

Carbonate Direct Fuel Cell Operation on Dual Fuel

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ABSTRACT

The ability to operate highly-efficient, pollution-free, distributed-generation power plants 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 secure power source for critical power operations. The ability to operate continuously on HD-5 propane also provides a valuable proposition to islands, remote sites, national parks, data centers, military bases, hotels, and hospitals. 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), cost, and ease of processing in the fuel cell power plant. 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 kW carbonate direct fuel cell for 1500 hours, which generated 300,000 kilowatt-hours (kWh) net AC electricity using HD-5 propane as fuel. Among the challenges addressed, lessons learned by FCE during initial operation on HD-5 propane included: 1) avoiding carbon deposition during pre-reforming of propane into 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.

DEMONSTRATION

Based on the success of this first full-scale demonstration, a second longer-term evaluation was conducted at CTC with operations initiated in January 2006 at 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.

This project was funded by the U.S. Army ERDC-CERL to mature the system design for military and commercial application. For this demonstration the standard FCE 250 kW Direct Fuel Cell (DFC)



Figure 1. 250 kW fuel cell power plant operating on propane at CTC.

product, namely the DFC300A, was modified to accept HD-5 propane as fuel. Modifications included working closely with FCE's engineering staff to construct and install the parallel fuel train within the confines of the power plants' fuel preparation compartment. CTC also provided the technical support to design and construct the propane storage and supply, fuel flow piping and instrumentation, and the data acquisition for process monitoring. Figure 2 shows a schematic of the propane fuel flow piping as installed. The ability to run on natural gas fuel was maintained, creating a dual fuel power plant, installed in such a manner as to allow instantaneous on-load transfer to propane as a back up fuel upon sensing loss of natural gas pressure.

The flow stabilizers were installed to ensure adequate fuel flow in cold temperatures. Vaporizers and flow stabilizers are used in propane field applications where low temperatures are anticipated to impede the natural vaporization process. Operation at FCE suggested that vaporizers (which are essentially direct or electrically heated boilers) would be detrimental to DFC300A operation they encourage high molecular weight hydrocarbon and sulfur carry over from the liquid to vapor phases. As an alternative, CTC employed flow stabilizers in an effort to increase the propane flow in cold environments without incurring carryover of unwanted constituents. Unlike vaporizers, flow stabilizers heat a portion

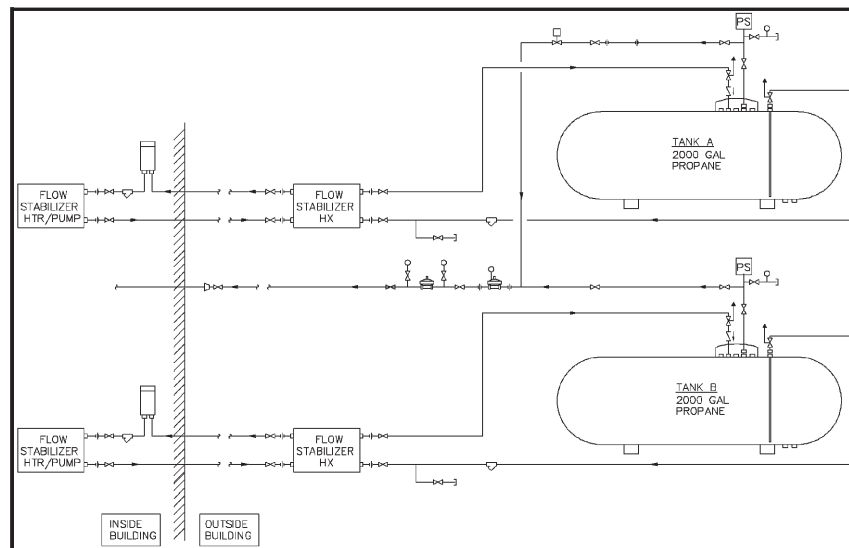


Figure 2. Propane fuel supply and fuel flow piping schematic.

of the liquid propane by exchanging heat with a heated glycol loop in a heat exchanger and returning it into the propane supply tank.

The primary goal of this demonstration was to further demonstrate success over the four technical challenges described above through long-term operation at various loads. A second goal was to demonstrate rapid fuel switching from natural gas to propane, to provide secure power in the event of sudden and unexpected disruption to the natural gas pipeline supply. CTC and FCE worked together leveraging FCE's capability in the existing power plant design, logic and control as well as CTC's capabilities in engineering design, installation, gas sampling and analysis for low level sulfur, process gas streams, and hydrocarbons, and data acquisition.

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 DFC300A system. The four activities entailed in the master test plan consist of basic operation, fuel swapping, reliability testing, and operational optimization.

Operation of the DFC300A fuel cell power plant on HD-5 propane commenced in January 2006 and is scheduled to end in August 2006. Activities conducted under basic operation reaffirmed that the DFC300A can be operated continuously on HD-5 propane. Figure 3 summarizes the power output in the basic operation portion of the project up to the end of March 2006. As of the end of June 2006, the power plant accumulated over 3060 hours of propane operation, generating over 425 MW hours (MWh) of electricity. In addition, operations on natural gas accumulated 550 hours and generated 45 MWh.

CTC created a performance test plan for the DFC300A operating on propane based on ASME Performance Test Code-50 [1]. The test boundary encompasses the DFC300A only. The assumptions associated with this test boundary are: the propane storage at any proposed site would be sufficient to support full load operation for the duration between propane tank fills regardless of temperature, and natural gas is available at a pressure of 15 psi or higher from an existing local utility supplier (i.e., compressor/electrical load to raise natural gas pressure is not required). Table 1 indicates that the efficiency on HD-5 propane is

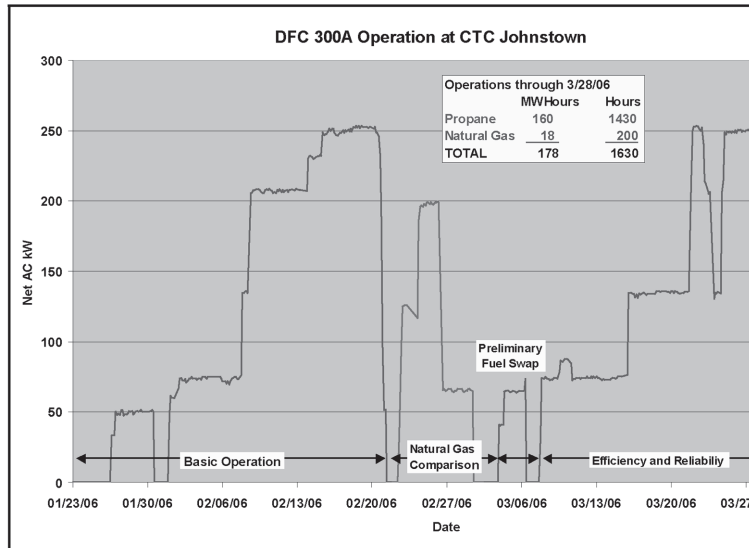


Figure 3. DFC300A fuel cell power plant—propane and natural gas operations.

high at 46 to 47% lower heating value (LHV) and is maintained over a wide range of power output. This efficiency is comparable to typical efficiency on natural gas.

It was determined during testing that use of the flow stabilizer method to increase propane vaporization flow rate caused increased levels of sulfur and high molecular weight compounds in the vapor phase. It was inconclusive if this was caused by constant circulation of liquid propane, as a result of the effect of heating the liquid propane, or both. Without the flow stabilizers, vaporization occurs at milder conditions. It was observed under natural vaporization conditions that less sulfur was produced in the gaseous phase and high molecular weight hydrocarbon compounds were virtually non-existent in the propane vapor.

Table 1. 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 %

FUEL SWAPPING

To switch rapidly from natural gas to propane and back again required improving the fuel flow control both in identification of fuel composition changes and in providing adequate steam during the transition. A novel approach developed by FCE was implemented to continually monitor the quantity of fuel being introduced to the stack, as affected by both the change in fuel and change in steam flow rate. This approach was key in evaluating the success of the instantaneous fuel swap, and it led to rapid development of fuel swapping at high loads with little or no drop in load. The approach was also necessary for propane operations because the gas composition changes significantly as the tank is depleted or refilled. This approach is also used to trim the fuel flow set point to maintain constant fuel value despite the changing composition.

The successful transfer from natural gas to propane should occur without any forewarning as the natural gas supply is choked off and the 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. And as a cascading effect, if the fuel flow rate is not sufficient, the fuel cell power output will be limited. This cascading effect was initially experienced resulting 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 fuel swapping, improvements were made by increasing the rate of steam addition, and decreasing the rate of fuel so that the new set point could be achieved without a drop in kW output. Figure 4 shows fuel and steam parameters as the fuel is swapped from NG to propane with no loss in load.

Switching back from propane to natural gas is much 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. Because 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, as a result of the inventory in the fuel train, the

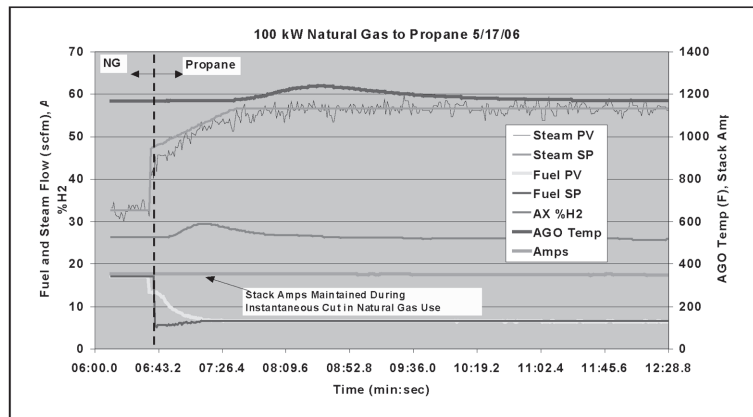


Figure 4. On-the-fly fuel swapping from natural gas to propane with no drop in power output on load.

power output can be allowed to stay high for the few seconds that are required for the fuel to achieve set point, therein eliminating any drop in power output.

RELIABILITY AND OPTIMIZATION

HD-5, by name and by specification, may contain up to 5% propylene. However, the HD-5 as received contained less than 1% propylene. Propylene in the HD-5 is expected to have greater potential for carbon formation in the preconverter than propane. To address this issue, the power plant was operated for several weeks on HD-5 with added propylene to bring the concentration to approximately 5%. This demonstration showed the ability to operate on HD-5 with the maximum propylene content allowed by the HD-5 specification.

The HD-5 propane can also contain a significant concentration of sulfur, up to 125 ppm. While not all of this sulfur comes off in the vapor, sulfur in the propane vapor must be removed prior to introduction to the preconverter catalyst. FCE assisted CTC in identifying ambient temperature sulfur adsorbents to adequately remove sulfur.

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. In addition, process parameters will be modified to operate the DFC300A under varying conditions to observe and optimize the steam/carbon ratio.

CONCLUSIONS AND RECOMMENDATIONS

The 250 kW DFC power plant was demonstrated to operate on HD-5 propane successfully for over 3000 hours, at high electrical efficiency of 46.7 to 47.1% LHV over a large range of power outputs. The power plant continued to generate base load electricity on a secondary fuel supply (propane) when the loss of its primary fuel source (natural gas) was triggered during testing. This rapid fuel switch was successfully demonstrated more than 40 times during operations exceeding 3000 hours.

Testing validated the DFC power plant's capability for continuous long-term high-load and high electrical efficiency operation on propane. In addition, instantaneous fuel switching from natural gas to propane was demonstrated 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.

In grid-connect operations, short-term drops in power output are of little to no consequence to the power plant operations 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 at all times. Because the transition from natural gas to propane has been demonstrated without any loss of fuel cell power output, the transition could occur in island as well as grid-connect mode. 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. Additional testing should be conducted to verify reliable transitions from grid-dependent to island operation.

FUTURE WORK

Upon completion of testing, the DFC300A will have demonstrated long term reliable operation on HD-5 propane as well as instantaneous

fuel swapping between natural gas and propane while on-load. The dual fuel capability provides the U.S. Army and the U.S. Department of Homeland Security with a secure power alternative for critical power operations. This capability also provides a valuable proposition to islands, remote sites, national parks, data centers, military bases, hotels, and hospitals.

As such, CTC and FCE are collectively researching military bases where this technology can be applied and further characterized in an applied setting. Commercial opportunities also exist. Natural disasters, like Hurricane Katrina or the Asian Tsunami, have paralyzed relief efforts because of non-existing or intermittent power. Mobilizing a fuel cell in conjunction with a transportable fuel could assist disaster response personnel and critical operation centers to serve the affected community needs with on-site power generation. In parallel, economic analyses of islands without a natural gas infrastructure, high electricity costs, or unstable power distribution are being conducted. The potential to supply power, in part, to these locations using fuel cell power are becoming more viable.

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

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ABOUT THE AUTHORS

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the independent, unbiased testing and validation of fuel cell and fuel processor systems for both military and commercial applications. The FCTec's primary goal is to significantly accelerate the development and commercialization of fuel cell systems through comprehensive research, development, test and evaluation, integration, and optimization services.

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