

250 Wet Reformer Fuel Cell System for Bio-Ethanol

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250 W_{el} Reformer Fuel Cell System for Bio-Ethanol

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Researchers at the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg developed a fully automated ethanol reformer fuel cell system in cooperation with several partners from industry. The electric power output of the system is 250 Watt. The system is fueled by denatured bio-ethanol. This fuel is renewable, inexpensive, non-toxic and commercially available to users throughout the world. One of the various applications is the off-grid power supply for medical equipment in emerging and developing countries.

The ethanol reformer fuel cell system can be used outdoors and operates at ambient temperatures ranging from -10 to +40°C. At the push of the start button, the electric power becomes available to the customer. A buffer battery is used during the start-up phase, when hydrogen is not yet flowing to the fuel cell. The technology demonstrator system including the tank has a total volume of 195 l and a weight of 35 kg, respectively. As shown in Figure 1, it consists of four modules (fuel cell, reformer with gas purification, electronics and tank). It has the potential for significant reduction in volume and weight. The main system functions are carried out by:

- a reformer with gas purification. The latter reduces the amount of carbon monoxide in the reformat gas to a level that is suitable for the following PEM fuel cell.
- a commercial low-temperature PEM fuel cell, which was optimized by the Fraunhofer researchers for operation with a reformat gas (product gas of the reformer).
- a tail gas combustor in which the off-gas from the anode is oxidized and provides the heat needed for evaporation and overheating the feed streams (ethanol, water and air).

The reformer system includes an autothermal reformer, high and low temperature shift reactors, a selective methanation reactor, a combined start-up and tail gas combustor, and a commercial PEM fuel cell (as depicted in Figure 2). A minimum amount of process controls and little internal heat integration kept system architecture simple. It has to be noted, that maximizing system efficiency was not a foremost design objective.

Process simulations provided optimal operating parameters, expected hydrogen yield, and system efficiency. The reformer temperature was selected to be 730 °C with minimal methane production and no soot formation in the reactor. The oxygen-to-carbon ratio (O/C) is determined by the temperature of feed streams, reforming temperature and heat losses. It was set to be in the order of 0.9. The steam-to-carbon ratio (S/C) has no significant impact on carbon monoxide concentration in the reformer system product gas, i.e. at the outlet of the selective methanation reactor. Therefore, S/C was selected to be 2.5, sufficiently high to avoid soot formation in the reforming reactor and yet small enough to keep the size of the water evaporator in a sensible range.



Figure 1: Mobile ethanol reformer fuel cell system for 250 W electric power output.

Reforming System Design

Steady State Operation

At first, we operated the reformer fuel cell system in a lab environment and investigated all reactors thoroughly. We optimized start-up and shut down procedures to minimize degradation of the catalysts. Finally, the complete reformer fuel cell system was integrated into four separate modules, and placed in one housing (refer to Fig. 1).

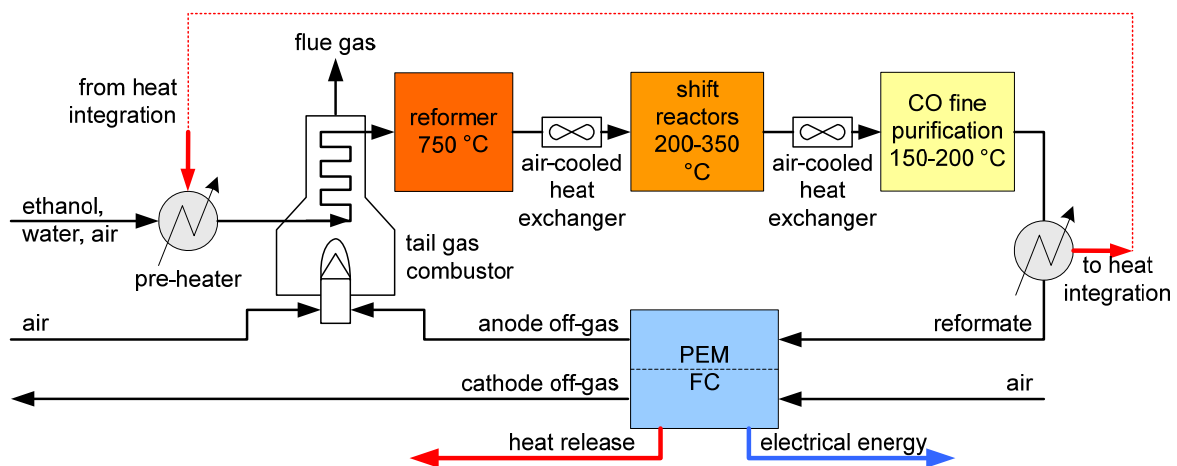


Figure 2: Process flow diagram of the ethanol reformer fuel cell system.

We operated the ATR test rig with constant operating parameters during various test campaigns up to 5 hours, accruing a total of over 150 hours on stream. Figure 3 shows the gas composition measured by on-line gas analysis for a typical test run. The dry gas composition at four locations throughout the reformer system is plotted over run time: at the outlet of the SelMet reactor, of the LTS and HTS and of the ATR itself. At each location the gas was analyzed for about ten minutes in this test run, before switching to the next sampling port upstream.

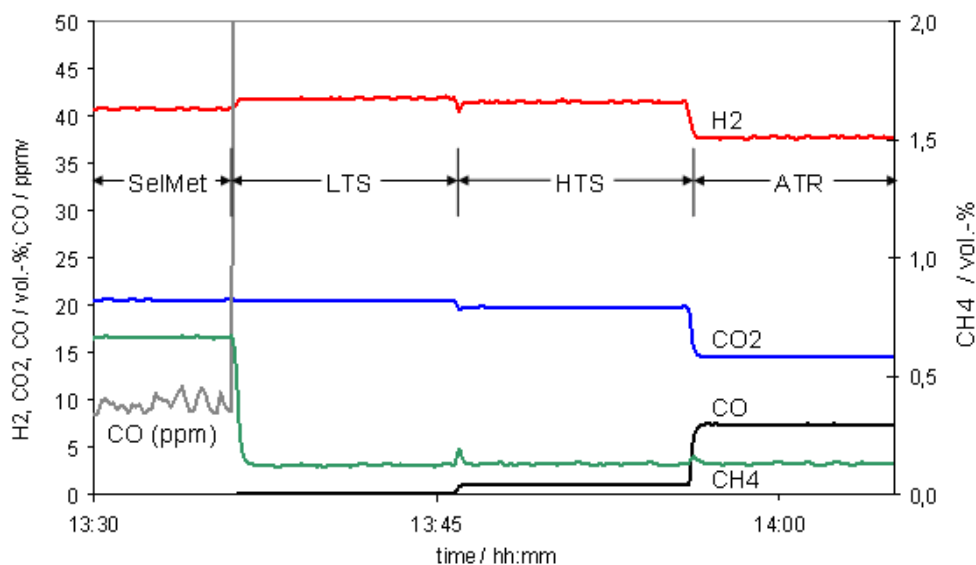


Figure 3: Gas composition (dry basis) measured by on-line gas analysis at various locations in the reformer systems. Operating parameters: S/C = 2.5, gas temperature at ATR inlet = 390 °C, O/C = 0.9.

Starting at the right hand side, the gas at the ATR outlet contains (on a dry basis) approx. 37.6 vol.-% H₂, the catalyst outlet temperature was 745 °C. This gas is cooled down in an air cooled heat exchanger to 420 °C and leaves the HTS with about 400 °C. The gas at the HTS outlet consists of approx. 41.5 vol.-% H₂. This catalyst demonstrates a very good shift activity reducing the CO content down to 1.0 vol.-% (dry). Prior to entering the LTS the gas is cooled down again in an air-cooled heat exchanger, this time the reactor inlet temperature is 290 °C. The LTS product gas leaves the reactor with a temperature of 280 °C. The SelMet catalyst, finally, is operated at a catalyst inlet temperature of 230 °C. The temperature decrease over the reactor length is about 10 K. The data confirm that the CO concentration is in the order of 10 ppmv, well below the specified value of 20 ppmv. The methane content in the gas stays below 0.7 vol.-% (dry basis) providing a selectivity of 65% for the SelMet catalyst in the selected temperature range. For further details see Aicher et al. (2009).

Operation with PEM Fuel Cell

We use a PEM fuel cell from Schunk Kohlenstofftechnik GmbH which delivers a nominal power of 360 W when operated with pure hydrogen and fully humidified gases on both sides. If operated with water saturated reformat on the anode and ambient air on the cathode we reached a power of approximately 300 W as shown in Figure 4. One reason for the reduced power are the trace amounts of CO in the reformat gas, which occupy some of the active centers of the anode catalyst. To minimize this effect we add at times small amounts of air to the reformat gas before the anode with an air bleed pump. This reduces the deactivation of the catalyst by oxidizing the CO. However, it has to be noted that the additional air not only oxidizes the CO but some hydrogen as well. A second reason for the reduced power output

compared to operating the fuel cell with pure hydrogen is the presence of CO_2 . Small amounts of this component are converted in the fuel cell into CO by the shift reaction, that cannot be removed by air bleed. This is not a serious problem because the remaining catalyst sites are sufficient for fuel cell operation.

The observed fluctuations in stack voltage stem from flooding effects on the anode side as the reformat gas is fully humidified. We remove accruing water drops within the anode flow channels by purging the anode r, which means that the anode off-gas is released to the ambience for some milliseconds. The resulting fluctuations in stack voltage are smoothed by the DC/DC converter.

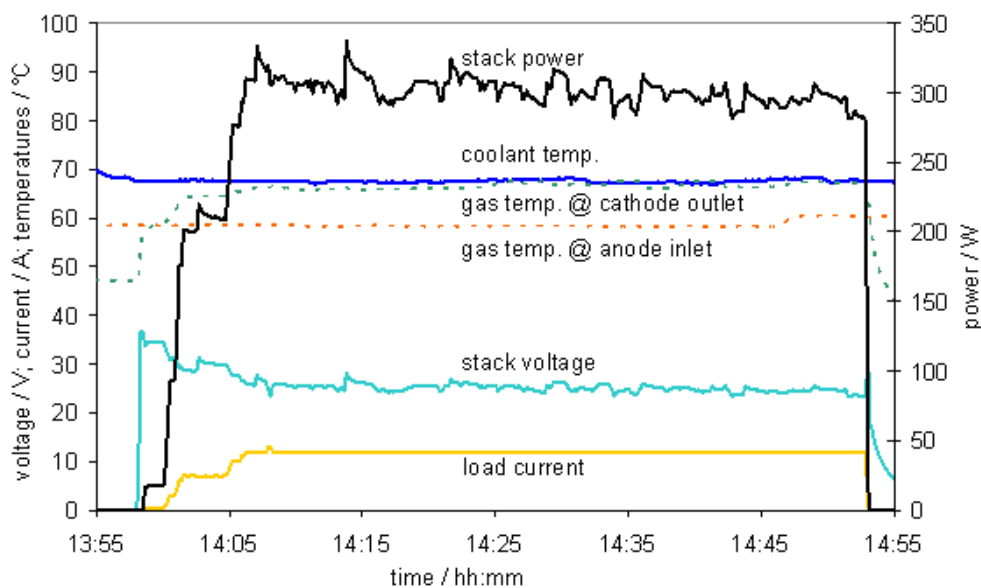


Figure 4: Fuel cell operating data measured during operation with reformat gas using a H_2 stoichiometry of 1.25 and the air stoichiometry on cathode side being 2.5. Operating parameters of the reformer system: $\text{S/C} = 2.5$, gas temperature at ATR inlet = $390\text{ }^\circ\text{C}$, $\text{O/C} = 0.9$.

Reference

- [1] T. Aicher, J. Full, A. Schaadt, "A Portable Fuel Processor for Hydrogen Production from Ethanol in a 250 W_{el} Fuel Cell System", *Int. J. Hydrogen Energy*, available online, DOI information: 10.1016/j.ijhydene.2009.07.064