SUBTASK 3.16 – LOW-BTU OIL FIELD GAS APPLICATION TO MICROTURBINES

Final Report

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ABSTRACT

Low-energy gas at oil production sites presents an environmental challenge to the sites' owners. Typically, the gas is managed in flares. Microturbines are an effective alternative to flaring and provide on-site electricity. Microturbines release 10 times fewer NO_x emissions than flaring, on a methane fuel basis. [1] The limited acceptable fuel range of microturbines has prevented their application to low-Btu gases. The challenge of this project was to modify a microturbine to operate on gases lower than 350 Btu/scf (the manufacturer's lower limit). The Energy & Environmental Research Center successfully operated a Capstone C30 microturbine firing gases between 100–300 Btu/scf. The microturbine operated at full power firing gases as low as 200 Btu/scf. A power derating was experienced firing gases below 200 Btu/scf. As fuel energy content decreased, NO_x emissions decreased, CO emissions increased, and unburned hydrocarbons remained less than 0.2 ppm. The turbine was self-started on gases as low as 200 Btu/scf. These results are promising for oil production facilities managing low-Btu gases. The modified microturbine provides an emission solution while returning valuable electricity to the oilfield.

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[1] Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, Chapter 2.4, November 1998; Product Data Sheet, C30 Natural Gas Microturbine Performance Specifications, Capstone Turbine Corporation.

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EXECUTIVE SUMMARY

Carbon emissions and clean air concerns will continue to drive more stringent environmental legislation. As oil companies seek traditional solutions for lowering emissions from associated gas, energy production from microturbines is emerging as a potential economic solution. This project explored the potential application of microturbines to low-Btu gas.

Many oil production sites contain and flare millions of cubic feet of associated gas daily. The barrier to microturbine applications in many oil field applications is the manufacturer's lower energy limit of 350 Btu/scf. The objective of this project was to modify a Capstone C30 microturbine to operate on gases lower than 350 Btu/scf. Breaking the lower energy barrier unlocks many opportunities previously considered infeasible.

A C30 Capstone microturbine was modified and tested at the Energy & Environmental Research Center. The microturbine was operated firing gases between 100–300 Btu/scf. The microturbine operated at full power firing gases as low as 200 Btu/scf. A power derating was experienced firing gases below 200 Btu/scf. As fuel energy content decreased, NO_x emissions decreased, CO emissions increased, and unburned hydrocarbons remained below 0.2 ppm. A catalytic converter can reduce CO for sites where CO emissions are a concern. The turbine achieved self-ignition on 200 Btu/scf gas. On-site start-up fuel (example: a natural gas line or storage tank) would provide an energy rich ignition source before switching to low-Btu gas.

These results are very promising for oil producers. Microturbines produced power from gases below the lower energy barrier. Low-energy flare gas can be used to create electricity while reducing emissions.

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INTRODUCTION

This study determined modifications that allow microturbines to operate on low-Btu gas. Many oil production sites contain abundant amounts of low-Btu associated gas. This gas is often burned in a flare. Typically, flares release 10 times the amount of NO_x that microturbines do, based on a methane fuel (1, 2). A baseline comparison is shown in Figure 1. Microturbines produce on-site electrical power; however, a 350 Btu/scf lower energy specification has limited their application to low-Btu gases.

OBJECTIVE

The objective of this project was to modify a commercially available microturbine to operate on low-Btu gas.

EXPERIMENTAL

The test apparatus included a C30 microturbine, a fuel supply system, and an external combustion can. The test procedure consisted of four tests: baseline tests, external combustor tests, performance tests, and ignition tests. A picture and a graphic of the test microturbine are shown in Figure 2. Figure 3 shows a flame exiting the external test combustor.

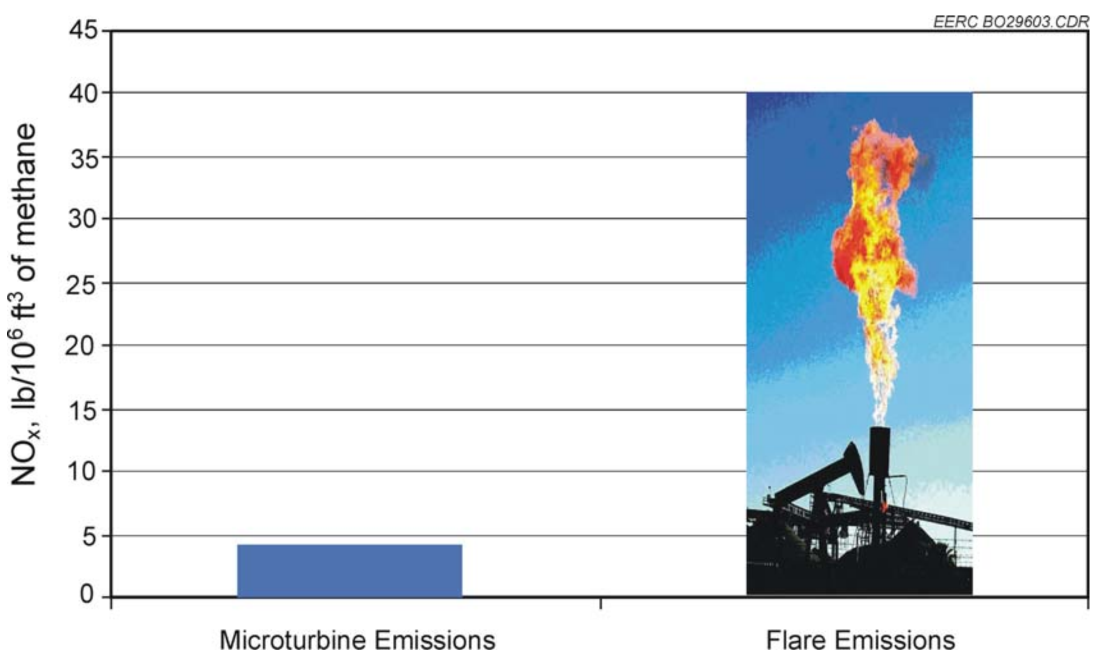

Figure 1. Baseline microturbine NO_x emissions compared to flare NO_x emissions (3, 4).

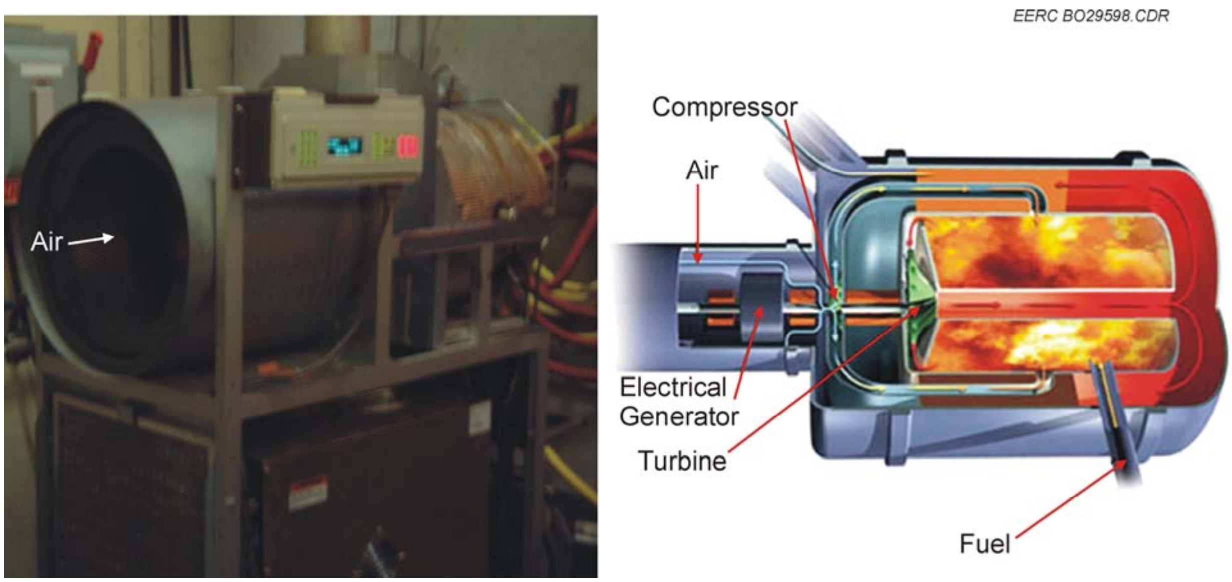

Figure 2. C30 microturbine utilized for low-Btu testing (3).

Figure 3. Flame exiting the external test combustor.

Baseline Tests

Baseline tests utilized the C30 microturbine and the fuel supply system. The fuel supply system blended natural gas and nitrogen upstream of the microturbine. A rotameter measured flow and a digital pressure gauge measured pressure in each line. Natural gas and nitrogen flow rates allowed energy density to be calculated, as shown in Appendix A. The inlet gas mixture was diluted with nitrogen until the microturbine failed to operate. Fourier Transform Infrared Spectroscopy (FTIR) measurements were compared to flow calculated heating values. FTIR measured the absorbance of light in the inlet gas stream and related the absorbance to that of known compounds. The known energy density of the known compounds was used to determine energy density.

External Combustor Tests

External combustor tests were conducted in an external combustion can. Air and gas flow measurements were recorded and the fuel injector flame location was observed. External tests gathered necessary information for microturbine modifications.

Performance Tests

Performance tests utilized modified microturbine parts in a C30 microturbine. Nitrogen diluted the inlet gas mixture until the microturbine failed to operate. A Landcom III portable gas analyzer measured emissions as fuel energy content decreased. Two modifications were tested.

Ignition Tests

Ignition tests utilized the C30 microturbine and a premixed gas mixture of nitrogen and natural gas. Nitrogen and natural gas were combined in a tank before each test. Start-up attempts on low-Btu gas were conducted with various gas mixtures.

RESULTS

Baseline Test Results

The unmodified microturbine failed to operate at 300 Btu/scf. FTIR-calculated gas energy values agreed closely to flow-rate calculated values, as shown in Figure 4. Other FTIR test results are shown in Appendix B.

External Combustor Test Results

External tests provided stoichiometry and flame speed information. Conditions inside the fuel injector were too rich for combustion. Figure 5 shows operating conditions inside the injector compared to upper and lower flammability limits. Inside the injector, fuel velocity was greater than the flame speed of methane.

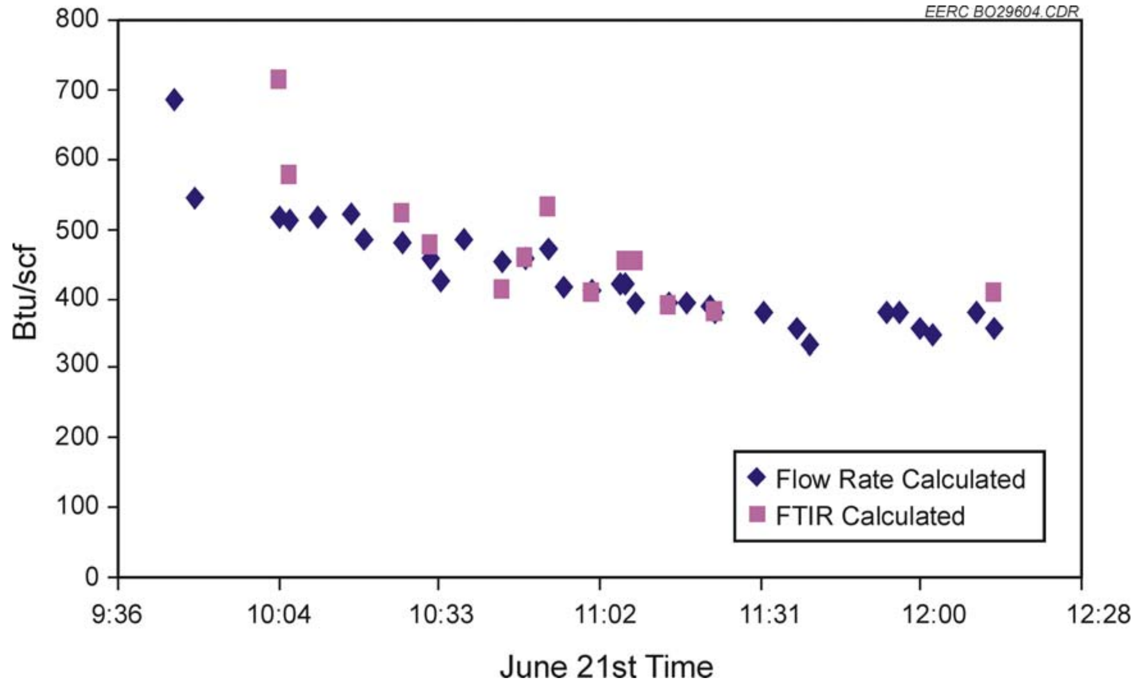

Figure 4. FTIR values compared to flow rate calculated values.

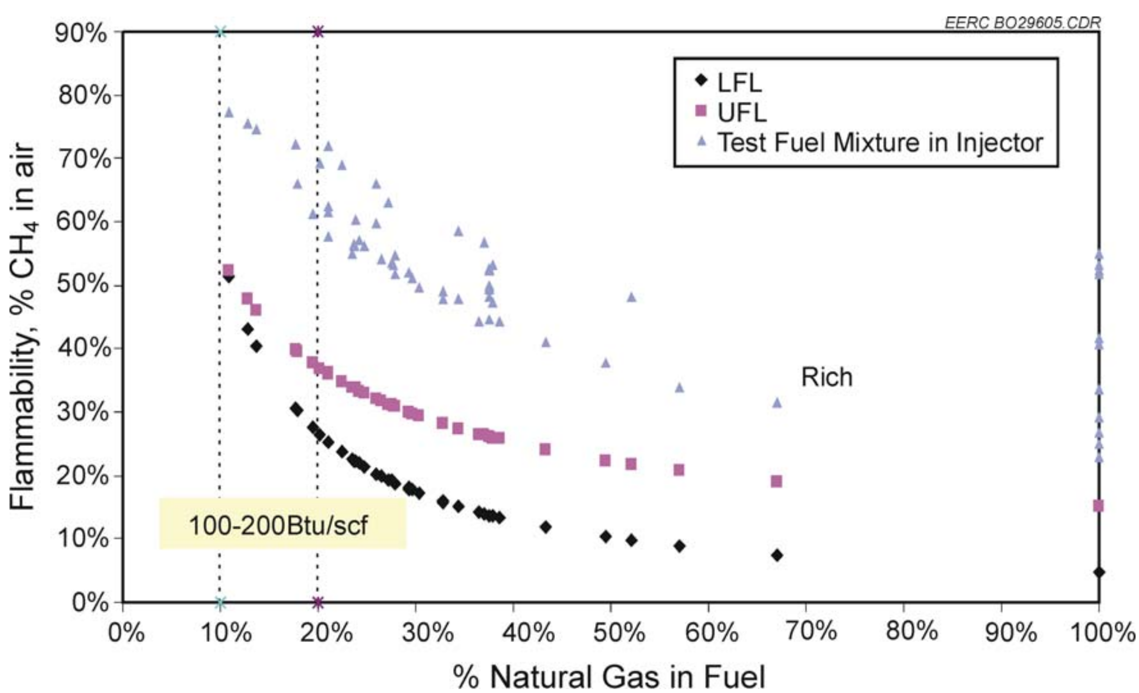

Figure 5. Fuel mixture inside the injector compared to upper and lower flammability limits.

Conditions at the injector exit were suitable for combustion. Figure 6 compares conditions at the injector exit to upper and lower flammability limits. Velocities inside the injector and at the injector exit are shown in Figure 7.

Performance Test Results

Modifications allowed the microturbine to operate on low-Btu gas. Figure 8 compares baseline operations to operations with Modification 1 and Modifications 1 and 2.

The unmodified microturbine was limited to a heating value of 300 Btu/scf and could not fire gases diluted further. Modifications enabled the turbine to operate below 300 Btu/scf. A power derating was experienced firing gases below 200 Btu/scf, and further modification was required to achieve combustion in the 100–150 Btu/scf range.

The microturbine produced 26 kW from 175 Btu/scf fuel when Modification 1 was installed. During testing, the microturbine recovered from a temporary fuel energy decrease to 139 Btu/scf.

The microturbine produced 20 kW of power from 150 Btu/scf gas for 37 minutes when Modifications 1 and 2 were installed. The microturbine recovered from a temporary fuel decrease to 101 Btu/scf. When gas energy content was permanently decreased to 133 Btu/scf, the microturbine shut down.

NO_x emissions decreased with increased nitrogen dilution. Unburned hydrocarbons (C_xH_y) remained below 0.2 ppm. Carbon monoxide emissions increased with increased nitrogen dilution. Emissions are summarized in Figures 9–11.

Ignition Test Results

The microturbine was able to self-ignite on gases down to 200 Btu/scf. Below 200 Btu/scf, the microturbine did not self-ignite.

DISCUSSION

Tests supported the hypothesis that microturbines can be modified to operate on low-Btu gases. Emission changes were not unmanageable. CO emissions increased with decreasing fuel energy content. Catalytic converters are known to reduce CO emissions. Unburned hydrocarbons remained below 0.2 ppm (0.0005 lb/hr). A small U.S. 4-cylinder 1997 passenger car equipped with a 3-way catalyst and traveling 60 mph typically produces 0.033 lb/hr of hydrocarbons (2, 6, 7). These numbers suggest that microturbines emit 66 times fewer unburned hydrocarbons than a typical automobile.

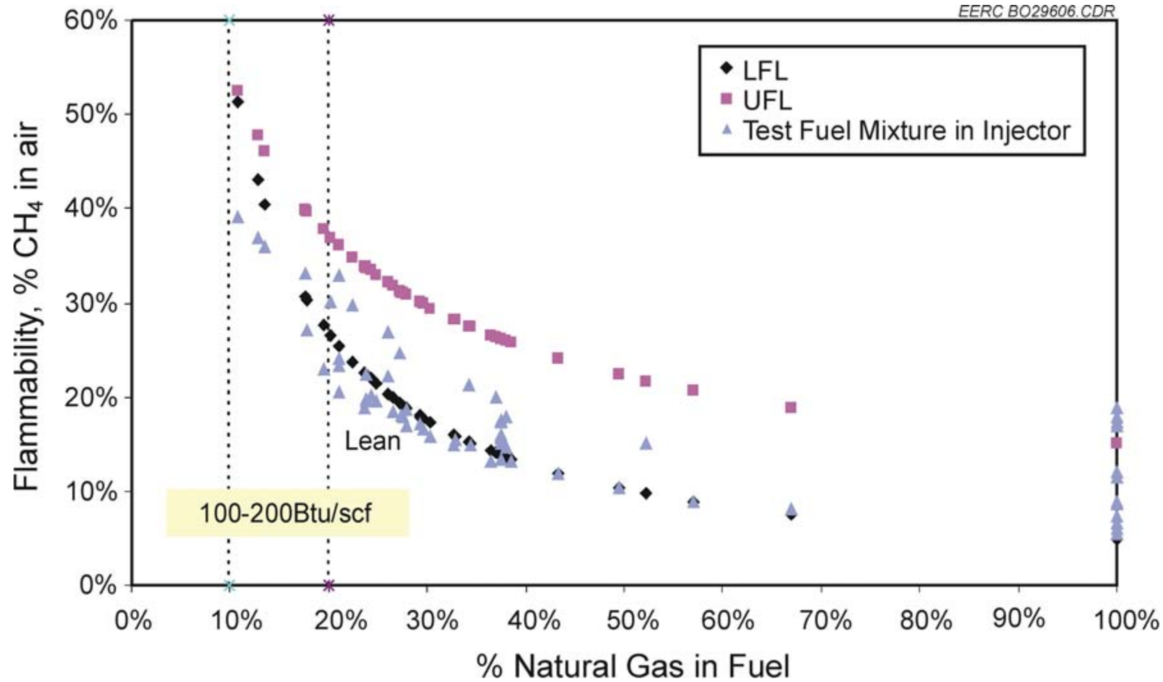

Figure 6. Fuel mixture at the injector exit compared to upper and lower flammability limits.

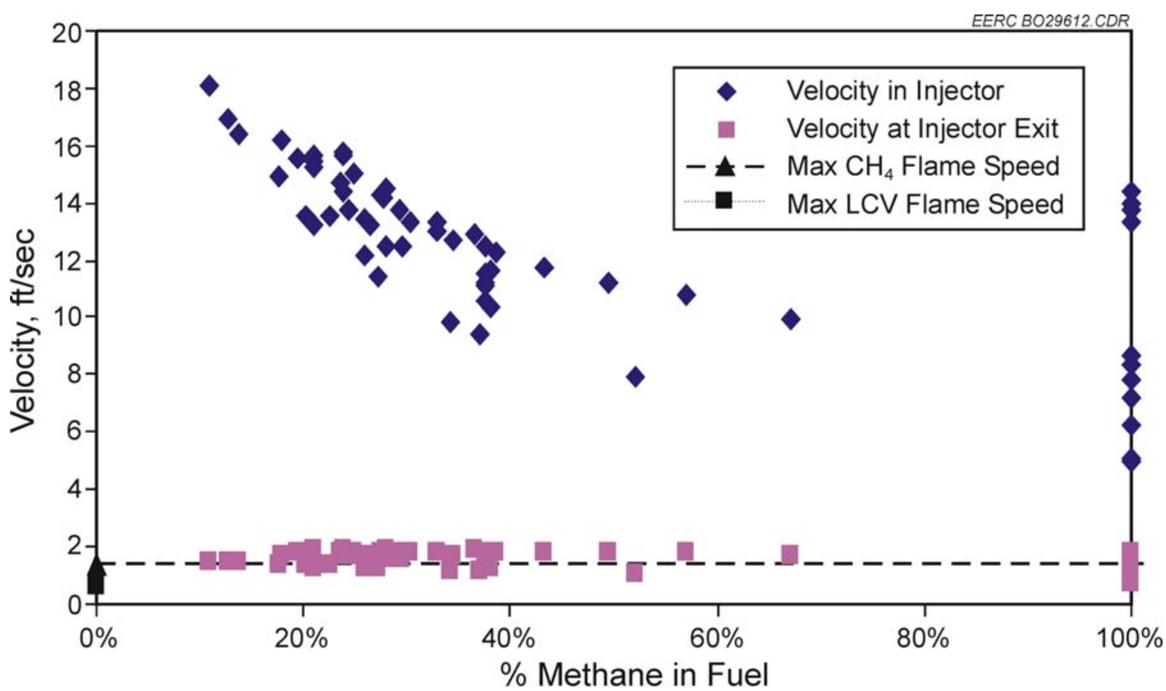

Figure 7. Gas velocity inside of the injector and at the injector exit compared to the maximum flame speed of methane and low caloric value (LCV) gas.

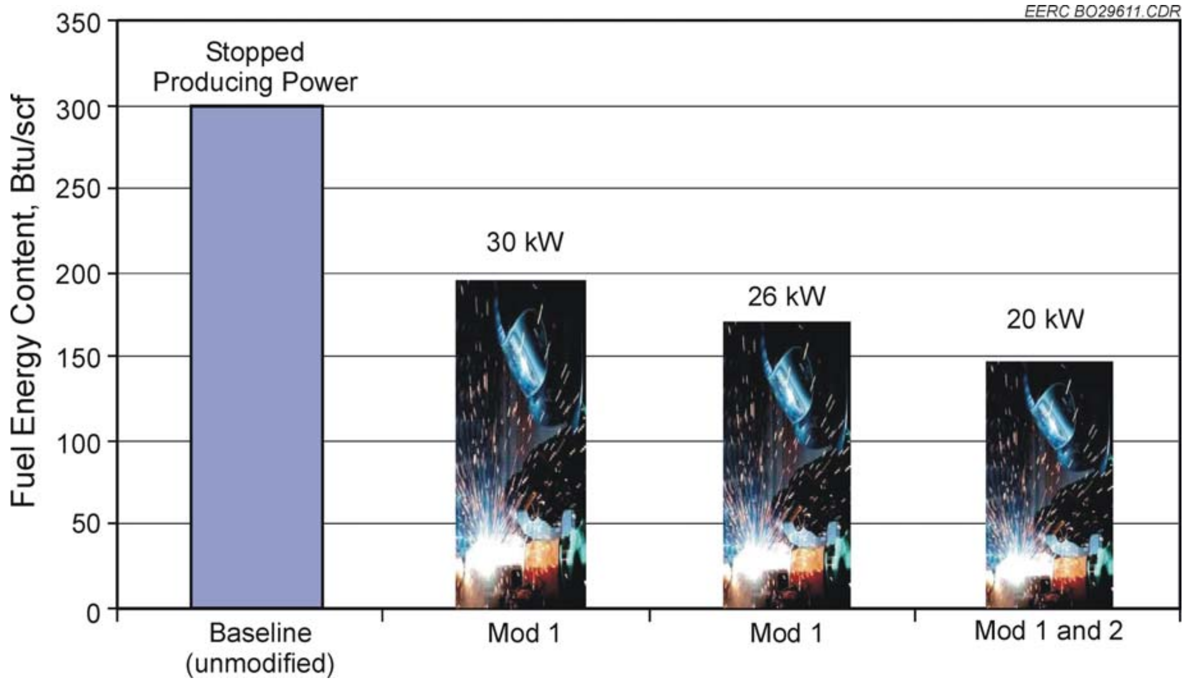

Figure 8. Modifications allowed a C30 microturbine to operate on gases lower than the baseline flameout value (5).

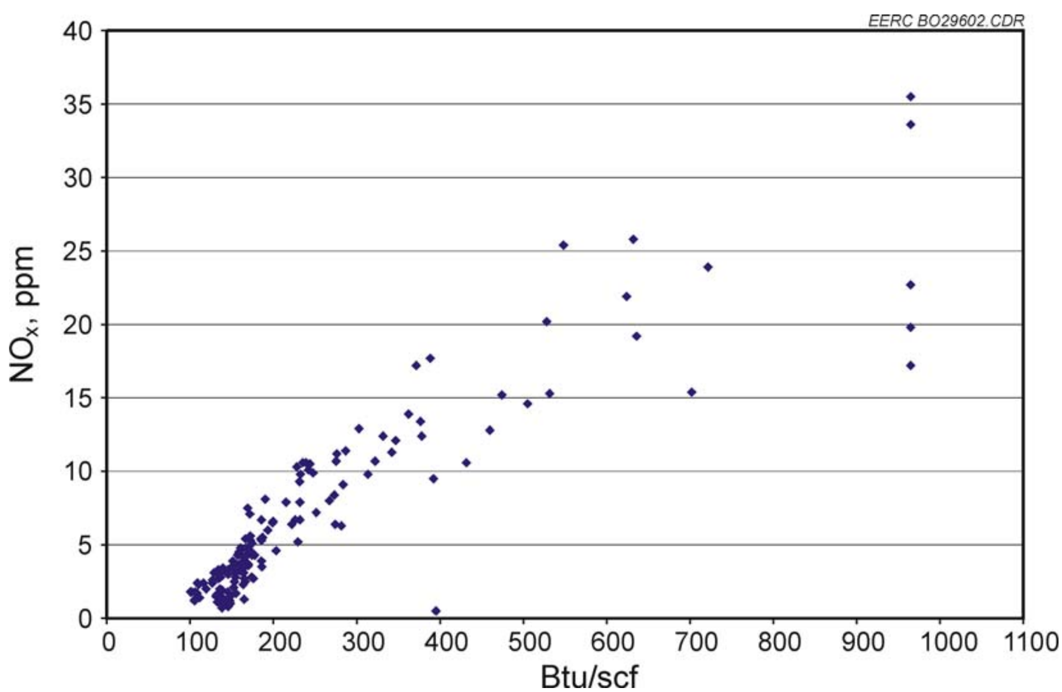

Figure 9. NO_x emissions decreased as fuel heating value decreased.

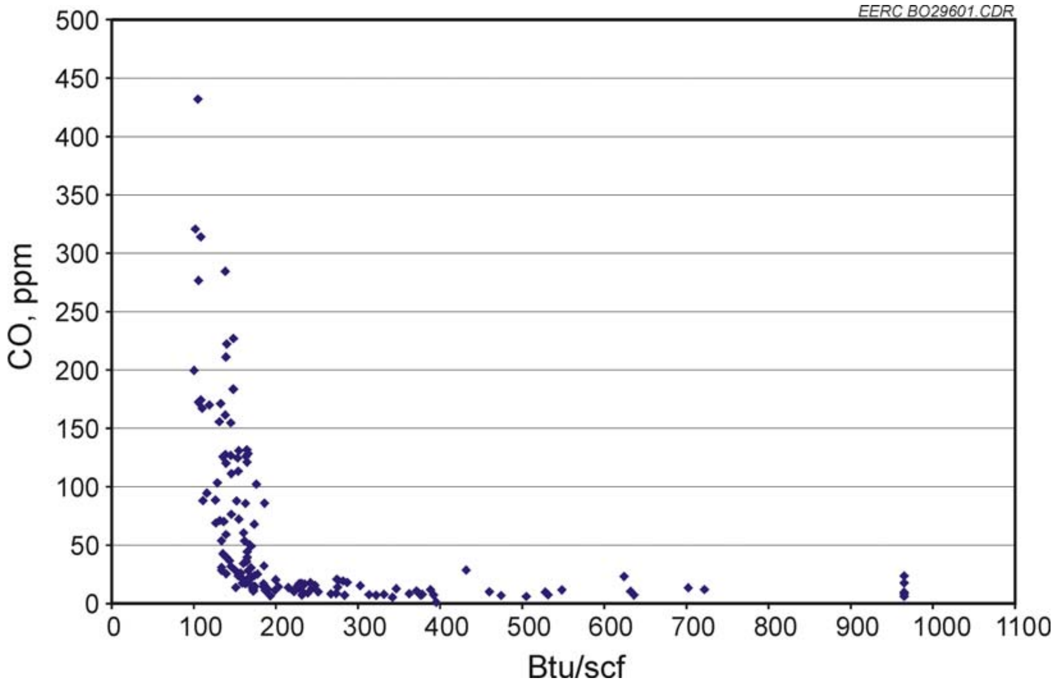

Figure 10. CO emissions increased as fuel heating value decreased.

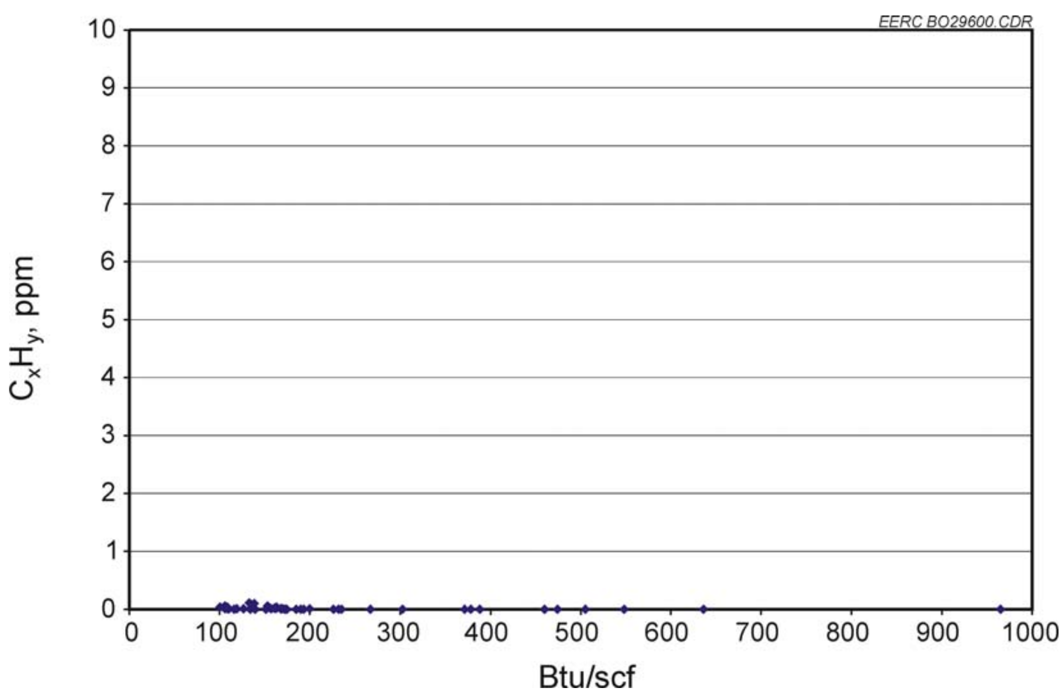

Figure 11. Unburned hydrocarbons remained below 0.2 ppm.

A commercially available C30 microturbine was utilized to minimize error introduced by scaling bench scale results to full scale. FTIR measurements added validation to the flow rate method of determining gas energy content.

Calculations for start-up gas energy content assumed constant temperature in the outside storage tank. To minimize the temperature differential between the tank and house gas lines, the tank was completely purged with nitrogen to evacuate natural gas and achieve a uniform temperature.

CONCLUSIONS

Modifications allowed a microturbine to operate on gases below the manufacturer's 350 Btu/scf lower limit. The emission reduction benefit for NO_x was better while firing low-Btu gas. Unburned hydrocarbons remained below 0.2 ppm, which is approximately 66 times less than the amount emitted by a small passenger car. CO levels increased when gas heating value dropped below 200 Btu/scf. Adding a catalytic converter could alleviate this issue. Power production results were promising for low-Btu applications. The microturbine operated on 175 Btu/scf gas with a 13% power derating and operated on 150 Btu/scf gas with a 33% power derating. The microturbine ignited on 200 Btu/scf gas. Below 200 Btu/scf, start-up gas will be required.

As environmental regulations continue to become more stringent, the energy sector will continue to alter its practices and processes to meet compliance. Burning low-Btu flare gas in a microturbine is a unique case where adding environmental control benefits both the environment and the company's bottom line. Typically, pollution control equipment costs are sunken costs that are incurred to allow continued operation. In contrast, microturbines pay for themselves in 2–3 years (8).

Modifications developed during this project will allow microturbines to operate on gases below the manufacturer's energy density specification. Oil fields with gas supplies less than 350 Btu/scf will benefit from modified microturbines.

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1. *Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources*; Nov 1998; Chapter 2.4.

2. Product Data Sheet. C30 Natural Gas Microturbine Performance Specifications. Capstone Turbine Corporation. 2006.

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7. Maricq, M.; Chase, R.; Podsiadlik, D.; Vogt, R. *Vehicle Exhaust Particle-Size Distributions: A Comparison of Tailpipe and Dilution Tunnel Measurements*; 1999; p 3.

8. Schmidt, D. Microturbine Application Reduces Sour Gas Flaring, Provides Partial Power. *World Oil* **2005**, *March*.

APPENDIX A

SAMPLE CALCULATIONS

SAMPLE CALCULATIONS

To convert actual flow (measured by rotameters) to standard flow:

$$cfh \times \sqrt{\left(\frac{psi_g + 14.7\, psi_g}{14.7}\right) \times \left(\frac{530°R}{T_{actual} + 460°R}\right)} \times F = scfh$$

Where:
cfh = actual cubic feet per hour
psi_g = gauge pressure, pound per square inch
°R = degree Rankin
T_{actual} = actual temperature of gas
scfh = cubic feet per hour at standard conditions
F = 1.22 for natural gas, 1.00 for nitrogen

To calculate a heating value for a mixture of natural gas (NG) and nitrogen (N_2):

$$\left(\frac{NGscfh}{NGscfh + N_2scfh}\right)\left(\frac{965BTU}{scfh}\right) + \left(\frac{N_2scfh}{NGscfh + N_2scfh}\right)\left(\frac{0BTU}{scfh}\right) = heating.value.of.mix$$

Where:
NGscfh = natural gas flow rate at standard conditions
N_2scfh = nitrogen flow rate at standard conditions

To make a gas mixture with a certain heating value:

Tank Volume = 500 gal = 66.84 ft^3
The tank was pressurized by a compressor to 110 psi_g. The following calculation converts actual tank volume at 110 psi_g to standard volume.

$$66.84\, ft^3 \times \frac{68°F + 460}{40°F + 460} \times \frac{110\, psi_g + 14.7}{0\, psi_g + 14.7} = 598.8\ scf$$

So, the 66.84 ft^3 of compressed gas equals 598.8 ft^3 of gas at standard conditions.

For a 200 Btu/scf fuel mixture, the mix must be 21% natural gas and 79% nitrogen (125.7 scf of natural gas and 473 scf of nitrogen).

To find at what pressure the 66.84 ft^3 tank will hold 473 scf of nitrogen:

$$473\,ft^3 \times \frac{0\,psi_g + 14.7}{\mathbf{X}\,psi_g + 14.7} \times \frac{40°F + 460}{68°F + 560} = 66.84\,ft^3$$

X = 84psi_g

So, the tank must first be filled with nitrogen to 84 psi_g.

The amount of natural gas required was 21% of 598.8 scf, or 125.7 scf.

$$125.7 scf \times \frac{40°F + 460}{68°F + 460} \times \frac{0\,psi_g + 14.7}{110\,psi_g + 14.7} = 14\,acf\ @110\,psi_g$$

To find how much volume the nitrogen takes up at 110 psi_g:

$$66.84\,ft^3 \times \frac{84\,psi_g + 14.7}{110\,psi_g + 14.7} \times \frac{40°F + 460}{40°F + 460} = 52.9 acf\ @110\,psi_g$$

Check to ensure the total gas in the tank at 110 psi_g is correct:

$52.9\,acf + 14\,acf = 66.9\,acf$ Correct

The tank now contains a 200 Btu/scf gas mixture at 110 psi_g.

APPENDIX B

RESULTS

RESULTS

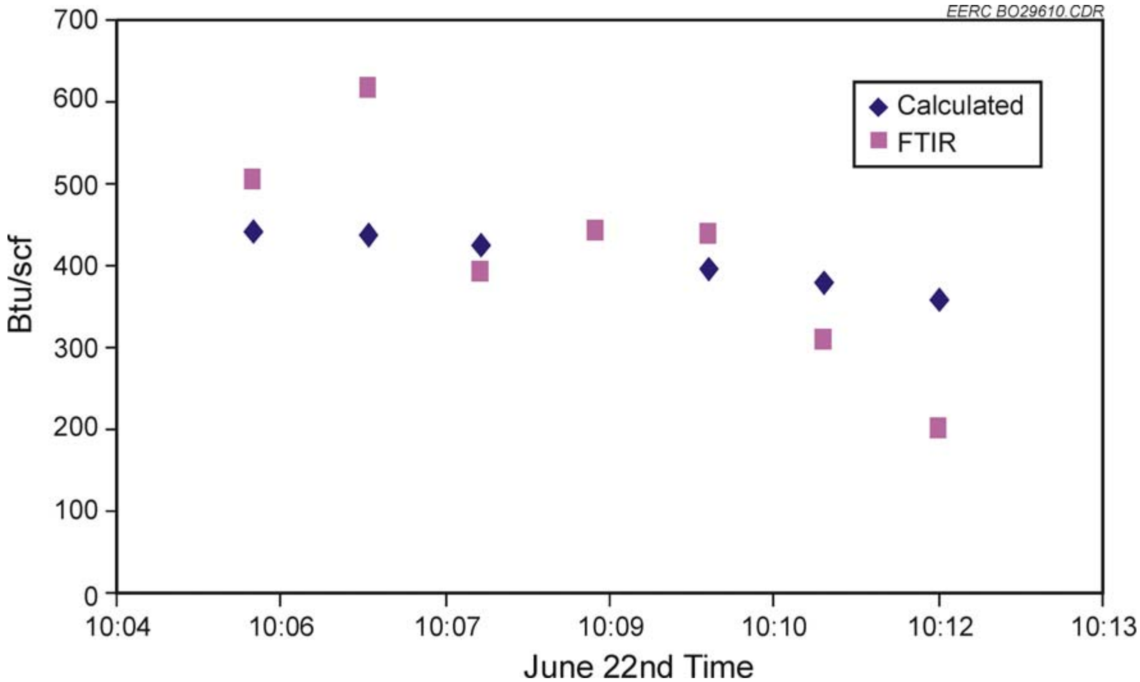

Figure B-1. FTIR measurements compared to Btu/scf calculations. Fuel index set at 11.

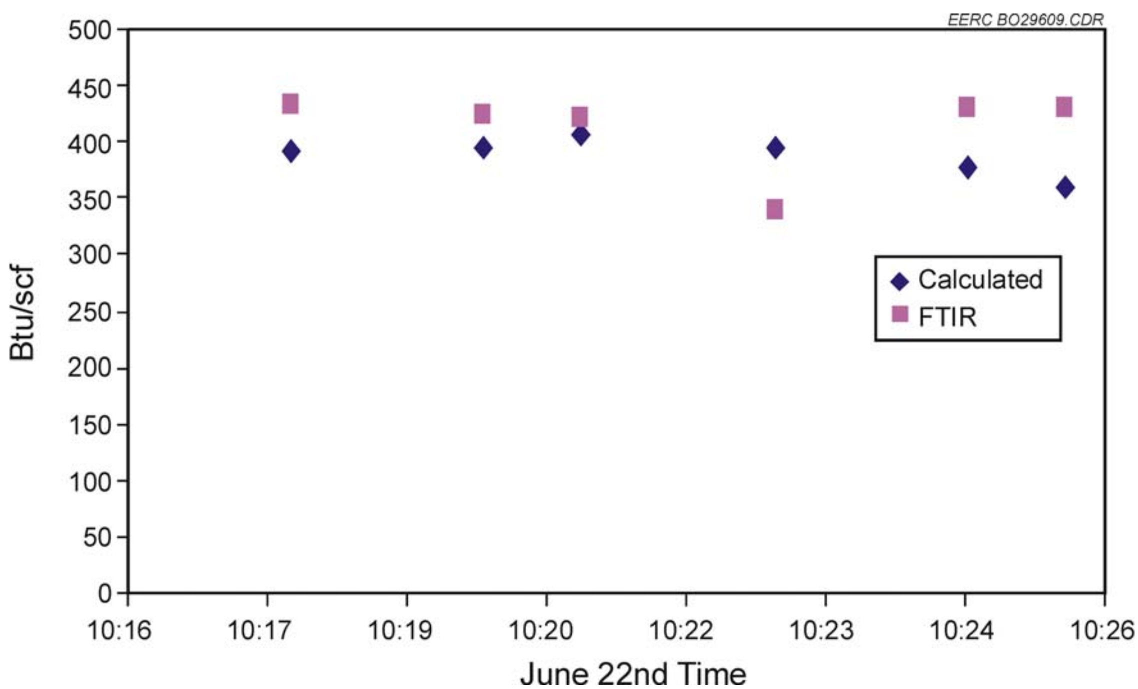

Figure B-2. FTIR measurements compared to Btu/scf calculations. Fuel index set at 14.

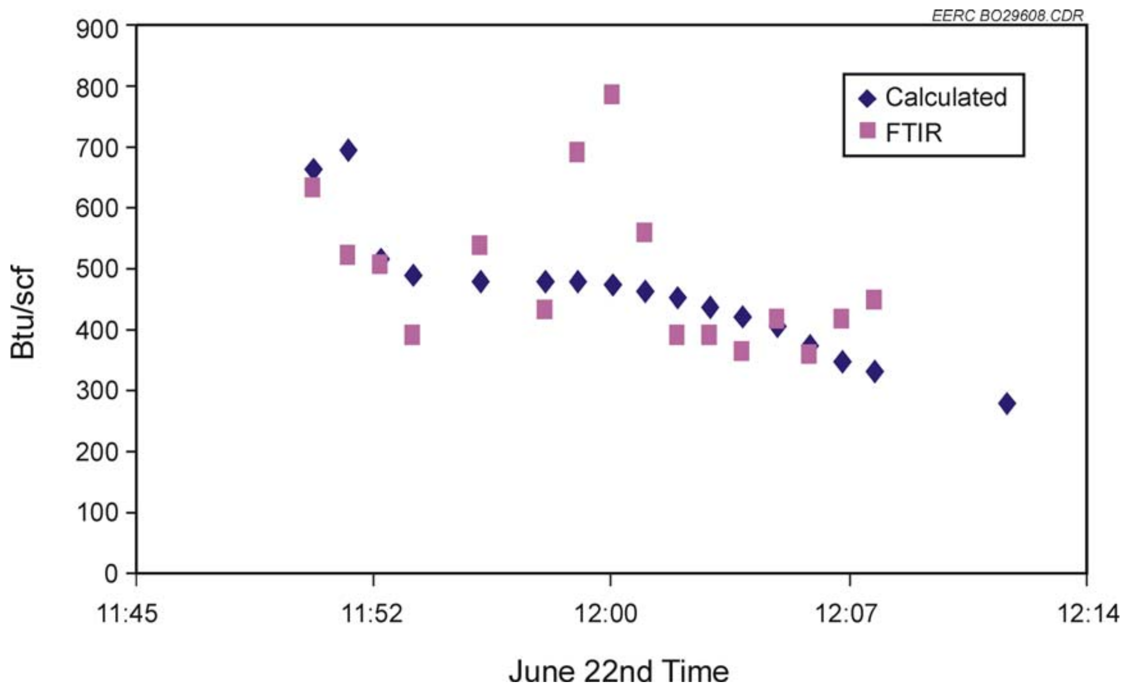

Figure B-3. FTIR measurements compared to Btu/scf calculations. Fuel index set at 11.

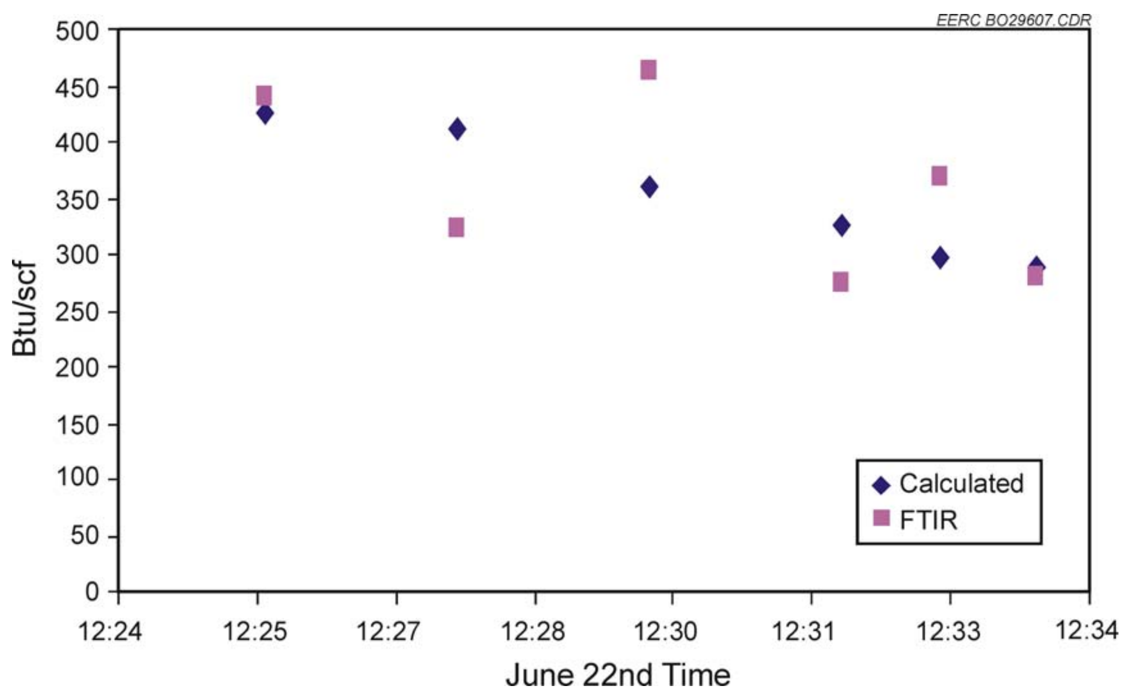

Figure B-4. FTIR measurements compared to Btu/scf calculations. Fuel index set at 14.

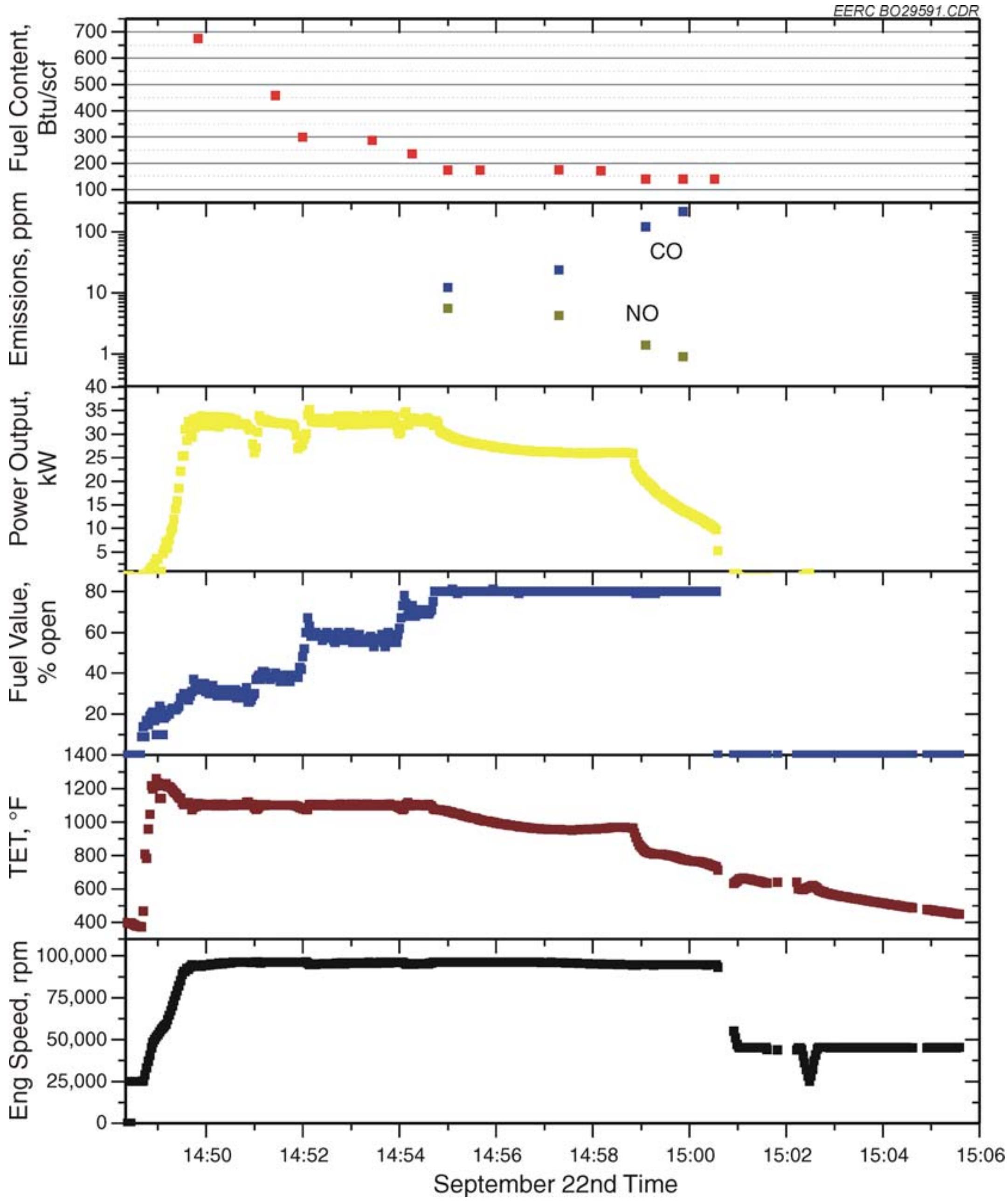

Figure B-5. First low-Btu test of second type of modified injectors.

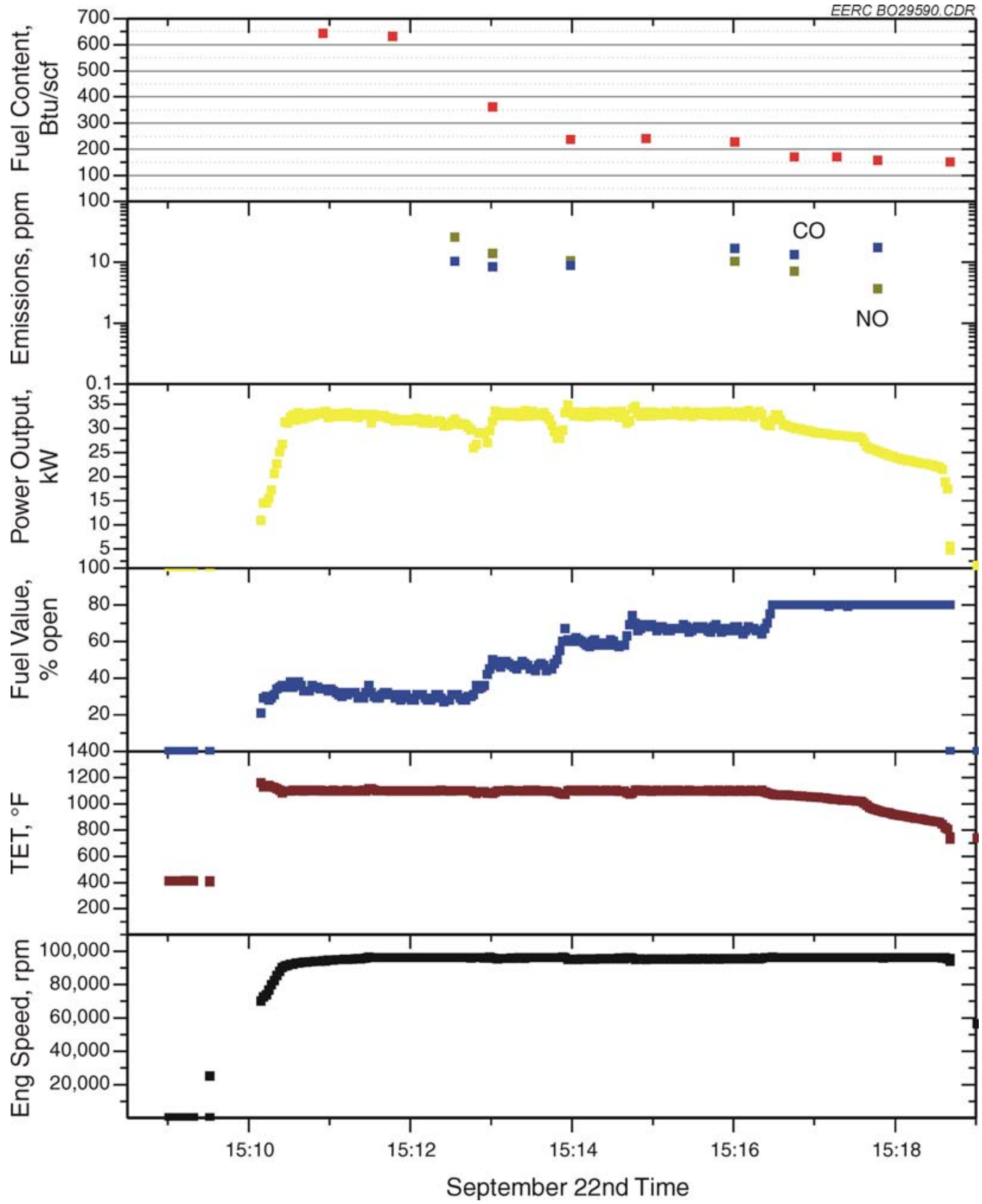

Figure B-6. Second low-Btu test of second type of modified injectors.

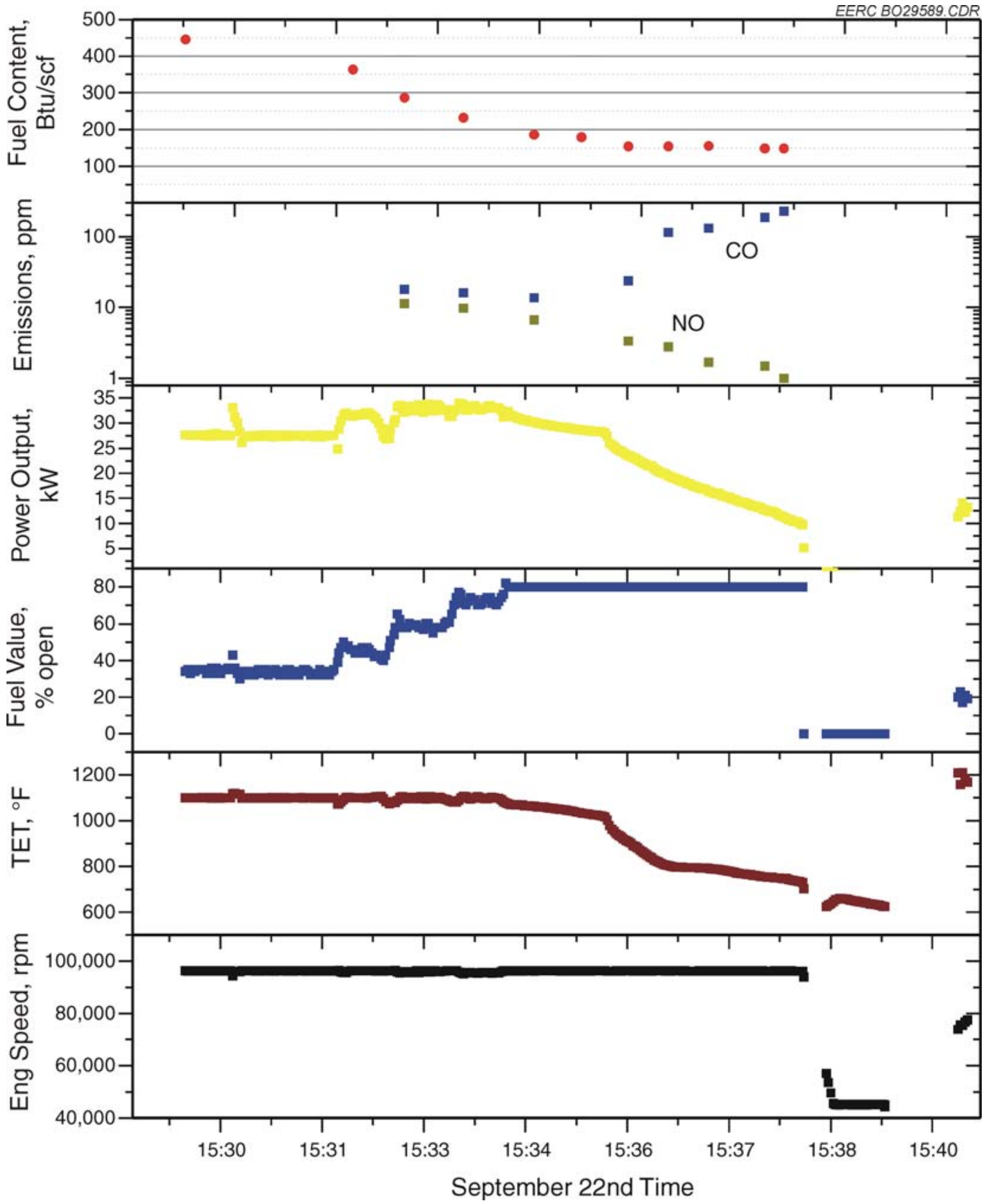

Figure B-7. Third low-Btu test of second type of modified injectors.

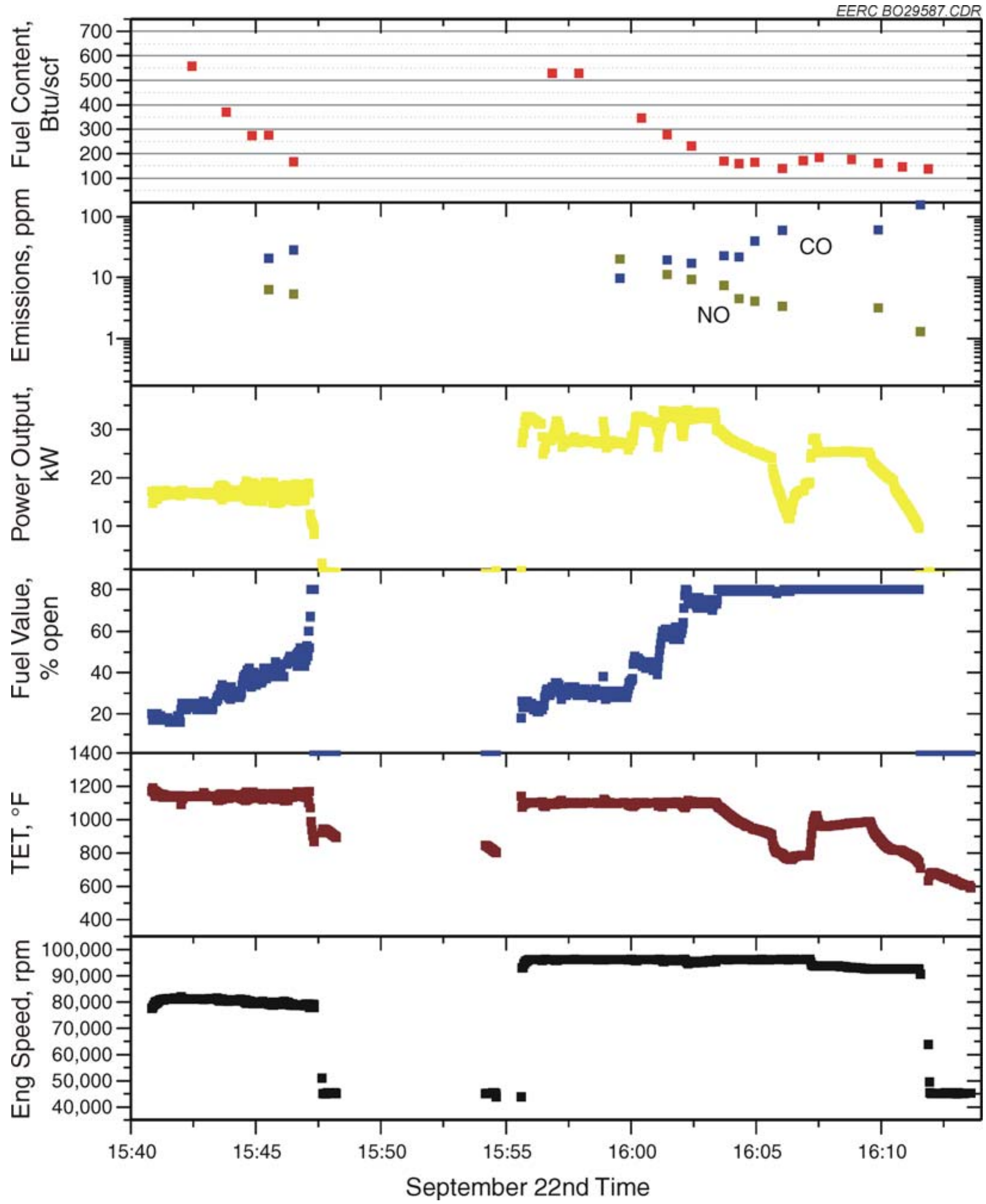

Figure B-8. Part load and fluctuating fuel content tests with second type of modified injectors.

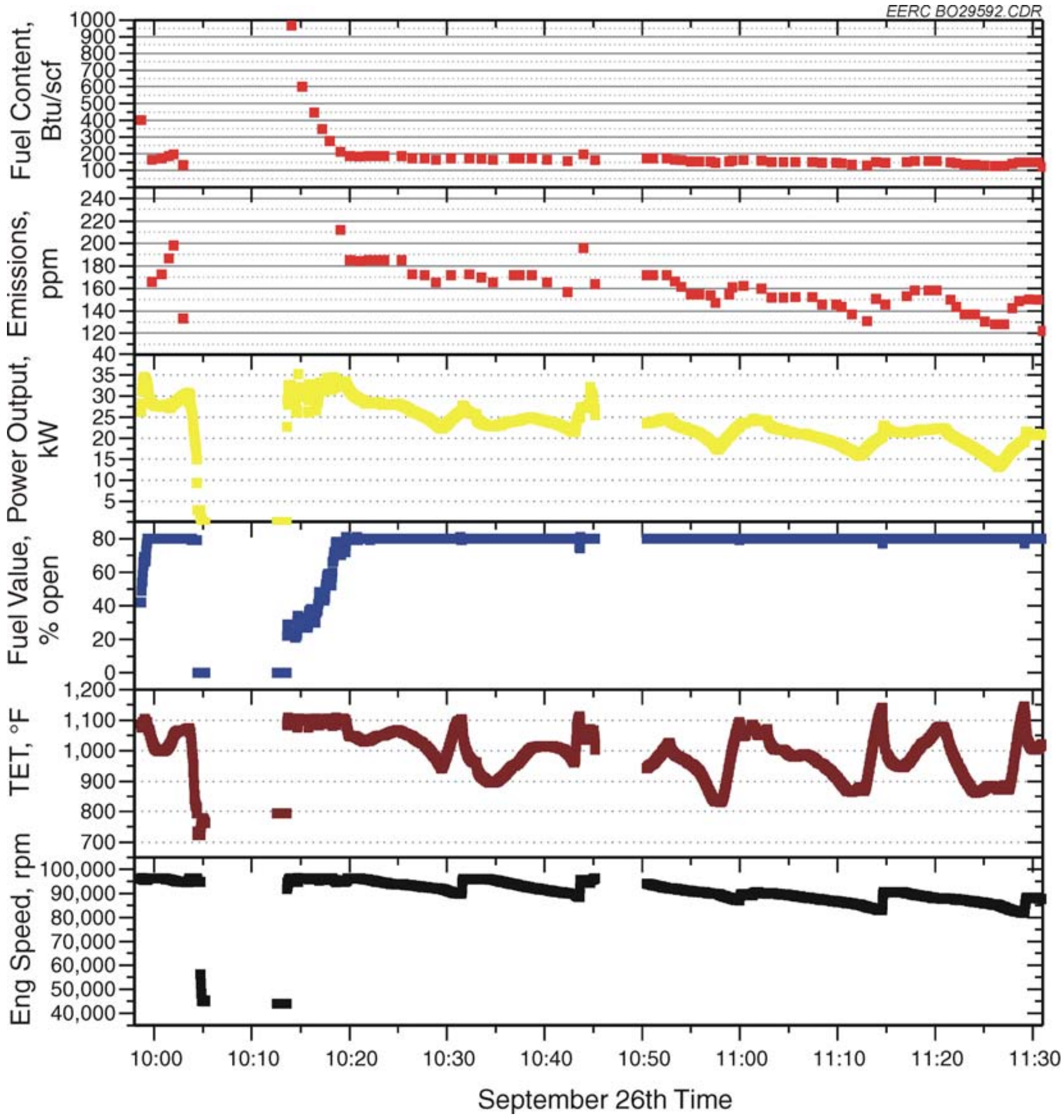

Figure B-9. Low-Btu testing with both modifications. Settings: low-Btu setting, power mode, 30 kW output, FI=14 (note: the top two graphs display the same information on different scales).

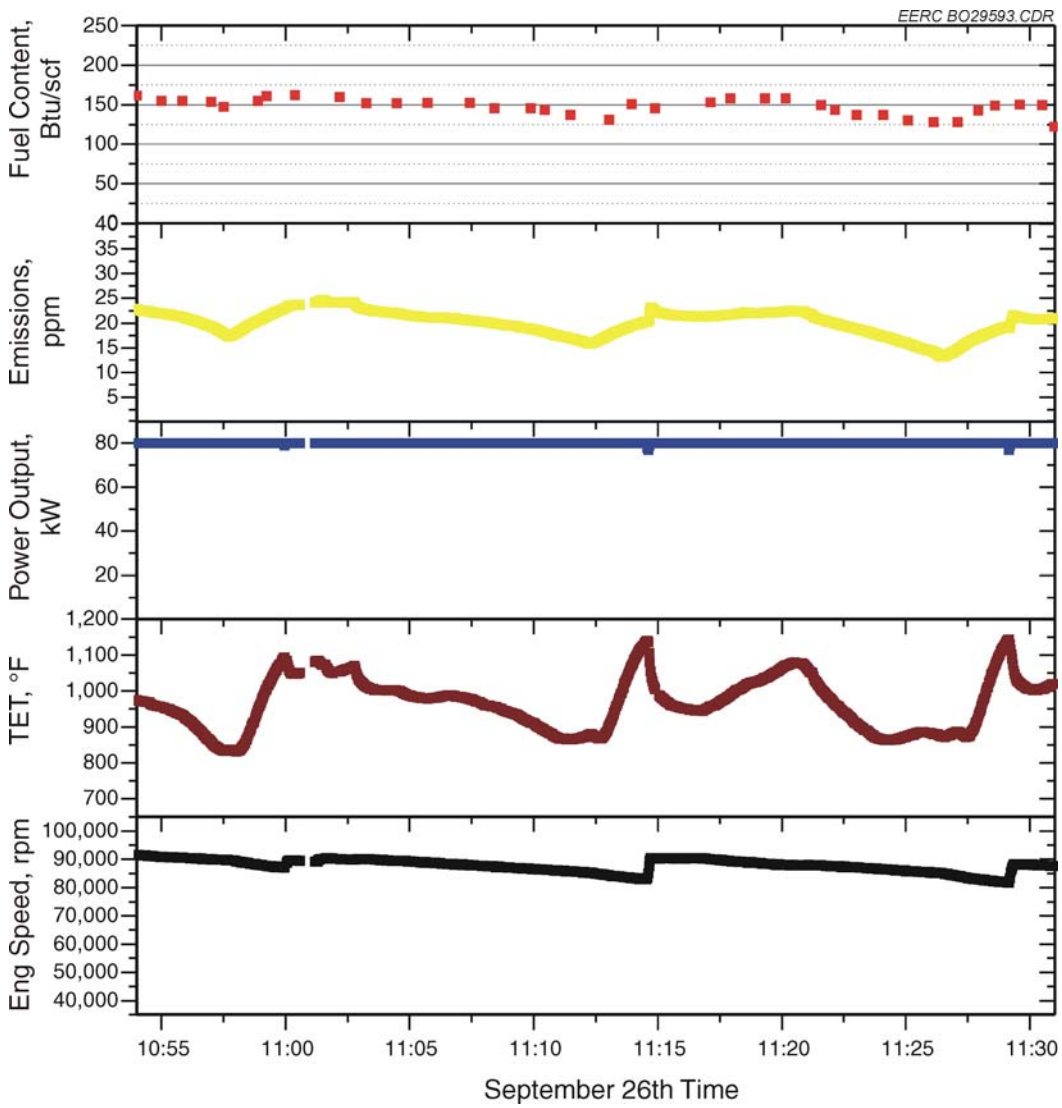

Figure B-10. During low-Btu testing with both modifications, the turbine produced 20 kW of power from 150 Btu/scf gas for 37 minutes. Settings: low-Btu setting, power mode, 30 kW output, FI=14.

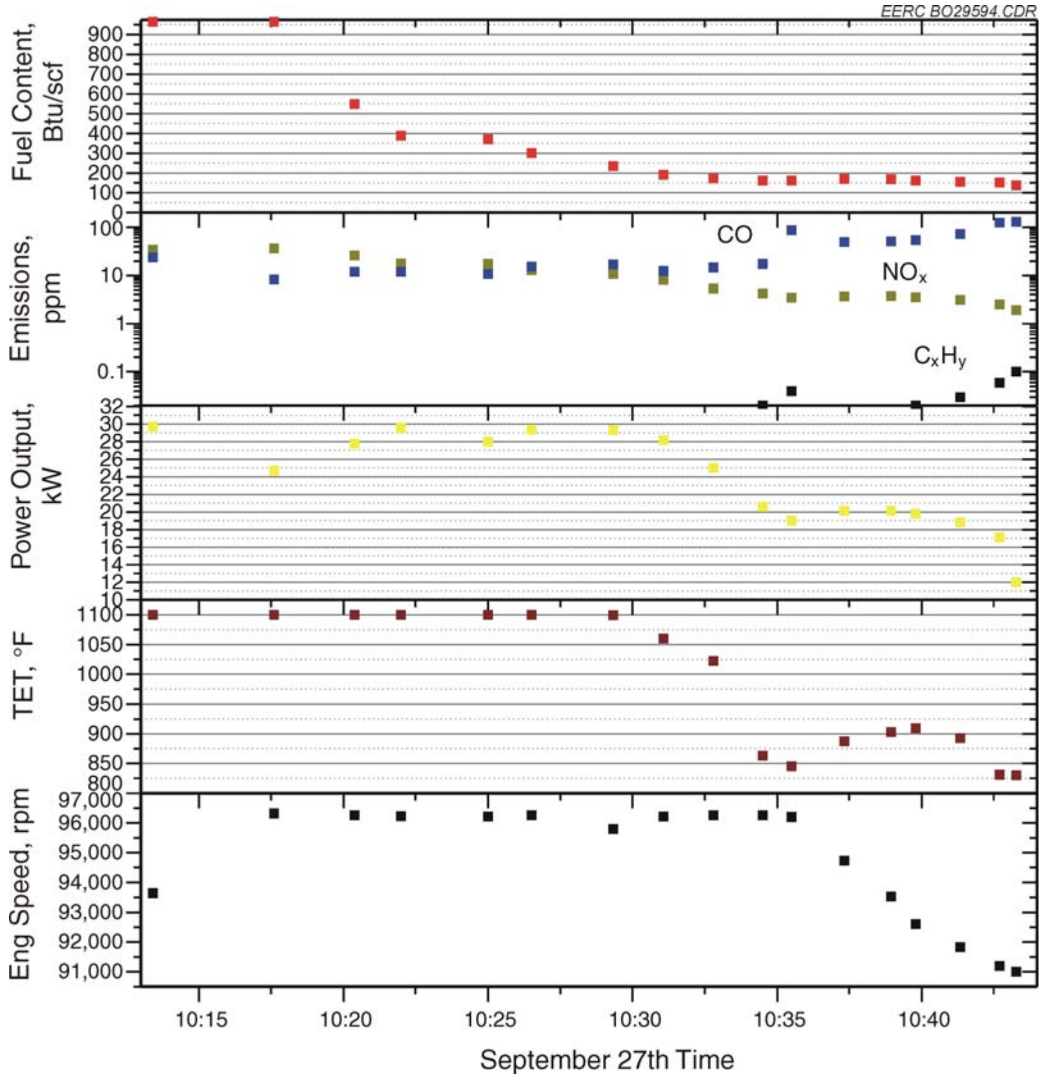

Figure B-11. Emissions when operating with both modifications.

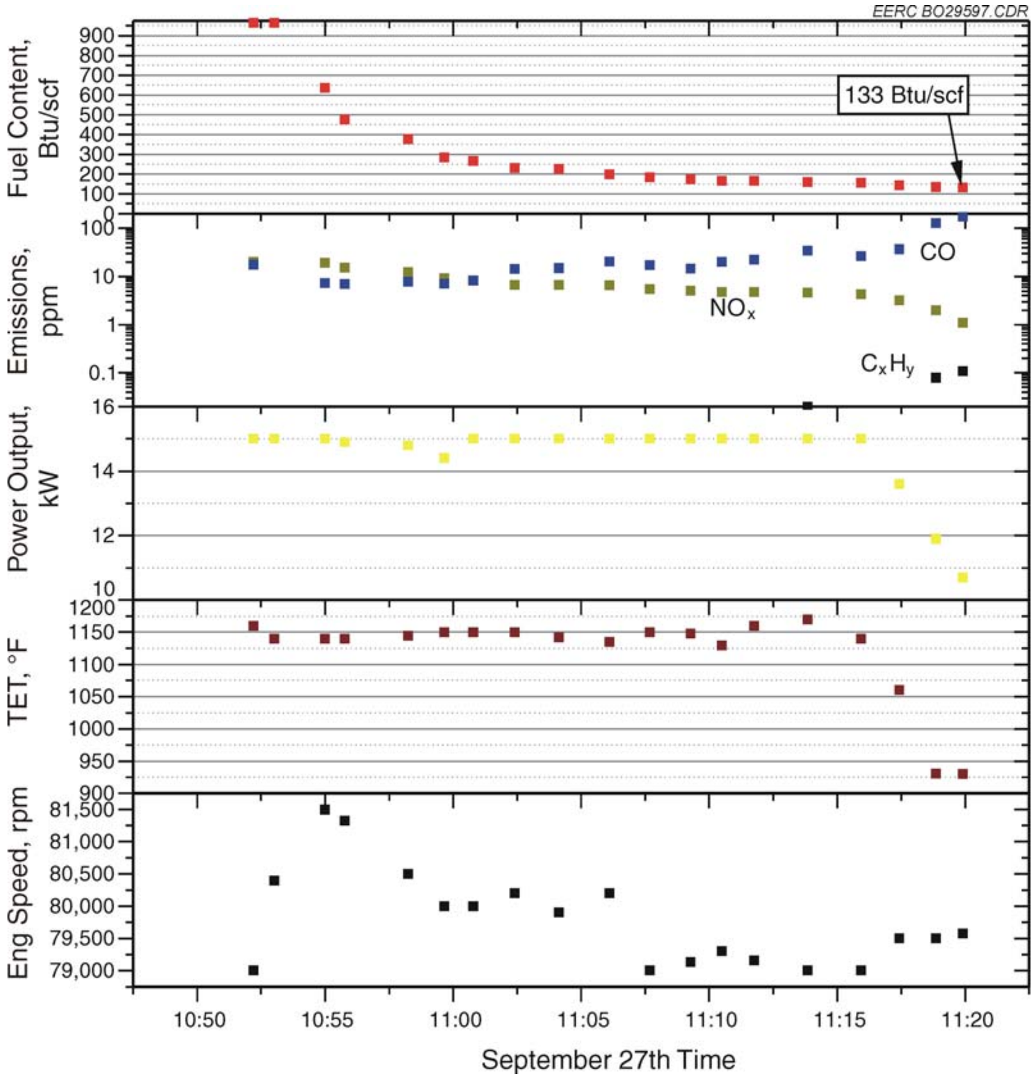

Figure B-12. Low-Btu testing with both modifications at partial load. Settings: Low-Btu setting, power mode, 15 kW output, FI=7.

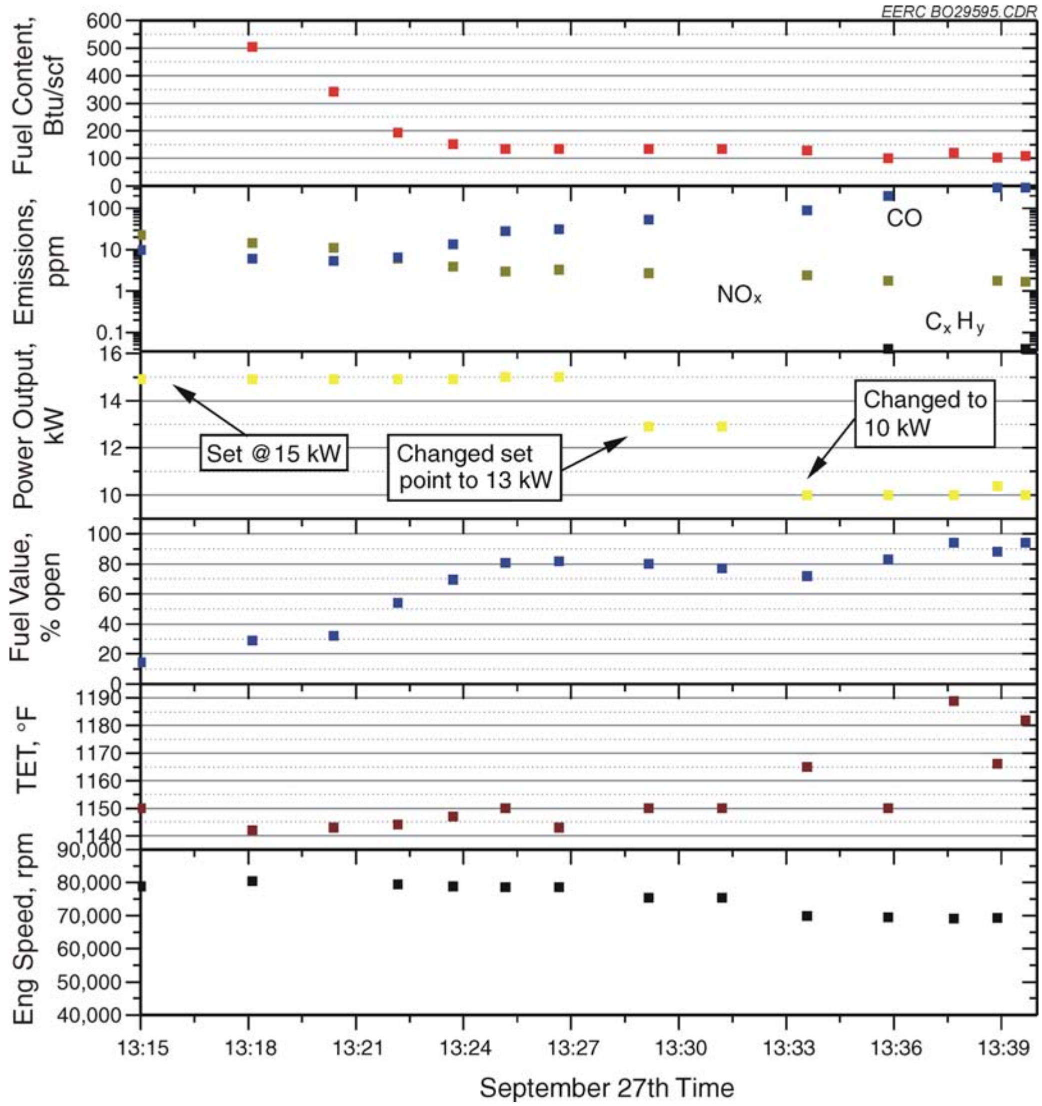

Figure B-13. Partial load tests with both modifications and varying power set point. Settings: Low-Btu setting, power mode, FI=14.

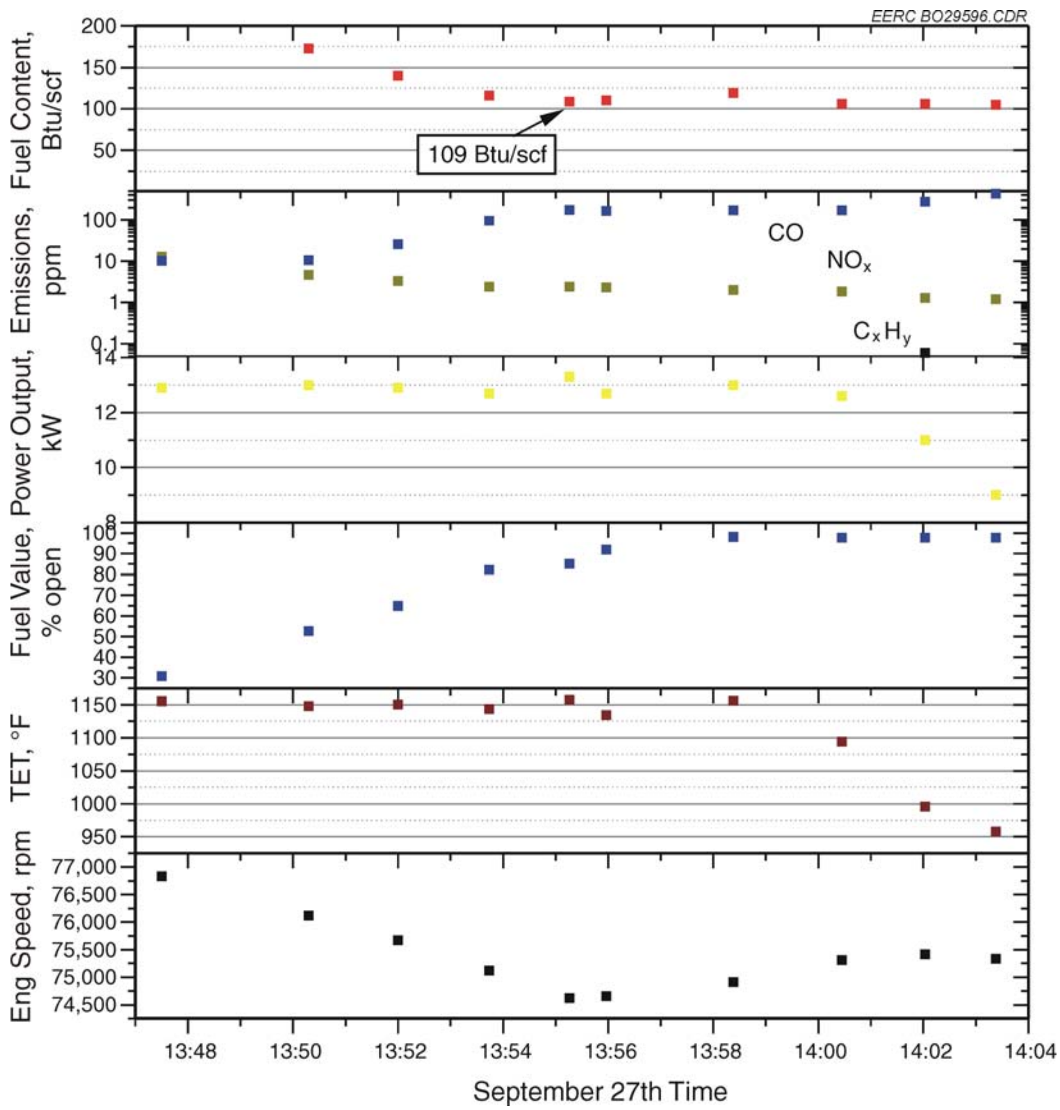

Figure B-14. Partial load tests with both modifications determined the minimum energy content while producing 13kW. Settings: Low-Btu setting, power mode, 13 kW power output, FI=14.