

Direct Fuel Cell Operation on Dual Fuel

J. Daly¹, G. Steinfeld¹, D. Moyer², F. Holcomb³

¹FuelCell Energy, Inc., Danbury, CT

²Concurrent Technologies Corporation, Johnstown, PA

³U.S. Army CERL, Champaign, IL

INTRODUCTION

The ability to operate highly efficient, pollution-free, distributed-generation power plants interchangeably on either natural gas or HD-5 grade propane is of interest to the U.S. Army and the U.S. Department of Homeland Security as a way to maintain secure power for critical power operations. Continuous long-term operation on HD-5 propane also provides a valuable proposition to islands, remote sites, national parks, data centers, military bases, hotels, and hospitals. Although natural gas distribution through utility pipelines is convenient, it is vulnerable to natural disaster, threats of terrorism, and simple repair outages. Propane, however, is routinely transported and stored as a liquid at ambient temperatures and offers a convenient and secure option for fuel cell operations. An adequate quantity of propane can be stored on site to sustain operations for several days in a variety of weather climates.

In response to the interest for a fuel flexible power plant, Concurrent Technologies Corporation (*CTC*), under contract to the U.S. Army Engineer Research and Development Center's Construction Engineering Research Laboratory (ERDC-CERL), is working with FuelCell Energy (FCE) to test an internally reforming 250 kW carbonate fuel cell. Previous to the demonstration at *CTC*, FCE operated a 250 kilowatt (kW) carbonate direct fuel cell for 1500 hours, which generated 300,000 kilowatt-hours (kWh) net AC electricity using HD-5 propane as fuel. The challenges addressed by FCE during initial operation on HD-5 propane included: (1) avoiding carbon deposition during prereforming of propane to a methane rich gas, (2) metering and controlling propane flow to account for variations in fuel composition, (3) removing sulfur from the propane, and (4) increasing the steam required for operation on propane. Peripheral issues that required additional investigation included identifying the number and volume of propane tanks and a vaporization system to deliver the required rate and quantity of fuel.



Figure 1. 250 KW Fuel Cell Power Plant Operating On Propane At *CTC*

DEMONSTRATION

Based on the success of the first full-scale demonstration at FCE, a second longer-term evaluation was conducted at *CTC* in the Department of Defense (DoD) Fuel Cell Test and Evaluation Center (*FCTec*) located in Johnstown, Pennsylvania. Figure 1 shows the 250 kW DFC300A power plant operating on propane in the *FCTec* facility.

ERDC-CERL undertook this project to address the technical challenges identified during the initial investigation and mature the system design for military and commercial application. For this demonstration, the

standard FuelCell Energy 250 kW Direct Fuel Cell (DFC) product, namely the DFC300A, was modified to accept HD-5 propane as fuel. The ability to run on natural gas fuel was also maintained, thereby creating a dual fuel power plant that allows instantaneous on-load transfer to propane as a back up fuel upon sensing loss of natural gas pressure.

The primary goal of this second demonstration was to further demonstrate success over the four technical challenges described above through long-term operation on HD-5 propane at various loads. A secondary goal was to demonstrate rapid fuel switching from natural gas to propane. This fuel flexibility provides secure power in the event of sudden and unexpected disruption to the natural gas pipeline supply. HD-5 propane, as opposed to other grades of propane, was selected as the back-up fuel of choice because of its availability, even in remote areas, and because of its ease of processing in the fuel cell power plant.

PROPANE OPERATIONS

Prior to system operation, CTC worked with FCE to develop a master test plan to detail the events and sequencing planned for the demonstration of the DFC-300A system. The four activities in the master test plan consisted of: (1) basic operation, (2) fuel swapping, (3) reliability testing, and (4) operational optimization.

Operation of the DFC300A fuel cell power plant on HD-5 propane commenced in January 2006 and is scheduled to complete in August 2006. Figure 2 below summarizes the operations during the demonstration period. As of July 31, 2006, the power plant operated for 3,354 hours on propane fuel and generated 369 megawatt hours (MWh) of electricity. In addition, operation on natural gas accumulated 1,034 hours and generated 111 MWh of electricity.

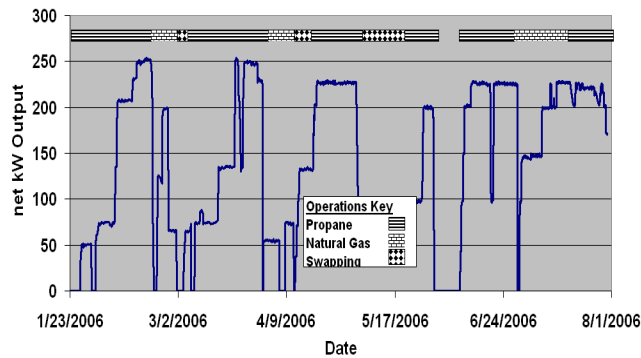


Figure 2. DFC300A Fuel Cell Power Plant - Propane and Natural Gas Operations

CTC created a performance test plan for the DFC300A operating on propane based on ASME Performance Test Code-50 [1]. Table 1 lists the test results and indicates that the electrical efficiency on HD-5 propane, maintained over a wide range of power output, is high at 46 – 47% lower heating value (LHV). This efficiency is comparable to typical DFC300A operation on natural gas.

Table 1. Electrical Efficiency of the DFC300A Fuel Cell Power Plant Operating on Propane

Power Level	Plant Efficiency (% LHV)
½ Load (133 kW)	47.3 %
¾ Load (199 kW)	46.7 %
Full Load (244 kW)	47.1 %

Propane consumption to produce a continuous 250 kW output is approximately 520 gallons/day of HD-5. To achieve the required vapor pressure of 15 psig, the temperature of the liquid in the tank must be warmer than minus 10°F. To support this vaporization rate on a continuing basis with a single 2,000-gallon propane tank, it was found that the ambient temperature needed to be about 45

°F or above. Vaporization is achieved at lower ambient temperatures using two 2,000-gallon tanks in parallel. Also, maintaining a higher fill level in the tank allows for higher draw rates at a given ambient temperature, due to increased wetted surface area available for heat transfer from ambient air to propane liquid. Vaporizers and flow stabilizers are commonly used in propane field applications where low temperatures are anticipated to impede the natural vaporization process. However, the propane operations at FCE and CTC indicated that both of these vaporization methods caused increased levels of high molecular weight hydrocarbons and sulfur compounds in the vapor phase, which can compromise the sulfur removal system. Therefore, for high, continuous draw rates and cold ambient temperatures, an external tank heater is anticipated to provide the required flow rate without carryover of the increased high molecular weight hydrocarbons and sulfur compounds.

FUEL SWAPPING

To switch rapidly from natural gas to propane and back again required improving the fuel flow control and providing adequate steam during the transition. The plant control logic was therefore modified and tested to accommodate the rapid response required for fuel swapping.

The successful transfer from natural gas to propane occurs without any forewarning as the natural gas supply is restricted and the supply pressure falls below a pre-set trigger point. As the fuel transitions from natural gas to propane, the major change that must take place is an increase in steam flow rate. This is to protect the preconverter, which needs more steam with propane because of its higher propensity for carbon formation. If the required steam is not present, the control system will reduce the fuel flow rate set point. As a cascading effect, if the fuel flow rate is not sufficient, the fuel cell power output will be limited. This cascading effect was experienced with initial fuel swaps, which resulted in power output reductions of up to 50%, from 200 kW to 100 kW, for a few seconds and full recovery in approximately 30 seconds. Subsequently, with experience in the fuel swapping, improvements were made by increasing the rate of steam addition, and decreasing the fuel flow rate gradually so that the new set point could be achieved without a drop in power output. Figure 3 shows fuel and steam parameters as the fuel is swapped from natural gas to propane with no loss in load.

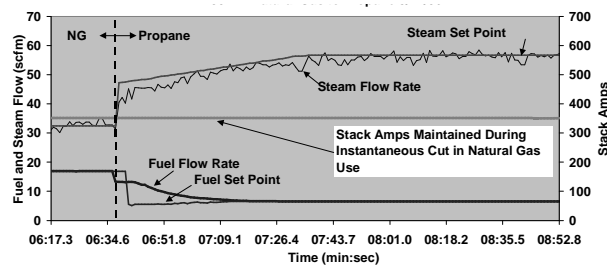


Figure 3. On-The-Fly Fuel Swapping from Natural Gas to Propane With No Drop in Power Output On Load

Switching back from propane to natural gas was simpler because excess steam is present, so there are no limitations to the natural gas flow rate set point. Furthermore, this is an operator-selected action, which is done deliberately and with forewarning, presumably when the utilities are otherwise secure and the power plant is grid connected. Since the natural gas flow rate is about 2.5 times greater for equal power output, there can be some drop in power until the flow rate reaches the new set point. However, due to inventory in the fuel train the power output can be allowed to remain high for a few seconds as the fuel increases to achieve set point, therein eliminating any drop in power output.

RELIABILITY AND OPTIMIZATION

The HD-5 can contain up to 5% propylene and a significant concentration of sulfur, up to 125 parts per million (ppm). While not all this sulfur comes off in the vapor, sulfur in the propane vapor must be removed prior to introduction to the preconverter catalyst. Further testing is being conducted to gather data on various adsorbents, reliability at high propylene concentrations, and to optimize the steam/carbon ratio. At the time of this printing, the DFC300A is operating at the maximum concentration of 5% propylene to verify stable and long term operation without the formation of carbon in the preconverter.

CONCLUSIONS AND RECOMMENDATIONS

The DFC power plant was demonstrated to operate on HD-5 propane successfully for over 3,350 hours, at high electrical efficiency ranging from 46.7 – 47.3% LHV over a large range of power outputs from 133 to 244 kW. The power plant continued to generate base load electricity on HD-5 propane upon the loss of its natural gas primary fuel. This instantaneous fuel switch was successfully demonstrated more than 40 times during operations exceeding 4,000 hours.

Testing validated the DFC power plant's capability for continuous long-term, high-load, and high-efficiency operation on propane, as well as instantaneous fuel switching from natural gas to propane in the event of loss of natural gas supply without loss of power. The unit can also switch back to natural gas from propane, instantaneously and on-load, once natural gas service is restored.

During grid-connect operations, short-term drops in power output are of little to no consequence to the power plant or the customer receiving fuel cell power. However, island operations require that the fuel cell consistently create the electrical energy to maintain the island voltage. Since the transition from natural gas to propane has been demonstrated without any loss of fuel cell power output in grid-connect mode, the transition could occur in island mode as well, although this aspect was not tested during this demonstration. This is important for secure power because of the vulnerability of the grid: if the back-up fuel is needed one should assume that the electric grid has already been disrupted and the plant is operating in island mode. While several DFC300A power plants routinely demonstrate successful transitions from grid-connect to island operation, additional testing should be conducted to verify reliable transitions from grid-connect to island operation with subsequent fuel swap from natural gas to backup propane.

Propane, a readily available fuel that can easily be stored on-site, is used as a primary fuel in isolated or sensitive locations such as islands, remote sites, national parks, data centers, military bases, hotels, and hospitals, and, therefore, is an ideal back-up fuel for DFC power plants. The notion of dual fuel operation is part of the rapid evolution of fuel cells as a replacement for conventional electric power where high efficiency, increased reliability, reduced harmful emissions, and lower noise levels are key requirements. This technology will continue to evolve and serve the military and commercial markets demanding secure and reliable power.

REFERENCES

1. Fuel Cell Power Systems, Performance Test Codes (ASME PTC 50-2002), The American Society of Mechanical Engineers, Three Park Avenue, New York, NY, November 29, 2002.