Control and experimental characterization of a methanol reformer for a 350W high temperature polymer electrolyte membrane fuel cell system

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Steam reforming of methanol for a HTPEM fuel cell stack

The experimental system consists of a membrane fuel pump for pumping the 60% (vol.) methanol/40% (vol.) deionized water mixture. The mixture initially enters an evaporator where heating, evaporation and superheating is carried out, primarily by the hot fuel cell cathode exhaust air during normal operation, and electrical heaters during start-up. The evaporated fuel mixture afterwards enters the methanol reformer, where it is reformed into a hydrogen rich gas containing also CO, CO2, water and unconverted methanol. The heat required for the steam reforming process is transferred by burning the exhaust fuel cell anode gas in an integrated burner inside the methanol reformer. The schematics of the experimental setup can be seen in figure 3.

In order to examine the performance of the system a series of primary input variables are defined, and a set of different measurement conditions are fixed and imposed on the running system. The input variables for the system in the presented measurement data are: methanol/water pump flow, reformer operating temperature, evaporator heating air flow and temperature, and burner hydrogen flow. The resulting temperatures, flows, and gas concentrations of the system can be seen in figure 4, 5 and 7.

The set of measurements conducted starts out with an initial heating of the system and fuel flow of 300 mL/hr, where the reformer temperature is settled at 260°C and 270°C in order to evaluate the gas output at this operating point. After this, the fuel flow is shortly set to 400 mL/hr in order to test the effect this operation has on the unconverted methanol in the outlet reformate gas. Afterwards the temperature is changed to 280°C, where the gas composition is evaluated at 200, 300 and 400 mL/hr. During the last of the examined fuel flows, the system was unable to remain at the desired temperature due to higher heat requirements than delivered by the 4.5 L/min hydrogen, which was throughout used during the tests. The presented tests some of the system states were kept constant in order to minimize their interference with the captured results. The tests shown were primarily used to validate the system control strategy of the reformer temperature. The reformer temperature control is carried out as a cascade PID control, as shown in figure 6.

The reformer temperature is controlled by two control loops in a cascade control structure, the inner loop controlling the burner temperature, which is a fast dynamic characteristic than the reformer temperature, which in the outer loop is controlled by slowly adjusting the burner temperature.

The reformer temperature is affected by many disturbances, the burner temperature, the fuel flow, the methanol conversion process and multiple heat losses in the system. In order to control this temperature, the cascade control strategy was chosen in order to test a strategy with capabilities of improving the speed and precision at which the reformer temperature could be controlled. As seen in figure 5, the burner set point, and the actual burner temperature act fast once step is imposed on the reformer set point temperature. The air flow to the burner is adjusted to meet the burner set point temperature. Meanwhile the slower acting reformer temperature controller adjusts the burner set point to finally enable control of the reformer temperature.

Conclusions

The experimental setup developed is able to conduct detailed measurements of the performance of the methanol reformer system. This can provide vital information of the critical operating parameters of such a system, including the transient behavior of the different state variable that all play an important role in predicting the usable hydrogen output by the system, and just as important, the content of different pollutants, including CO and residual unconverted methanol. Such results, and models able to predict this behavior are important when designing control strategies. The gas concentrations measured during the tests can be seen in figure 7, below.

Future Work

The further work with the presented experimental setup include a detailed analysis of system operating range, identifying the upper and lower bounds of operation. This is important in order to structure the start-up and shut-down scheduling of the system. Such an analysis would e.g. be able to identify the minimum fuel pump flow, which depends on the available heat transferred from the fuel cell exhaust air to the evaporator. Further more an analysis of transient system capabilities will be conducted to develop simulation models that can be used in designing optimal system control structures with respect to e.g. load change speed, system efficiency, low and CO content. Being able to make online predictions of the important system states is expected to increase the lifetime of such system, if combined with advanced control strategies.

The integration of fuel cell stack and the reformer will play an important role in the next phase of the system testing, and is also required for evaluating the validity and relevance of the developed controllers. It is expected that different control approaches should be matched to the particular application and its requirements.