Direct Fuel Cell/Turbine Power Plant

Technical Progress Report
For
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ABSTRACT

In this reporting period, a milestone was achieved by commencement of testing and operation of the sub-scale hybrid direct fuel cell/turbine (DFC/T®) power plant. The operation was initiated subsequent to the completion of the construction of the balance-of-plant (BOP) and implementation of process and control tests of the BOP for the subscale DFC/T hybrid system. The construction efforts consisted of finishing the power plant insulation and completion of the plant instrumentation including the wiring and tubing required for process measurement and control. The preparation work also included the development of procedures for facility shake down, conditioning and load testing of the fuel cell, integration of the microturbine, and fuel cell/gas turbine load tests. At conclusion of the construction, the process and control (PAC) tests of BOP, including the microturbine, were initiated.

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1.0 EXPERIMENTAL

The tests consisted of simulation of fuel cell conditioning and operation, integration of the microturbine with fuel cell, power plant trip and ramp scenarios, and control loop checks. Improvements in system control, instrumentation, and operational procedures resulting from the PAC tests were implemented. In collaboration with Capstone, the microturbine PLC software was modified and means for the communication of the microturbine controller and the power plant control system were established. The installation of stack was completed including process and instrument connections to the balance-of-the-plant. The fuel cell stack was connected to a dc-to-ac inverter, independent of the microturbine high-speed generator. The inverter and the alternator were connected to the grid in parallel. This configuration allowed independent tests of the inverter and the generator during the unplanned grid failures (forced outages) and planned grid-disconnect tests.

2.0 RESULTS AND DISCUSSIONS

Figure 1 shows a picture of the sub-MW hybrid power plant including a 250 kW fuel cell stack. The operational test of the 250 kW fuel cell stack integrated with the Capstone Model 330 microturbine was initiated in July 2001. Subsequent to the stack conditioning, the DFC/T power plant was operated under a myriad of operating conditions including ramps of microturbine speed (rpm) and fuel cell load ramps both concurrently and independently (varying one while holding the other constant).

Figure 1. SubMW DFC/T® Proof-of-Concept Power Plant

The microturbine was operated at its maximum rotational speed of 96,000 rpm. No major issues were observed during the operation of the sub-megawatt DFC/T system, and most of the tests planned were completed. The control strategies and thermal management of the system were checked out. The microturbine was integrated, deintegrated, and operated independent of stack operations in accordance with the design.

A finned-tube humidifier was also designed and installed in the power plant for testing. The finned – tube humidifier (HEX 360) was projected to increase the power plant efficiency by utilizing the waste heat from the power plant exhaust. Figure 2 shows the modified process flow diagram subsequent to the installation of the finned – tube humidifier.

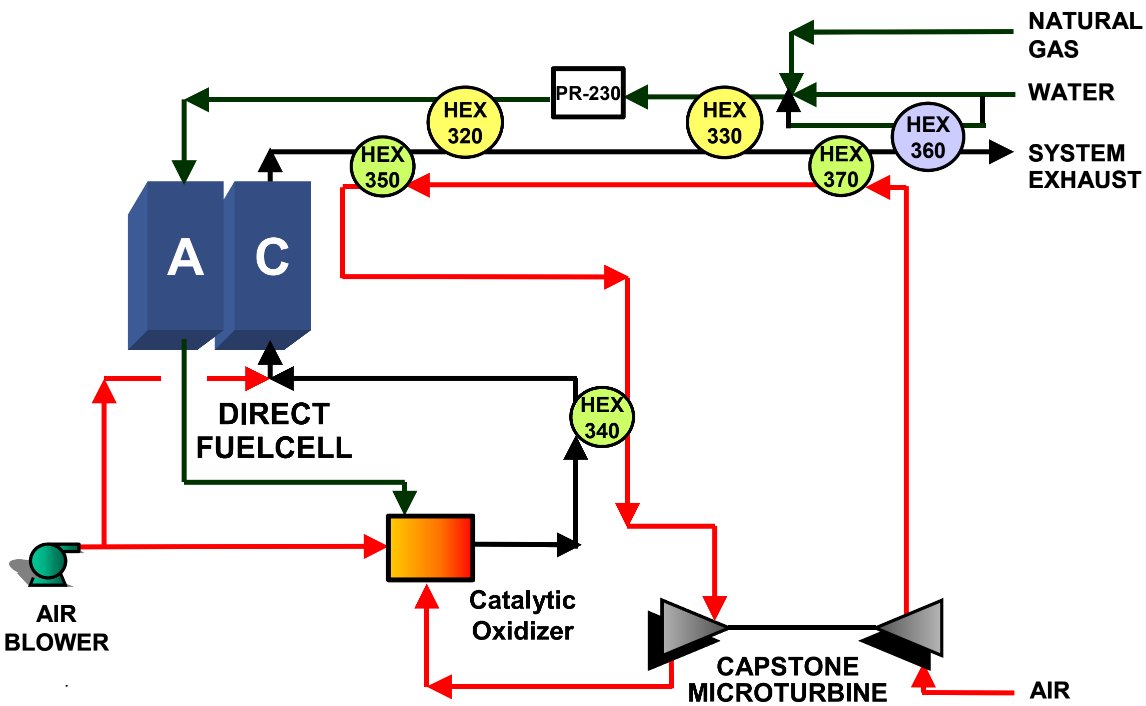

Figure 2. Simplified subMW DFC/T Process Flow Diagram

The low-temperature recuperator (HEX-370) was modified by insertion of twisted tape turbulators with the anticipated benefit of increased heat transfer coefficient resulting in more effective recuperation of heat from the balance-of-plant to the microturbine. Figure 3 shows a picture of the HEX-370 with the twisted pair wires inserted in the heat exchanger tubes.

Figure 3. Twisted Tape Wire Inserts Installed in HEX 370

The high-temperature recuperator (HEX 340) was replaced by a modified unit with larger heat transfer area and overall heat transfer coefficient. The high temperature anode oxidation catalyst was also replaced by an alternative catalyst for evaluation. Figure 4 shows a picture of the replacement monolith catalyst.

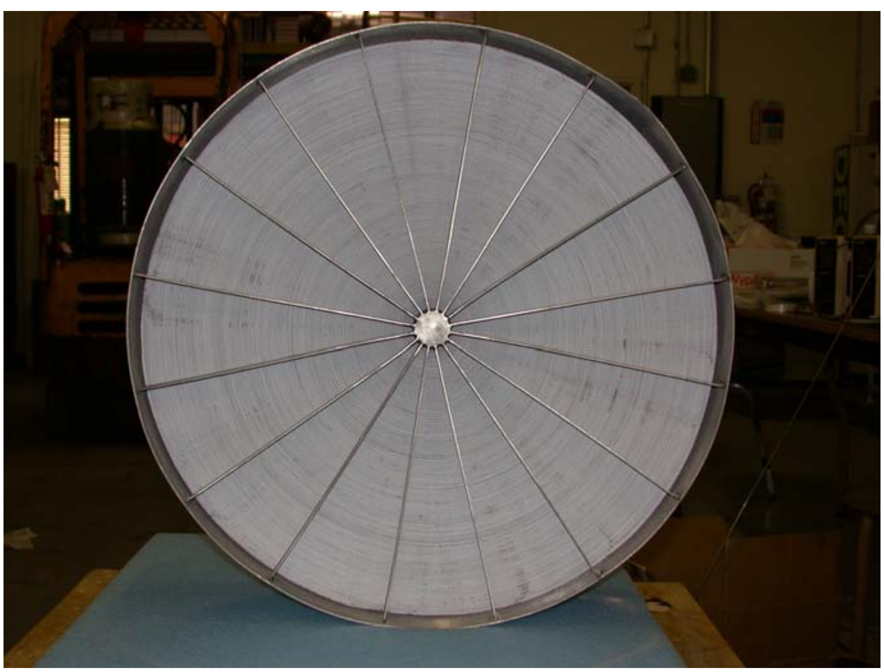

Figure 4. Monolith Catalyst for Anode Gas Oxidation

The power plant modification/upgrade work was completed, and heat-up of the fuel cell stack was commenced for continuation of the hybrid power plant tests. To date, the R&D efforts have resulted in significant progress in validating the DFC/T cycle concept. Procedures were developed and implemented for start-up, power ramp (up and down), shutdown, and plant trip. The procedures were refined during the demonstration tests as the lessons learned. Computer simulation of the power plant including mass and energy balances was utilized as analytical tool during the testing period. The operational aspects of the hybrid system related to the integration of microturbine and heat exchangers with the fuel cell and process flow and thermal balances were investigated. Figure 5 shows typical operational test data for the DFC/T hybrid power plant mapped around the original system concept. The hybrid power system test results verified that efficiency gains are realizable by integration of gas turbine with the fuel cell.

One of the objectives of the demonstration was to develop the control logic for the operation of DFC/T. During the testing period, refinements in power plant control strategies were implemented. The control system modifications included thermal management of the stack and microturbine. The power plant emergency shutdown procedures resulting from grid failures and forced outages were tested successfully. Additionally, the demonstration tests provided valuable insight with respect to the potential for load following, increased reliability, and enhanced operability.

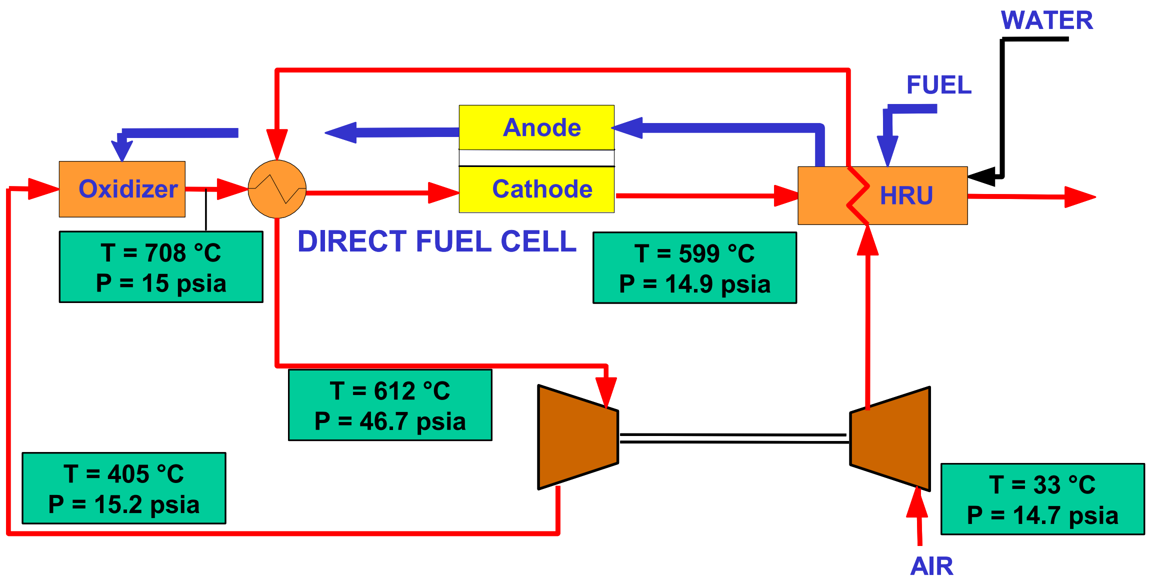

Figure 5. Integrated DFC/T Hybrid Power Plant Test Results

The balance-of-plant equipment and the microturbine performances were also monitored and evaluated during the course of the tests. The test results were utilized in quantification of the power plant heat losses and performance of the heat exchangers in recuperation of heat from the balance-of-plant to the microturbine. The finned tube humidifier (HEX 360) results showed a benefit in recovering waste heat from the system exhaust by providing up to 80 lbs/hr steam to the fuel cell anode. The heat transfer coefficients for recuperators were analyzed against the vendor supplied information. The power plant test facility had significant amount of the heat loss from the pipes and equipment. The shell-and-tube heat exchangers exhibited heat transfer coefficients in the order of 1 – 5 Btu/hr °F ft^2 for the gas-to-gas heat recuperation. Figure 6 shows the results of the analysis performed on HEX 370, comparing the overall heat transfer coefficient before and after twisted tape inserts.

The microturbine airflow was not adequate for operation at high power densities. Supplementary air was required during the high power operation. The ambient air supplemented to the anode exhaust oxidizer resulted in lower than desired temperature at the gas turbine inlet. Tests were also conducted by augmentation of the low-Btu anode exhaust gas with natural gas in order to raise the turbine inlet temperature to 700 °C and to demonstrate a higher gas turbine power output.

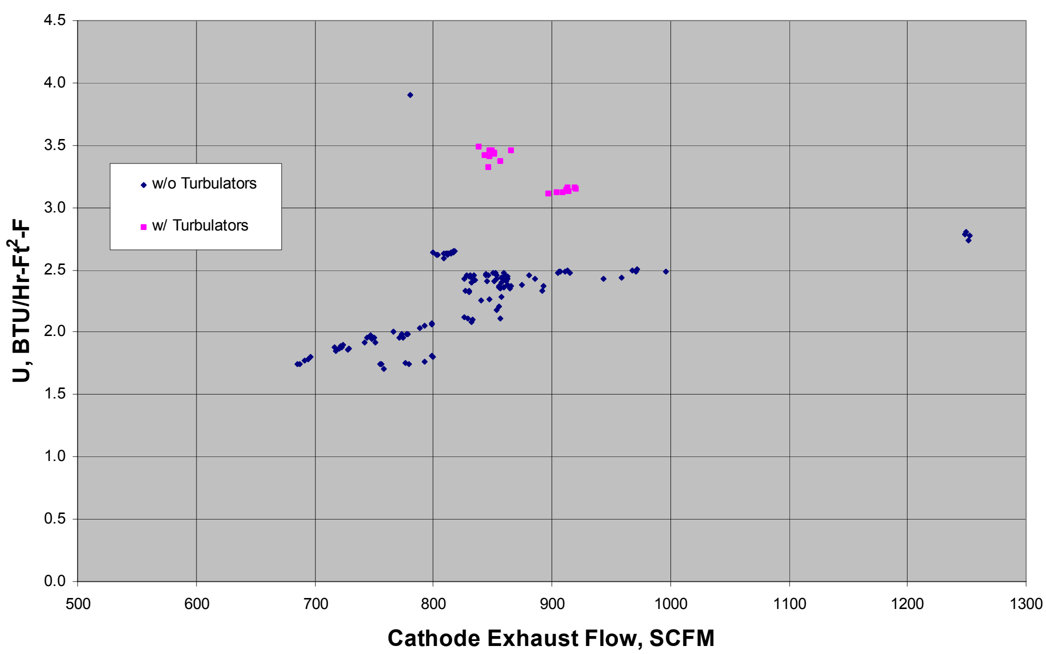

Figure 6. HEX 370 Overall Heat Transfer Coefficient

The dual mode operation confirmed that greater efficiencies could be obtained by integration of microturbine with the fuel cell. The efficiency gains in the DFC/T system are related to additional power produced from the gas turbine and reduction of auxiliary power consumption by the air blower. The test results have indicated that smaller sub-MW and MW-Class DFC/T hybrids are attractive for the distributed generation applications.

3.0 CONCLUSION

One key objective of the DFC/T demonstration was to obtain design information and operational data that will be utilized in the design of 40-MW high efficiency Vision 21 power plants. The results of the subMW system tests have indicated that effective recuperation of heat to the gas turbine and minimization of the heat loss from the balance-of-plant equipment are important factors in the design of DFC/T power plants. The combination of high heat losses and less than adequate heat transfer coefficient from the recuperators may limit the power from gas turbine in the hybrid power system. This effect is more enhanced at higher ambient temperature, due to sensitivity of the gas turbine electric output to the ambient temperature.

Another key objective of the hybrid power plant demonstrator was the development of control strategies including the fuel cell cathode temperature and the turbine inlet temperature. The power plant shutdown and emergency trip control logics were also developed. The control strategies developed and refined during the operation of the sub-MW power plant will be utilized in the development of piping and instrumentation diagrams for the larger 40 MW scale Vision 21 power plants.

The power plant operation at high power densities required an airflow rate beyond the capability of Capstone model 330 microturbine. The tests at high power output were conducted by supplementing the microturbine air with additional air from a blower at the exhaust of the microturbine. A Capstone's model C60 microturbine was ordered for installation in place of the Model 330 microturbine. The model C60 is capable of providing the airflow for full load operation of the DFC stack. The implementation of higher flow also is expected to entail in additional gain in efficiency and increase in the power plant net output.

4.0 REFERENCES

None