-utilization concept. The experiment lead to similar conclusions as the previous, isolated combustor tests. No problems were encountered concerning combustion regime or material temperatures, the MGT was operated successfully on syngas at 60-65% load.

The existing Drogenbos power plant is being considered for future application of a moderate amount of biomass co-utilization in the proposed manner. As such, it has been simulated in great detail. To avoid the difficulties in measuring small perturbations on large scale plants, a mathematical model based on perturbation analysis is presented, allowing for accurate determination of marginal efficiency and performance for biomass co-firing (energetic) fuel fractions down to 0,1%.

Finally, an overview of the exergetic balance is shown for the co-utilizing Drogenbos Combined Cycle. The analysis allows to identify components affected by the proposed technology and to isolate significant losses or gains in useful energy. From the analysis, it became clear that the reduction in exergy loss obtained in the combustion chamber thanks to a change in the chemical composition of the fuel, is cancelled by the introduction of the biomass burner. As a result, the exergetic efficiency of both the co-utilizing and the reference Combined Cycle are nearly equal, in accordance with the results found for the energetic efficiency.

To properly evaluate a new concept for power production from biomass, special attention must be given to the commercial/economic aspect. No idea or concept can be commercialized if the economic evaluation favours its competitors. An estimation of the capital investment and the operational costs associated with the proposed technology is discussed. The results are compared to scenarios for various ‘green benefits’ based on required marginal efficiency and maximum cost to ensure a certain payback period on the investments.