Test results from a prototype thermoelectrochemical system

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To fast forward biopower commercialization, the U.S. Department of Energy (DOE), National Renewable Energy Laboratory (NREL) and Oak Ridge National Laboratory (ORNL) are actively pursuing the development and demonstration of biomass gasification, advanced gas turbine, combined cycle and combined heat and power technologies and dedicated feedstock supply systems. This effort targets large-scale (> 30 MW_e) units due to considerations of both efficiency and economics; for gas turbine and steam turbine performance improves with size and the total plant cost decreases with an increase in plant size. While the large-scale unit development can enhance biomass utilization, it leaves a void in the rapidly growing world market for modular, small-scale biomass power systems. The traditional direct-firing route, if employed, will not only be inefficient but also will cause pollution and may require frequent maintenance. For example, the power generation efficiency is typically less than 20%, gaseous emissions (CO, HC, NO_x and particulates) are significant and heat exchanger fouling due to ash (silica and potassium) carryover is a major problem. Therefore, MTCI has proposed an advanced concept [1] that integrates a thermochemical reaction subsystem with a fuel cell subsystem. This is termed the ThermoElectroChemical System (TECS) and offers the potential for modularity, economy, high efficiency, minimal emissions, climate change mitigation and “green” power generation.

The thermochemical reaction subsystem includes PulseEnhanced™ steam reformer, gas cleanup train, heat recovery steam generator (HRSG) and air heater. Part of the product gas generated by the steam reformer is used in the pulse heaters and the remainder is sent to the fuel cell subsystem for power generation. The fuel gas generated by the steam reformer undergoes one or more gas polishing and conditioning steps in order to meet the fuel gas cleanliness requirements of the fuel cell. The fuel cell subsystem typically includes fuel processor, fuel cell power section and power conditioner. The fuel processor could simply be a pass-through/delivery device if hydrogen is the fuel or could have sulfur polisher, reformer, shift reactor, particulate filter, and burner if a conventional gaseous fuel (natural gas, propane, butane, etc.) is used. Analyses and computer simulations [1] indicated steam reformer integration with the Solid Oxide Fuel Cell (SOFC) type to be the most efficient in generating power from biomass.

A team comprising MTCI, ThermoChem and SWPC is developing this advanced biopower system under the sponsorship of the U.S. Department of Energy Small Business Innovation Program. A prototype test system has been assembled to experimentally establish the attributes of this technology. The test system comprises two steam reformers, one capable of processing solid biomass and the other slurry-type biomass, a thermal oxidizer, a gas cleanup and polishing subsystem and a SOFC test station. The two steam reformers are each capable of generating sufficient fuel gas to support the operation of a 12 to 20 kW_e fuel cell stack. The SOFC that is used for the prototype development, however, is a module of four cells operating on a slip-stream of the reformate gas produced by either of the steam reformers. SWPC loaned a test station and supplied a test fuel cell article consisting of 4 cells of 50-cm nominal length rated at a total power of about 160 W. The fuel cell is an air electrode supported tubular design. A gas cleanup and polishing train was designed, assembled and integrated. The objective here was to evaluate/screen multiple solvents for acid gas absorption and different sorbents for gas polishing to comply with the SOFC tolerance limits for impurities. Many tests were conducted with solid biomass as well as with spent liquor from the pulp and paper industry to debug the operation of the gas cleanup and polishing train. Several modifications were made. The gas cleanup and polishing train ensured fuel gas quality at the outlet commensurate with the solid oxide fuel cell tolerance limits for impurities.

On February 7, 2001, a historical chapter was written for the future of the Forest Products Industry as well as for distributed power generation from biomass when hydrogen-rich syngas from steam-reformed spent pulping liquor was fed to a fuel cell to produce electrical power. Heralded as a first-ever accomplishment, the test proved the power of the steam reformer -fuel cell integration concept. The black liquor was steam reformed at an operating temperature of 1,120?F (604?C). A slipstream of syngas was conditioned through several steps of gas cleanup, resulting in a syngas rich in hydrogen (>65% by volume) with a higher heating value (HHV) of approximately 280 Btu per dscf (10.4 MJ/m^3 dry). The cleaned syngas was metered to the SOFC. Operating at 1,832?F (1,000?C), the SOFC produced a net 2.6 volts D.C., 62 amps or an equivalent of 161 watts of “green” power.

Tests are scheduled in March/April 2001 with solid biomass i.e. wood waste. Engineering assessment is also planned. These results will be presented at the conference.

References

[1] Chandran, RR and Mansour MN, Thermoelectrochemical System for Power Generation from Biomass, Proceedings of the Fourth Biomass Conference of the Americas, Addendum, Oakland, CA., August 29 – September 2, 1999.