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A Summary of the LPP Combustion System Development

by

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In developing the LPP Combustion System, Combustion Science & Engineering (CSE) and LPP Combustion, LLC used the procedures employed by gas turbine Original Equipment Manufacturers (OEMs) such as GE, Siemens, and Solar Turbines. This approach generally involves testing new combustor hardware first at bench-top scale. The bench scale tests usually begin at atmospheric pressure conditions and progress to high pressure conditions if the atmospheric tests are successful. The next step in development typically involves testing full commercial scale hardware at atmospheric pressure conditions. If these full scale tests are successful, the final testing stage prior to deployment to an operating gas turbine is testing the commercial hardware at full operating pressure and temperature conditions on a combustor test stand. These test stands usually test a sector of the entire gas turbine combustor annulus. During testing, important performance parameters such as emissions and flame stability are usually measured.

The LPP Combustion system was first tested on a 200W laboratory Bunsen burner. The liquid hydrocarbon fuel was introduced to the Bunsen burner as a mixture of vaporized hydrocarbon in nitrogen (LPP Gas). This testing showed that the LPP system could, on operation of fuel vapors mixed with nitrogen (LPP Gas), provide a stable blue flame similar in appearance and emissions (NOx, CO, particulates) to the same burner operated on natural gas. No changes to the burner hardware were made to accommodate LPP Gas operation.

The next testing of the LPP Combustion system took place in a bench-top swirl-stabilized, lean, premixed burner. This burner had been previously used to provide bench-top data on lean, premixed natural gas flames for several projects carried out on behalf of gas turbine OEMs. For this testing, heptane, kerosene, or #2 fuel oil was vaporized into a nitrogen gas stream at an approximately 5:1 molar ratio to create an LPP Gas with combustion properties similar to natural gas. The LPP Gas was then introduced into the burner through the same flow system normally used for natural gas operation. Emissions were measured and lean blow-off (LBO) was determined. Again, the results showed that the LPP Gas flame was as stable as a natural gas flame with similarly low emissions from lean, premixed operation. No flashback or autoignition of the LPP Gas prior to arrival at the flame front was observed.

In a parallel effort, a flow reactor a study was used to measure the ignition delay time of LPP Gas as a function of nitrogen dilution ratio. This study was conducted at atmospheric pressure to provide baseline data for modeling the autoignition delay time of LPP Gas at gas turbine operating conditions (typically 10-15 atm with an air pre-heat of 600F-800F). This testing and analysis showed that LPP Gas (heptane, kerosene, and #2 fuel oil were all used as

LPP Gases) has an ignition delay time of greater than 50ms at typical gas turbine operating conditions while lean, premixed combustion systems have a typical residence time, between the mixing region and the flame front, of 10ms or less. Thus, this analysis showed that LPP Gas would not cause flashback or autoignition in a commercial gas turbine combustor at full pressure and temperature operating conditions.

Subsequent testing of the LPP Combustion system took place in a bench-top, high-pressure, swirl-stabilized burner. This burner had also been previously used for testing of lean, premixed natural gas combustion on behalf of gas turbine OEMs. The burner, though much smaller in throughput than a commercial gas turbine burner, had a similar geometry to commercial gas turbine burners. As with the previous tests, the LPP Gas derived from n-heptane, kerosene, or #2 fuel oil was introduced through the natural gas flow system with no modifications to the burner hardware. Emissions were measured and LBO was determined. Results of the testing showed particulate-free blue flame with emissions and stability similar to those observed during natural gas operation.

The first test of the LPP Combustion system on commercial gas turbine combustor hardware was achieved by installing a Solar Turbines SoLoNOx^{tm} burner on a test stand at Combustion Science & Engineering, Inc. This test stand was equipped with an air inlet heater to allow for preheating the combustor air to typical combustor inlet temperatures (600F-800F). The combustion test stand was also designed with a quartz combustion liner so that the flame zone could be readily observed. For these tests, the combustor was started on natural gas and then transitioned to operation on LPP Gas (from N-heptane, kerosene, or #2 fuel oil) by introducing LPP Gas to the fuel inlet system as the natural gas was turned off. A smooth transition from natural gas to LPP Gas operation was observed. The swirl-stabilized flame maintained its shape and light blue color throughout the transition. Once steady-state operation on LPP Gas was achieved, emissions were measured (NOx, CO) and LBO was determined. The light blue flame color on LPP Gas provided a visual indication that no combustion generated particulates were present in the flame. The NOx and CO emissions were as low as those observed for natural gas at the same equivalence ratio. Similarly, LBO performance was as good as or better with LPP Gas than that achieved with natural gas. For these tests, no modifications to the burner hardware were made and the LPP Gas was introduced through the same fuel flow system as the natural gas. Subsequent testing in this burner of petroleum naphtha, JP-8, S-8, ethanol, and several different biodiesels all showed similar emissions and LBO results to those achieved from natural gas.

Final stage testing of the LPP Combustion system involved developing a prototype skid that could operate a 1/12th sector of a Taurus 60/70 gas turbine combustion system at full operating conditions. This prototype skid was shipped to Solar Turbines' test facility in San Diego and set up to operate a commercial SoLoNOx^{tm} burner on a test stand. The combustor was baselined on natural gas and the tested on LPP Gas derived from kerosene and #2 fuel oil. The combustor was started on natural gas and then transitioned to operation on LPP Gas without interruption of operation. The LPP Gas was introduced to the burner through the normal natural gas fuel system with no modifications to the combustor hardware. For all tests, emissions, combustion dynamics, and LBO were measured. Tested were conducted at a variety of part load and full load conditions for both the Taurus 60 and the Taurus 70 (the main difference between these two machines is that the Taurus 60 operates at approximately 12 atm at base load while the Taurus 70 operates at approximately 16 atm at base load). At max output, the combustor was rated at approximately 2 MW thermal. As with all previous tests, operation on LPP Gas showed similar emissions (NOx and CO) and performance to operation on natural gas. In addition, a camera imaging the flame zone of the combustor showed the same blue flame with LPP Gas as with natural gas, indicating that no combustion generated particulates were present. One significant difference observed in the testing at Solar was that the combustor could be operated significantly leaner on LPP Gas before LBO than was possible on natural gas.

Currently, an LPP Combustion system is operating on a 30kWe Capstone 30 microturbine at the LPP Combustion facility in Columbia, Maryland. This turbine is design to operate in a lean, premixed combustion mode using natural gas. Testing on liquid fuels has demonstrated measured emissions are as low as or lower than those obtain on natural gas operation. The thermal output of the combustor for this turbine is approximately 125 kW. This turbine is providing electric power for the LPP Combustion facility and provides power to the local electric grid through an interconnect with BGE (the local utility).

In summary, the LPP Combustion system has been tested on both atmospheric and high pressure burners ranging in output from 200W to 2MW. These tests demonstrate that the technology scales over four orders of magnitude of burner output. In addition, the technology has been demonstrated for both atmospheric burners such as those used in commercial and industrial combustion systems and in burners at pressures up to 16 atmospheres such as those used in gas turbine combustors.