# LNG Research Study

# Testing of a Horizontal-Condensing Forced Air Unit (FAU)

Prepared for
The Southern California Gas Company

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## Disclaimer



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- Mr. Kevin Shea

### Air Emissions Advisory Committee (AEAC)

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## RESULTS SUMMARY

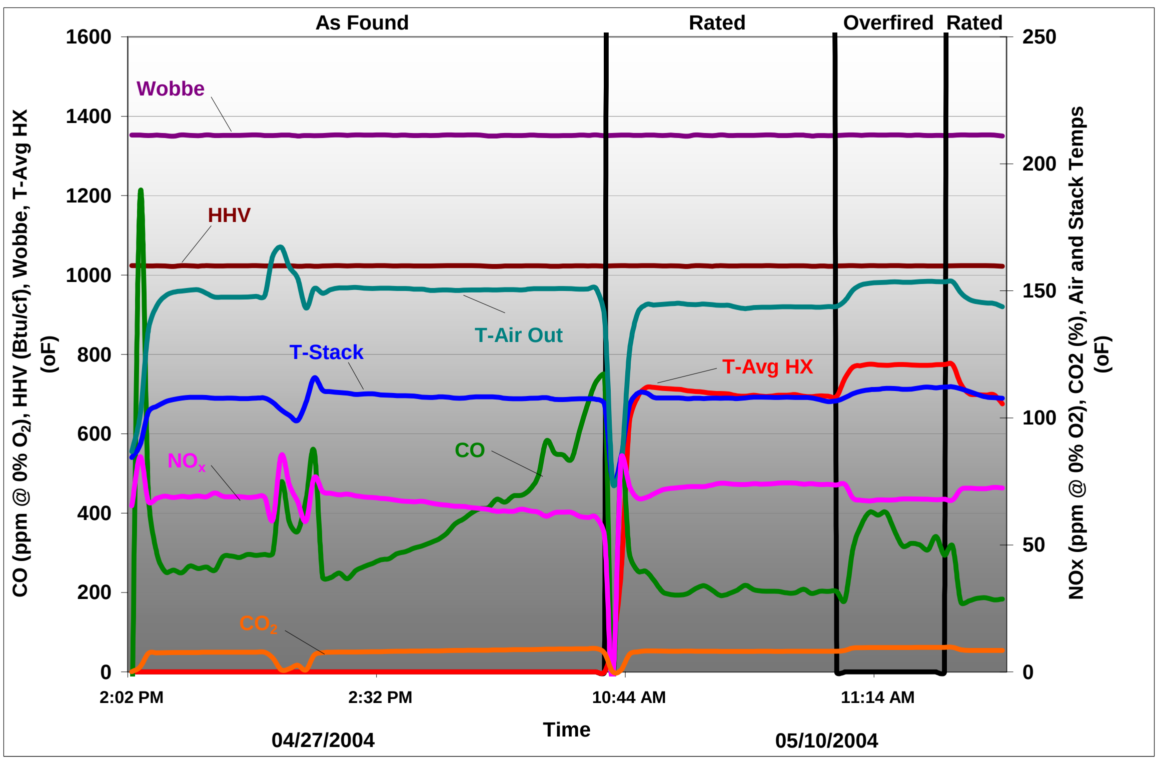
The horizontal condensing forced air unit (HCFAU) was tested over a wide range of operating conditions, gas properties and composition and did not show significant sensitivities to the gas blends tested with regard to safety, performance or emissions. A summary of results for each of these tests is provided below, with more detailed analyses in the Results section. Tables of average measured and calculated values are presented in Appendix F.

As Found, Rated, and Overfired Test

$NO_x$ emissions (corrected to air-free) during the test sequence ranged from 63 ppm (as found input rate) to 74 ppm (rated input). Corrected CO emissions ranged from 182 ppm (rated input) to 534 ppm (as found input).

The as found input was 85.9% of the nameplate rating. The rated input test was conducted at 97.9% of the nameplate rating. The overfired test was conducted at 110.6% of rated input. Heat exchanger thermocouples were not installed for the as found test, so temperature data is unavailable. Heat exchanger temperatures were higher when operating at the overfired condition (average of 773 $^oF$) compared with the rated condition (696 $^oF$). A summary of the continuous test data and calculations for the as found, rated, and overfired test is shown in Figure 1.

Figure 1 – Summary of HCFAU As Found, Rated, and Overfired Testing



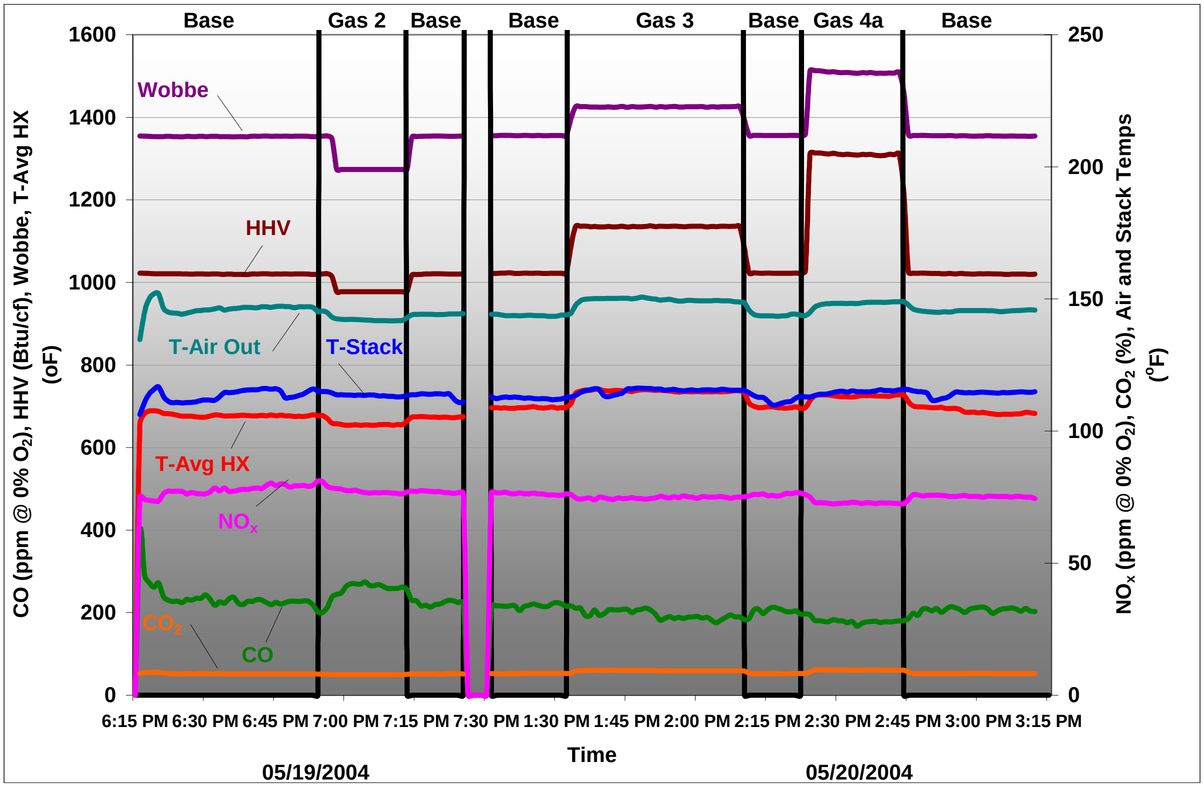

Emission test results are for information purposes. They are not the result of certified tests.

Performance Test

$NO_x$ emissions (corrected to air-free) during the test sequence were statistically equivalent, ranging from 73 ppm (Gas #4a) to 77 ppm (base gas). Corrected CO emissions ranged from 179 ppm (Gas #4a) to 260 ppm (Gas #2). $NO_x$ and CO emissions decreased when operating on richer gases. All baseline firing rates were within 2% of nameplate rated input.

Heat exchanger temperatures were slightly higher when operating on the richer fuels (Gas #3 and Gas #4a), but remained well below temperatures that would pose an operating concern. A summary of the continuous test data and calculations for the performance test is shown in Figure 2.

Figure 2 – Summary of HCFAU Performance Testing

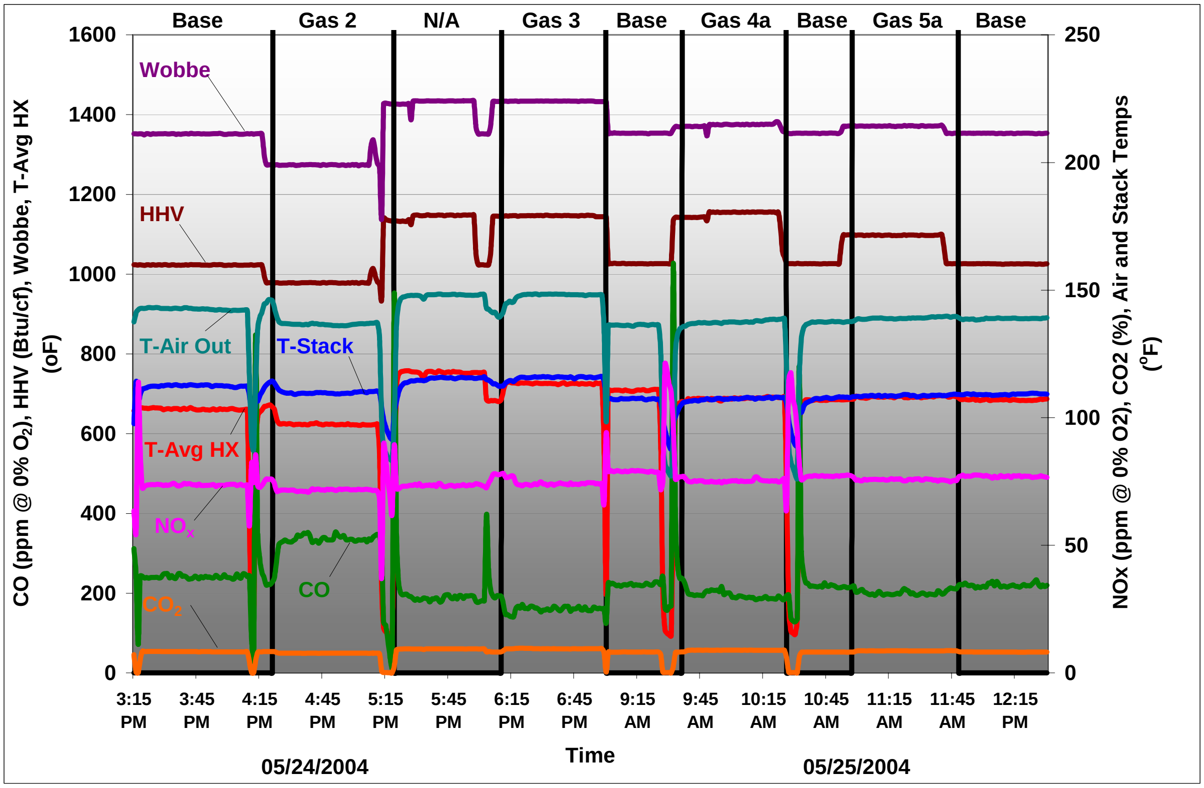



[1] Emission test results are for information purposes. They were not the result of certified tests.

Emissions Test

CO emissions, corrected to air-free, ranged from 162 ppm (Gas #3) to 333 ppm (Gas #2). The average baseline firing rate was 102.6% rated input, which is slightly higher than the protocol target of +/- 2% rated input. A summary of the continuous test data and calculations for the emissions test is shown in Figure 3.

Figure 3 – Summary of HCFAU Emissions Testing




[1] Emission test results are for information purposes. They were not the result of certified tests.

Ignitions Test

Ignition tests were conducted with various gases with different manifold pressures, hot and cold operation, and in repetitive sequences. All ignitions were normal, with no issues related to ignitions with the gas compositions used in this study.

## EQUIPMENT SELECTION CRITERIA

The particular feature of this residential furnace that make it important to study is that it represents modern technology that has recently entered the market. The protocol development was guided by the ANSI and ASHRAE standards and the regulations of the South Coast Air Quality Management District.

## EQUIPMENT SPECIFICATIONS

Description: Gas-fired Category IV forced air furnace
Burner Type: Induced combustion system with in-shot burners firing into a tube-type heat exchanger
Input rating: 105,000 Btu/hr
Air temperature rise: 50 – 80 $^{o}$F
Type of fuel: Natural gas
Required fuel inlet supply pressure: 5.0 – 10.5” W.C.
Gas manifold pressure: 3.5” W.C.

## STANDARDS

A test protocol was developed based on the following standards:

- ANSI Z21.47-2001, Standard for Gas-Fired Central Furnaces, including addenda ANSI Z21.47a-2001 and ANSI Z21.47b-2002.
- South Coast Air Quality Management District Rule 1111, NOX Emission from Natural-Gas-Fired, Fan-Type Central Furnaces, last amended July 8, 1983.
- South Coast Air Quality Management District Protocol, Rule 1111, NOX Emission from Natural-Gas-Fired, Fan-Type Central Furnaces, July 12, 1994.

A detailed description of the protocol and rationale is presented in Appendix A.

## INSTALLATION

The overall setup of the equipment included a number of sub systems, including gas supply, gas composition blending and analysis, gas appliance, flue gas monitoring, and data acquisition. A schematic of the overall test system is shown in Appendix B (Figure B1).

The HCFAU was installed and instrumented in a laboratory test cell according to the manufacturer's specifications and the test protocol. Thermocouples were installed to measure process temperatures, including air in and out, heat exchanger surfaces, and flue gas. Pressure transducers were installed to measure supply, gas meter, manifold, and atmospheric pressures. A schematic of the instrumented HCFAU is shown in Appendix B (Figure B2).

Installation Specific to Initial Tests and Performance Tests

For performance testing (including as found, rated, overfired, and gas blending tests), the flue outlet was connected to 65 ft. of 3" PVC pipe with six (6) $90^o$ elbows (maximum vent recommended by manufacturer). A single point emissions sampling probe was installed directly in the vent pipe, approximately 3 ft. downstream of the appliance flue outlet.

Installation Specific to Emissions Tests

For emissions testing, an integrated sampling probe was installed in a five-foot vertical section of vent pipe. The vent pipe was attached to the appliance flue outlet with one (1) $90^o$ elbow, per the SCAQMD Rule 1111 protocol.

Once instrumentation was installed, the HCFAU was operated on pipeline gas to verify that the furnace and all instrumentation operated properly. Manifold and supply pressures were not adjusted during setup.

## TEST GASES

Several sources of gases were used for the project, including pipeline gas and special blends of gases either prepared by a provider of specialty gases or on site.

The project required testing the range of gas compositions shown in Appendix C (Table C1). As indicated in the Table, there were primary, secondary, and tertiary gases. The primary gases included the baseline or set up gas and others that outlined the boundary conditions for compositions determined by Southern California Gas Company (SCG). Secondary gases were intermediate gases within the boundary conditions and were used for processes that exhibit sensitivities to primary gases. Tertiary gas compositions depended on results from the secondary gases and had properties that were incremental changes in heat content or Wobbe number, depending on results from the secondary gas.

## TEST PROCEDURES

Four types of tests were conducted in evaluating the HCFAU:

1) As Found, Rated, and Overfired
2) Performance
3) Emissions
4) Ignitions

Testing the HCFAU for this project followed the protocol shown in Appendix A. The test protocol was designed to discriminate changes in the operation of the gas equipment for the range of gas properties and compositions in the study. In the interest of time and applicability to the scope of this work, some simplified procedures were developed from existing test standards. These simplified procedures were developed in consultation with the manufacturer and other technical parties to ensure applicability.

While each test adhered to the protocol, generally each day followed a similar sequence of steps as outlined below.

1. All emissions analyzers were calibrated.
2. The furnace was turned “on” and allowed to heat up to a steady state condition while running on baseline or pipeline gas.
3. Data loggers were synchronized and temperatures, pressures and gas flow readings were inspected.
4. Data recording was started while running with baseline/pipeline or test gas.
5. Each test was run for approximately 15-30 minutes with the burner at a specified power level and gas with all temperature, emissions and composition monitors being data logged. During the test, visual and photographic observations were made of the flame in order to determine yellow tipping and flame lifting phenomena or lack of same.
6. Drift inspections were performed on all emissions analyzers.
7. Steps 5 and 6 were repeated for other firing rates and for the range of test gases in the matrix as indicated in Appendix C. High-speed transitions (~14 seconds) were made from baseline gas to substitute gas while recording observations. Transitions were also performed from each gas blend back to base gas. Phenomena of interest included: flame color change, flame lifting, flashback or rollout, pilot burner instability or outage, etc.

<u>As Found, Rated, and Overfired Tests</u>
The gas supply was set to the manufacturer’s rated manifold pressure, with all other parameters left in the “as-received” settings. The furnace was operated for approximately 1 hour at this condition. The orifice set was then changed to allow for adjustment to 100% firing rate at rated manifold pressure. The furnace was

operated for a minimum of 15 minutes at rated condition, followed by a 15-minute segment at a 110% overfired condition (achieved by increasing manifold pressure above rated). The unit was returned to rated input for a short segment following the overfired test.

Performance Tests

The furnace blower was set to maintain a constant 65 $^{o}$F air temperature rise. The gas supply was set to within 2% of the manufacturer's rated input on baseline gas. The furnace was operated for approximately 15 minutes at this condition, followed by 15-minute segments using gas #2, gas #3, and gas #4a. The unit was returned to baseline gas for short periods between each gas blend switch.

Emissions Tests

The emissions tests consisted of a series of 30-minute runs at steady state with the air temperature rise set to 65 $^{o}$F on baseline gas at rated input. It was not adjusted thereafter and was allowed to change with gas blend. Emissions measurements for calculation purposes were based on the last five minutes of burner operation for each gas tested. Emissions tests were conducted using baseline gas, Gas #2, Gas #3, Gas #4a, and Gas #5a. As with the performance tests, the unit was returned to base gas between the gas blend switches.

Ignition Tests

The HCFAU was tested for burner and ignition operating characteristics under a variety of conditions. This series of tests included both cold and hot ignitions at three different gas supply pressures, and additional tests with the gas blends. Burner operation was initiated by means of a switch at the wall thermostat terminals. The burners were allowed to operate for 5-second periods, with observations made with respect to immediate ignition and carryover to all burners, flashback, flame rollout, and instability of the main burner flames.

## RESULTS

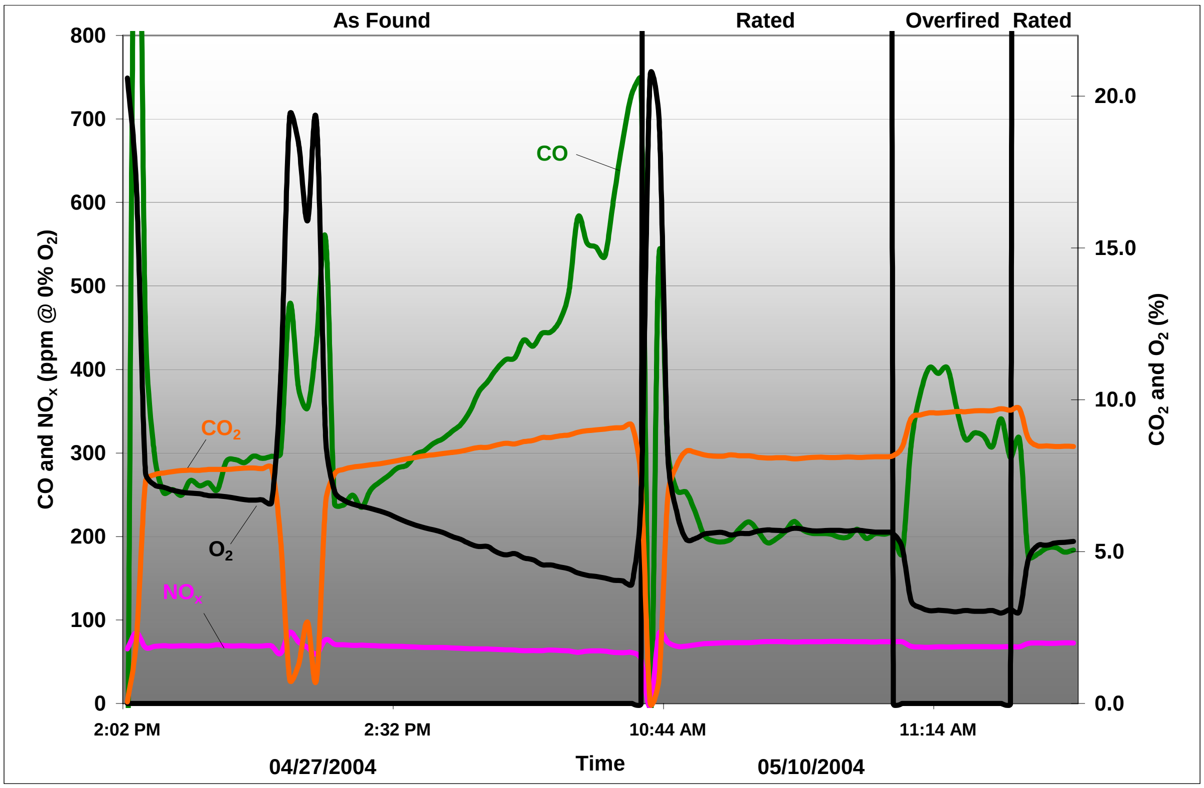
<u>As Found, Rated, and Overfired Test</u>

*Emissions*

An anomaly was found during the as found test, where the flue vent inside the unit was accumulating condensate. This caused a gradual buildup of carbon dioxide and carbon monoxide (and decrease in oxygen). The problem was corrected before running the rated and overfired tests. $NO_x$ emissions during the as found, rated, and overfired test ranged from 63 ppm (corrected to 0% $O_2$) for the as found condition to 74 ppm (@ 0% $O_2$) for the rated condition. NOx emissions fell to an average of 68 ppm (@ 0% $O_2$) during the overfired condition.

CO emissions for the as found condition averaged 534 ppm (@ 0% $O_2$), but were skewed higher due to the gradual buildup of condensate noted above. CO emissions at rated input averaged 193 ppm (@ 0% $O_2$). During the overfired input condition, the average CO emissions were 348 ppm (@ 0% $O_2$). Figure 4 presents the continuous emissions measurement data for this test sequence.

Figure 4 – Emissions Data (As Found, Rated, and Overfired Test)

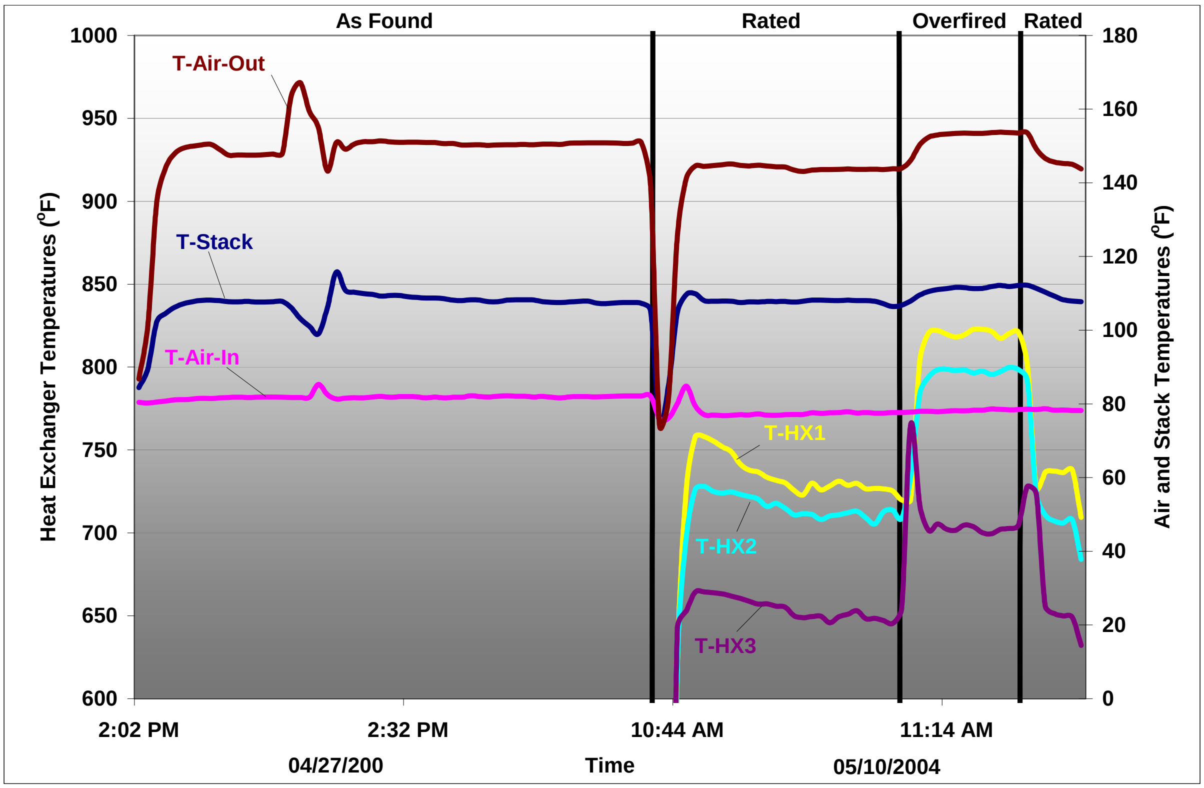



Emission test results are for information purposes. They are not the result of certified tests.

*Temperatures*
Per the protocol, heat exchanger thermocouples were not installed until after the as found test. Therefore, heat exchanger temperature data was not included in this segment. As expected, heat exchanger temperatures and outlet air temperatures were higher when operating on the overfired condition vs. the rated condition.

Figure 5 presents the continuous temperature measurement data for this test sequence.

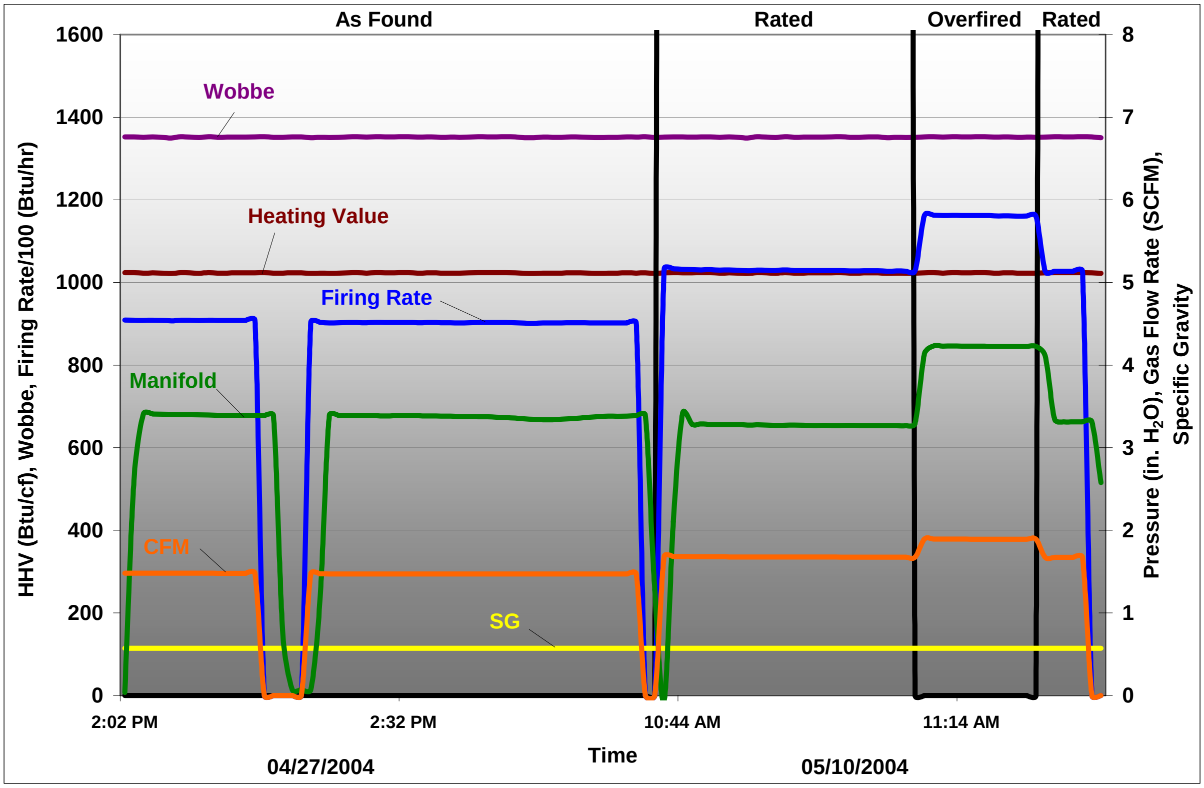
Figure 5 – Temperature Data (Performance Test)



*Gas Input*
The average as found condition firing rate was 85.9% of the nameplate rating. The average rated condition firing rate was 97.9%, and the average overfired condition firing rate was 110.6% of the nameplate rating. Fuel gas analyses show a consistent heating value and Wobbe over the course of the test sequence.

Figure 6 presents the continuous gas input measurement data for this test sequence.

Figure 6 – Gas Input Data (As Found, Rated, and Overfired Test)

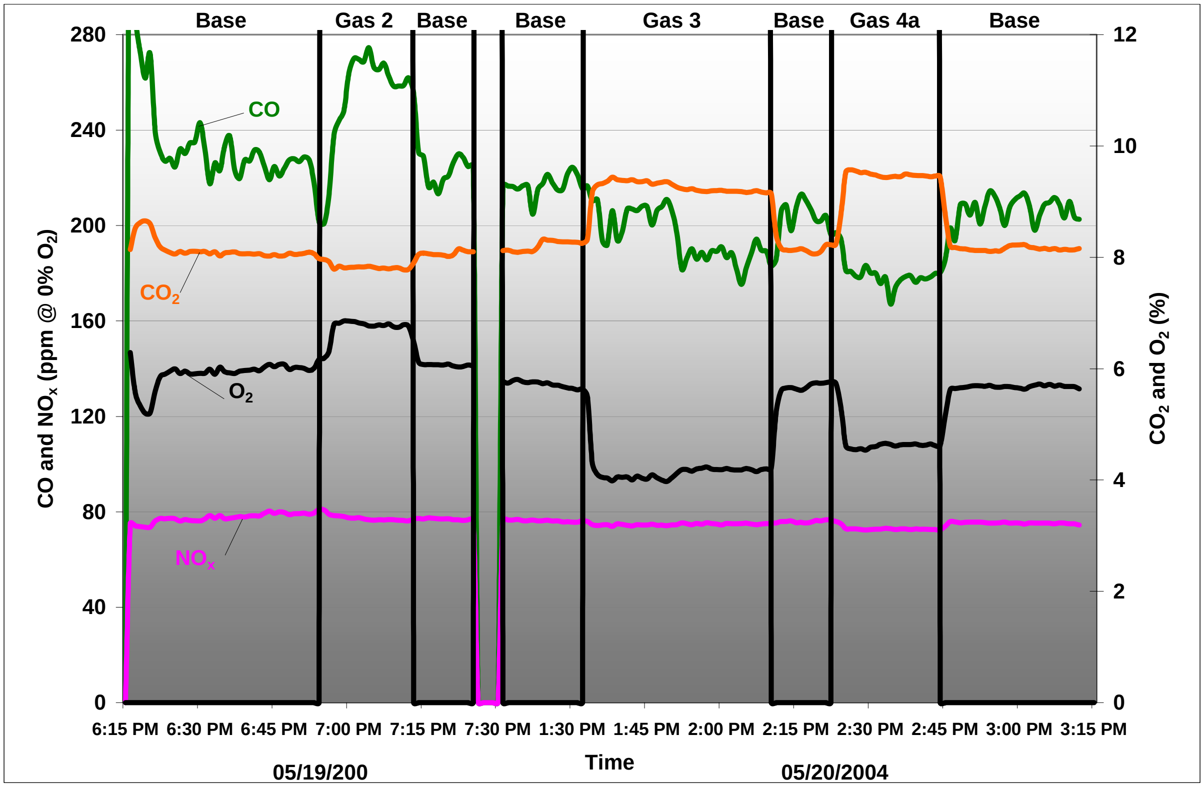


Performance Test

*Emissions*
$NO_x$ emissions during the performance test fell within a narrow range of corrected concentrations over a large range of gases tested. $NO_x$ emissions concentrations for the base gas condition averaged 77 ppm (corrected to 0% $O_2$). The average $NO_x$ concentration for the blend gases ranged from 73 ppm (@ 0% $O_2$) with Gas #4a to 77 ppm (@ 0% $O_2$) with Gas #2.

CO emissions using base gas averaged 216 ppm (@ 0% $O_2$). CO emissions were higher with the lean Gas #2 (260 ppm @ 0% $O_2$), and lower with the rich gases #3 and #4a (189 ppm and 179 ppm @ 0% $O_2$, respectively) Figure 7 presents the continuous emissions measurement data for this test sequence.

Figure 7 – Emissions Data (Performance Test)




Emission test results are for information purposes. They are not the result of certified tests.

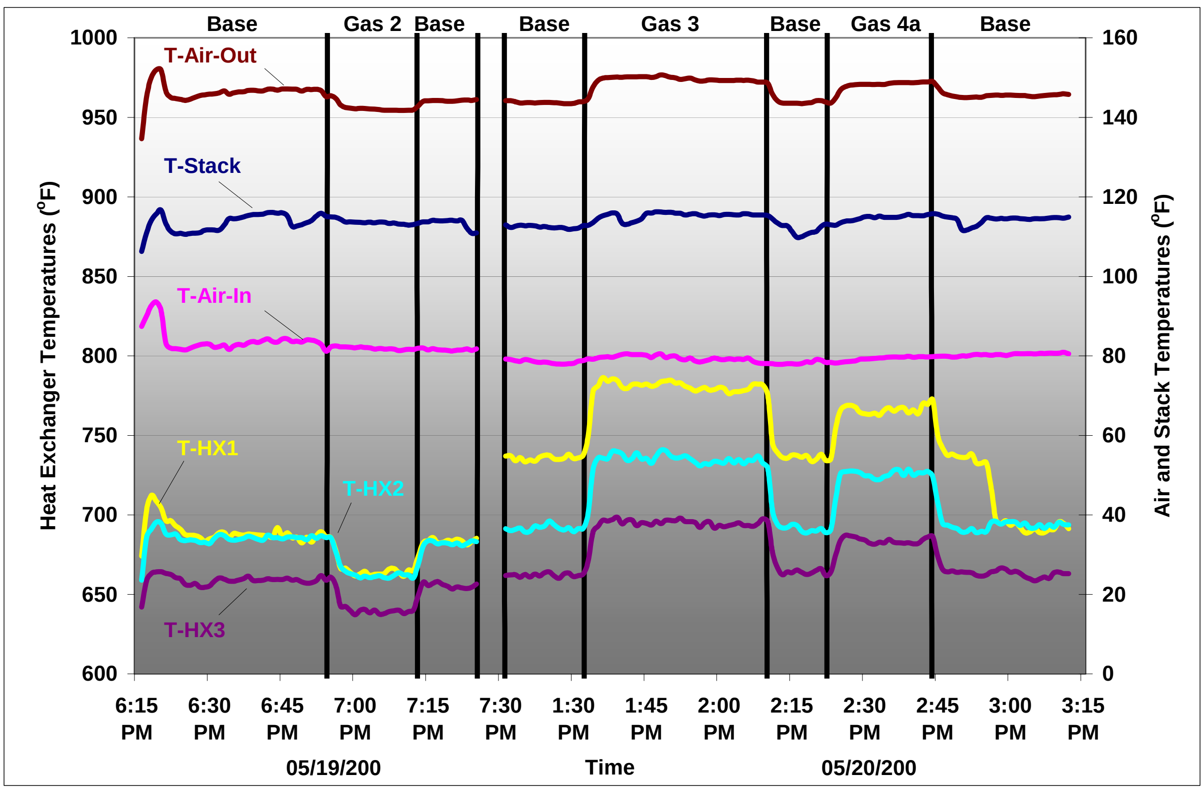
*Temperatures*

As expected, heat exchanger temperatures and outlet air temperatures were slightly higher when operating on high Btu fuel (Gas #3 and Gas #4a), but remained well below temperatures that would pose an operating concern.

Measurement anomalies were noted in one of the heat exchanger thermocouples (labeled "T-HX1"). For approximately half of the test period, measured temperatures from this thermocouple were higher than the other two heat exchanger thermocouples. For the other test segments, the measured temperatures mirrored the thermocouple labeled "T-HX2." Post-test observations found that the "T-HX1" thermocouple had a loose solder connection, and was periodically losing contact with the heat exchanger surface.

Figure 8 presents the continuous temperature measurement data for this test sequence.

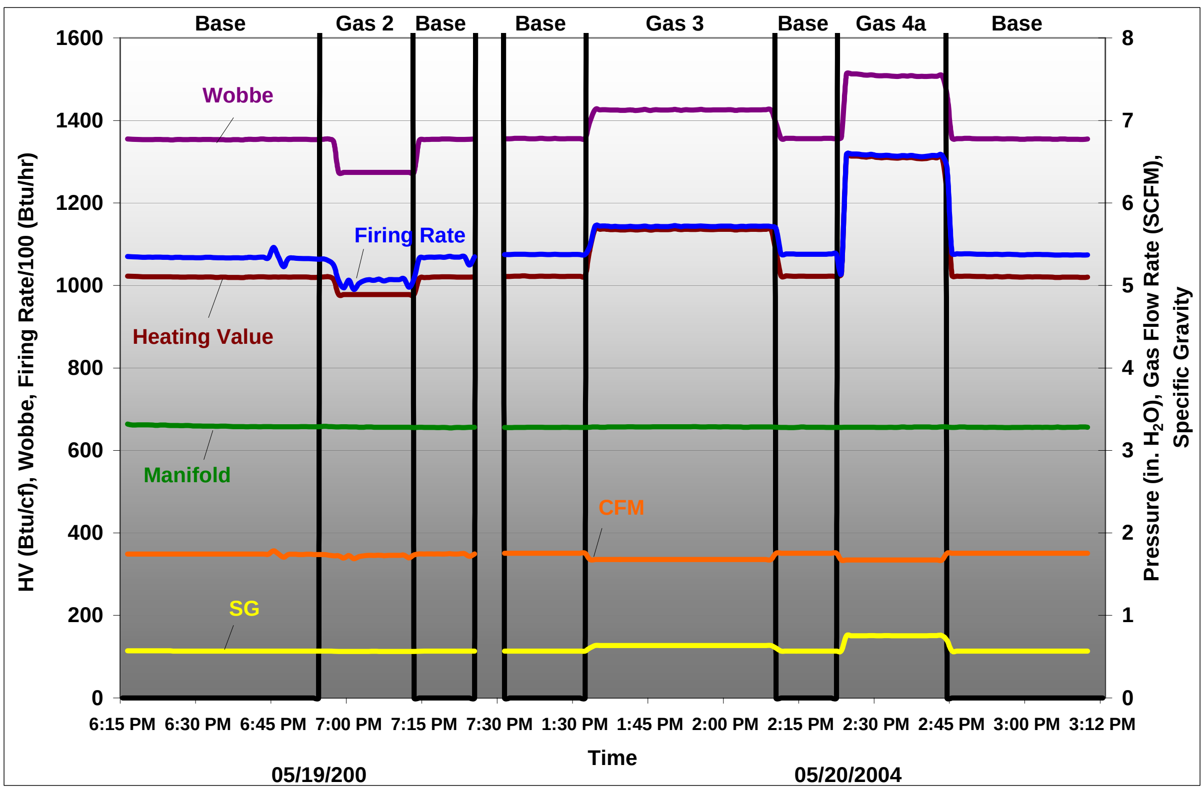
Figure 8 – Temperature Data (Performance Test)



*Gas Input*
The average Base gas firing rate (5 tests) was 102.0% of the nameplate rating. The Gas #2 firing rate averaged 96.3% of the nameplate. Gas #3 resulted in a 108.9% of the nameplate firing rate. Gas #4a yielded a 125% of the firing rate. The measured heating value and Wobbe for Gas #4a was 1309 Btu/cf and 1507, respectively. These were higher than the target values of 1150 Btu/cf and 1375 for HHV and Wobbe, due to an error in the propane mass flow control setting. The performance results, however, were not affected by the richer gas. Fuel gas analyses for the other gas blends show a consistent heating value and Wobbe over the course of the test sequence.

Figure 9 presents the continuous gas input measurement data for this test sequence.

Figure 9 – Gas Input Data (Performance Test)



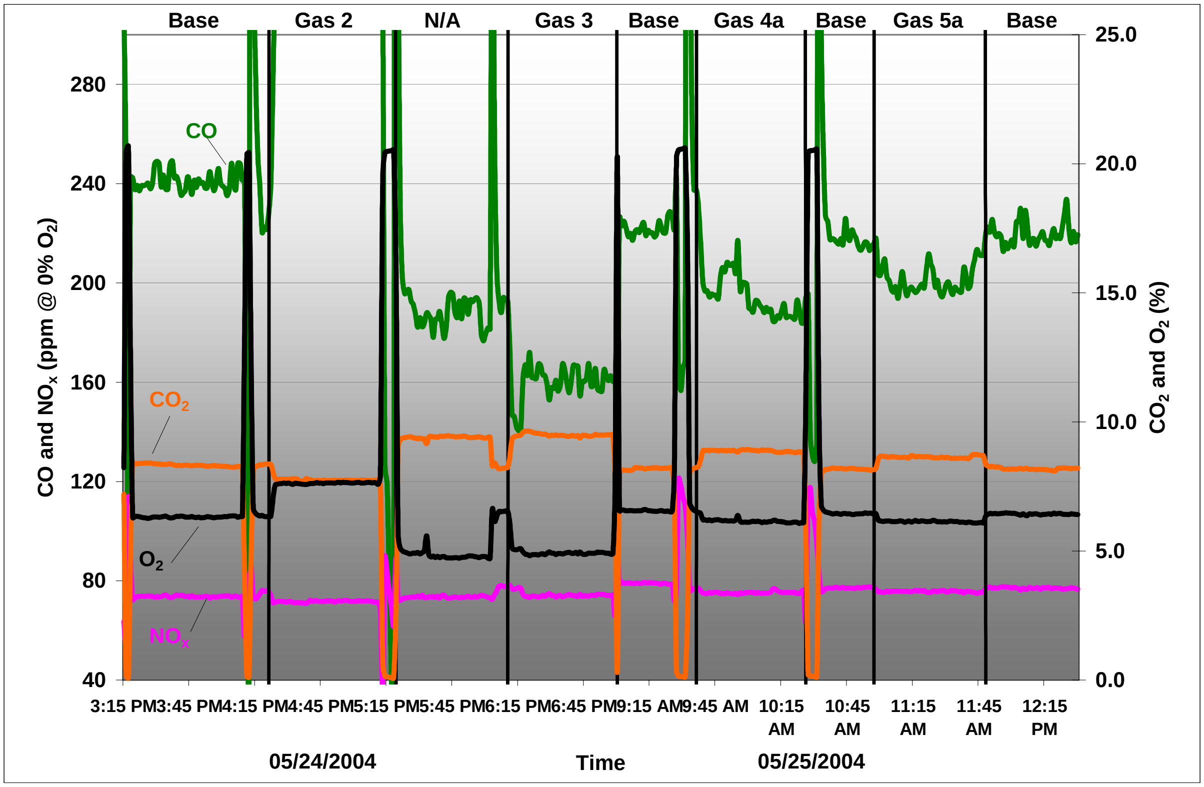
Emissions Test

*Emissions*

As observed with the performance test, $NO_x$ emissions during this test fell within a narrow range of corrected concentrations over a large range of gases tested. $NO_x$ emissions concentrations for the base gas condition averaged 77 ppm (corrected to 0% $O_2$). The average $NO_x$ concentration decreased to 72 ppm (@ 0% $O_2$) after switching to Gas #2. The average $NO_x$ concentration (@ 0% $O_2$) using Gas #3 was 74 ppm. The average $NO_x$ concentration (@ 0% $O_2$) using Gas #4a was 75 ppm.

CO emissions over the entire test ranged from 162 ppm (@ 0% $O_2$) for Gas #3 to 333 ppm (@ 0% $O_2$) for Gas #2. Figure 10 presents the continuous emissions measurement data for this test sequence.

Figure 10 – Emissions Data (Emissions Test)



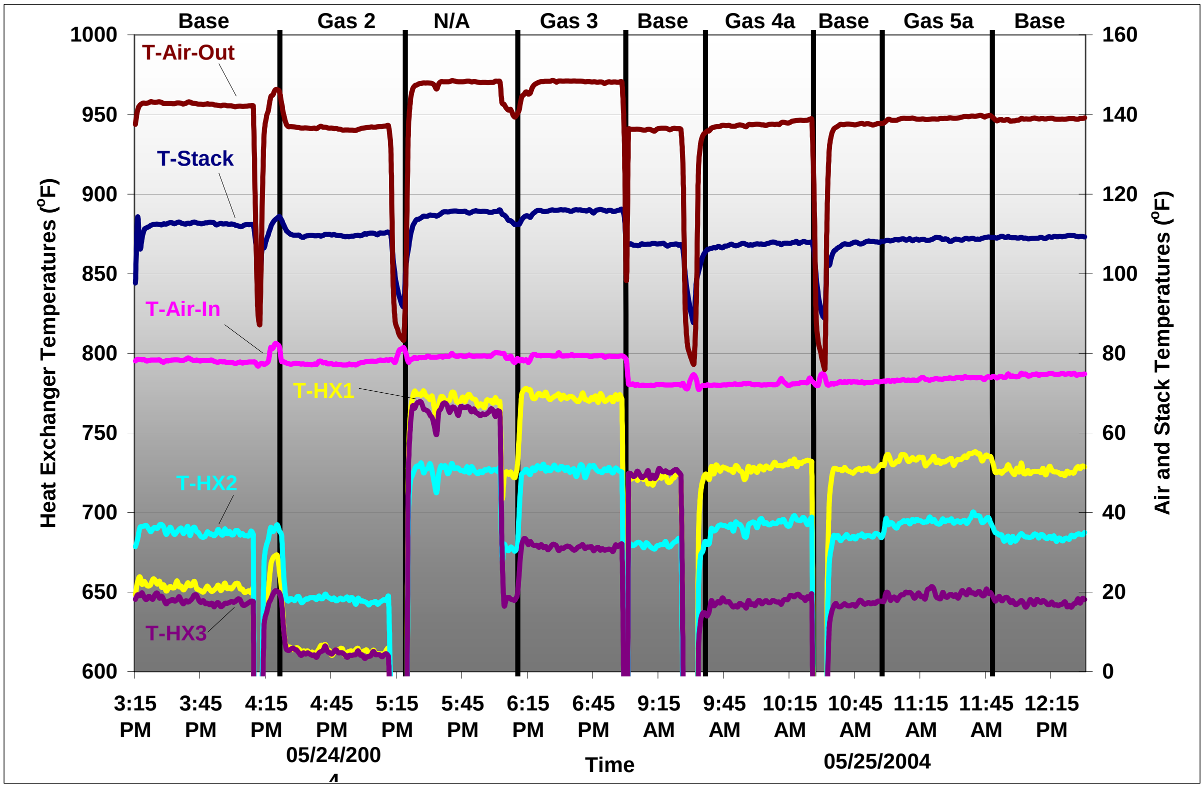

Emission test results are for information purposes. They are not the result of certified tests.

*Temperatures*

Maximum stack temperatures ranged from 107 $^oF$ (Base Gas) to 116 $^oF$ (Gas #3). Maximum average heat exchanger temperatures ranged from 622 $^oF$ (Gas #2) to 726 $^oF$ (Gas #3).

Figure 11 presents the continuous temperature measurement data for this test sequence. “T-HX1”, “T-HX2”, and “T-HX3” temperatures refer to thermocouples at three different locations on the heat exchanger surface.

Figure 11 – Temperature Data (Emissions Test)

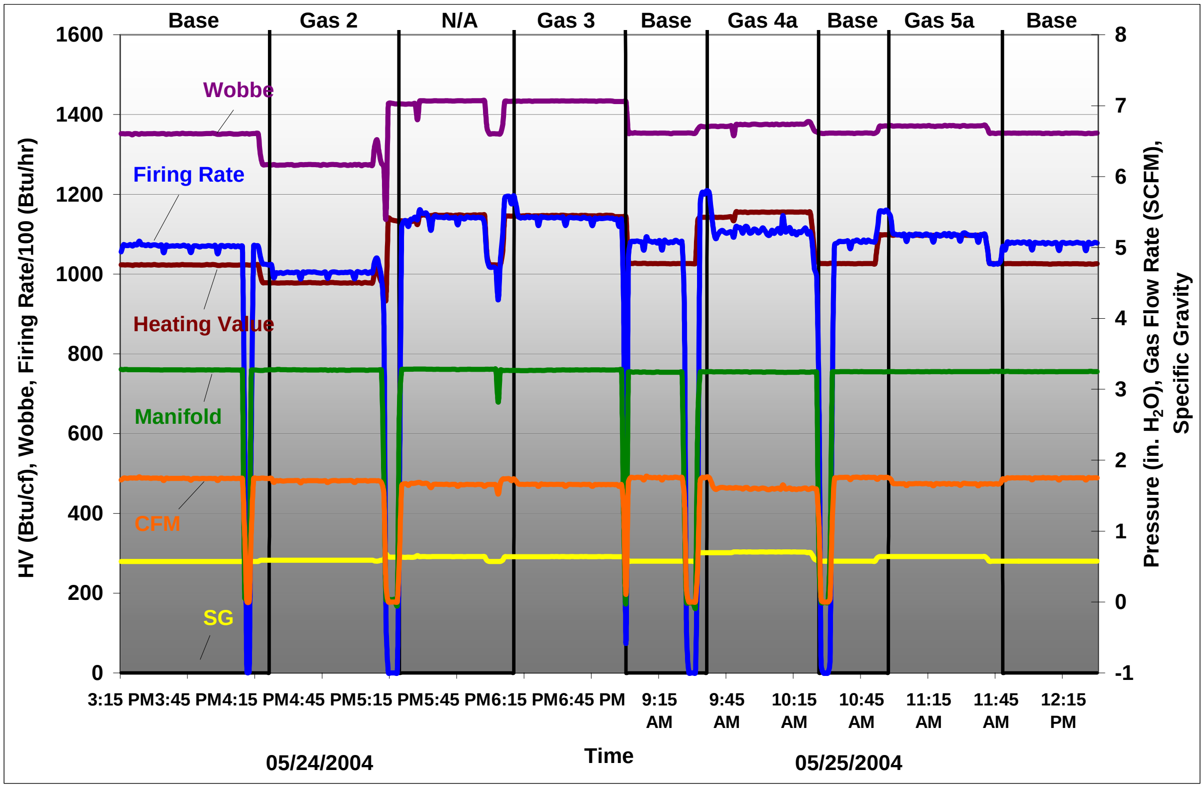


*Gas Input*

The average Base gas firing rate (4 tests) was 102.6% of the nameplate rating. The Gas #2 firing rate averaged 95.7% of the nameplate. Gas #3 resulted in a 108% of the nameplate firing rate. Gas #4a resulted in a 105.4% of the firing rate. Gas #5a resulted in a 104% of the firing rate. Fuel gas analyses show a consistent heating value and Wobbe over the course of the test sequence.

Figure 12 presents the continuous gas input measurement data for this test sequence.

Figure 12 – Gas Input Data (Emissions Test)



## Ignition Testing

A series of ignition tests was performed on the HCFAU according to the protocol detailed in Appendix A. These included hot and cold ignitions conducted at standard gas supply pressure, increased manifold pressure, and reduced gas supply pressure. These tests were conducted with pipeline gas, Gas #2 (lean gas), and Gas #3 (rich gas). In all cases, there was smooth flame carryover and no flashback observed during ignition. Results suggest that there are no issues related to ignition of this HCFAU with different gas compositions.

Table 1 – Ignition Test Observations

| Gas | Input Condition | Conclusion | Comments and Observations |
|---|---|---|---|
| Base | cold start, rated pressure | normal | immediate ignition and flame carryover |
| Base | cold start, increased manifold pressure | normal | immediate ignition and flame carryover |
| Base | cold start, reduced supply pressure | normal | immediate ignition and flame carryover |
| Base | hot start, rated pressure | normal | immediate ignition and flame carryover |
| Base | hot start, increased manifold pressure | normal | immediate ignition and flame carryover |
| Base | hot start, reduced supply pressure | normal | immediate ignition and flame carryover |
| 2 | hot start, rated pressure | normal | no discernable difference from base case |
| 3 | hot start, rated pressure | normal | slight orange tipping in flames |
| 4a | hot start, rated pressure | normal | slight orange tipping in flames |

# Appendix A
# Test Protocol – Forced-Air Furnaces

## 1. Objectives and General Approach

This protocol specifies procedures for conducting and reporting tests of forced-air furnaces with respect to their operation with re-gasified natural gas. The study is to evaluate the ability of a furnace to operate through a change to or from LNG and the effect of LNG on the operation, safety, combustion emissions or other aspects of furnace performance.

The project is to be conducted by the Center for Environmental Research and Technology of the University of California, Riverside under contract with the Southern California Gas Company. The overall approach is to evaluate furnace operation successively with a “baseline” gas and gas mixtures of high and low heat content and Wobbe Number. The gases and the sequence of their introduction are specified in the Phase II LNG Research Study Scope of Work, January 2004.

## 2. Applicable Standards

- ANSI Z21.47-2001, Standard for Gas-Fired Central Furnaces, including addenda ANSI Z21.47a-2001 and ANSI Z21.47b-2002.
- South Coast Air Quality Management District Rule 1111, NOX Emission from Natural-Gas-Fired, Fan-Type Central Furnaces, last amended July 8, 1983.
- South Coast Air Quality Management District Protocol, Rule 1111, NOX Emission from Natural-Gas-Fired, Fan-Type Central Furnaces, July 12, 1994.

## 3. Furnace Data

Record descriptive and technical data, including the following:

3.1 Furnace rating plate data

a. Model number
b. Serial number
c. Rated input
d. Temperature rise range
e. Manifold pressure

3.2 AFUE rating per FTC label

3.3 Component data (to the extent it can be observed)

a. Gas valve manufacturer & model number
b. Pilot burner or igniter manufacturer & model number. For a pilot burner, record the gas orifice diameter if marked.
c. Flame sensor manufacturer & model number and a written description

d. Ignition control type, manufacturer & model number
e. Inducer manufacturer, model number and significant rating label data
f. Diameter (or drill number) of main burner orifices

3.4 Copy installation instructions and other information shipped with the furnace.

3.5 Photograph the furnace and significant design/construction features.

## 4. Test Arrangement

4.1 Basic Setup

Unless recommended otherwise by the furnace manufacturer, an upflow furnace is to be tested on the floor with airflow into one side of the furnace. An opening is to be cut into the side of the furnace adjacent to the direct-drive circulating blower motor.

A down flow furnace is to be mounted on a duct designed to support the furnace weight and constructed otherwise in accordance with the outlet duct specified in the following section.

A horizontal furnace is to be supported on a ¾" plywood surface the same size as the furnace profile and painted flat black.

4.2 Air flow and test ductwork

A single thermocouple is to be placed at the center of the air inlet opening.

A duct with adjustable outlet shutter arrangement and nine-point thermocouple grid, constructed per section 2.3 of ANSI Standard Z21.47-2001, is to be provided at the outlet of the furnace. A four-point piezometer ring is to be provided in a plane 2" above the top of the furnace.

The outlet of a duct for an up flow furnace is to be to the side opposite the furnace inlet air opening. The discharge for a down flow furnace may be to either side. The discharge of a horizontal furnace is to be directed downward, the duct terminating at least 12 inches above the floor.

4.3 Vent pipe

4.3.1 Category I Furnaces

For all testing, a straight vertical vent pipe, five feet in length and of the diameter of the furnace vent collar, is to be provided. An integrated sample probe, per the SCAQMD Protocol for Rule 1111 is to be provided in the pipe. For furnaces with induced-draft blower immediately upstream of the vent collar, a single thermocouple is to be placed at the center of the vent pipe 6" above the vent collar (or 6" above the elbow at the collar of a horizontally discharging furnace). For furnaces judged to have less than well-mixed vent gases, a five or seven-point thermocouple grid, per Section 7.6 ASHRAE Standard 103-1993 is to be provided. Aluminum foil-faced insulation of R-value not less than seven is to be provided over the first 12" of vent pipe.

4.3.2 Category III & IV Furnaces

4.3.2.1 All testing except $NO_x$ emission tests

Based on the manufacturer's installation instructions, provide a vent with the maximum-recommended restriction. For furnaces with induced-draft blower immediately upstream of the collar, a single thermocouple is to be placed at the center of the vent pipe 6" above the vent collar (or 6" above the elbow at the collar of a horizontally discharging furnace). Provide a single-point sampling probe immediately above the thermocouple. For furnaces judged to have less than well-mixed vent gases, provide a five or seven-point thermocouple grid, per Section 7.6 ASHRAE Standard 103-1993 and an integrated sampling probe.

4.3.2.2 $NO_x$ emission tests

Provide a five-foot vent pipe per section 4.3.1 preceding.

4.4 Fuel Gas

Fuel gases are to be provided at the pressures required by test methods specified later in this protocol. Pressure is to be measured at the inlet pressure tap of the furnace gas control.

4.5 Electrical Power

Electrical power is to be provided at the voltage specified on the furnace rating plate ± 1%. If necessary to maintain air temperature rise and static pressure specifications, power to the circulating blower is to be provided separately and varied as required.

4.6 Instrumentation

Instrumentation is to be per the SCAQMD Protocol for Rule 1111. Instrumentation not specified in the Protocol is to be per ASHRAE Standard 103-1993.

4.7 Special Measures – Heat Exchanger Thermocouples

The furnace heat exchanger is to be provided with at least three thermocouples located at the hottest places. If possible, location is to be specified and thermocouples are to be applied by the furnace manufacturer. If this service is not available, locations and application is to be done per the procedure in the later section "Setup Run". Thermocouples are to be welded to the surface with minimal junction bulk and leads are to be routed away from the junction along the surface of the exchanger in a manner that will minimize fin-effect cooling of the junction.

4.8 Special Measures – Windows & Camera Access

Windows or openings for viewing the flame are to be provided to the extent that they will provide useful information and not affect furnace operation.

## 5. Test Gases

The following gases will be utilized during testing and their composition details are specified in the appendix.

| | |
|---|---|
| Baseline Gas (Gas 1) | Low Wobbe (1,330 Btu/cf), low heat content gas (1,017 Btu/hr) |
| Gas 2 | Lowest Wobbe (1,269 Btu/cf), lowest-heat content gas (974 Btu/cf) |
| Gas 3 | Highest Wobbe (1,436 Btu/cf), highest-heat content gas (1,152 Btu/cf) |
| Gas 4 | Medium Wobbe (1,370 Btu/cf), highest-heat content gas (1,145 Btu/cf) |
| Gas 4A | (4 component mix) – Medium Wobbe (1,371 Btu/cf), highest-heat content gas (1,148 Btu/cf) |
| Gas 5 | Medium Wobbe (1,374 Btu/cf), high-heat content gas (1,099 Btu/cf) |
| Gas 5A | (4 component mix) – Medium Wobbe (1,374 Btu/cf), high-heat content gas (1,100 Btu/cf) |

## 6. Basic Operating Condition

Unless required otherwise by specific test requirements, the following are to apply:

6.1 Room temperature

Hold between 65 and 85$^{o}$F. Room temperature is to be measured as specified in Section 8.5.1 of ASHRAE Standard 103-1993.

6.2 Gas supply pressure

7.0” WC ± 0.3” WC, measured during steady operation.

6.3 Firing rate

Firing rate is to be that delivered when the furnace is operated at rated manifold pressure with provided gas orifice fittings. In general the firing rate will *not* be that indicated on the rating plate.

6.4 Manifold pressure

As specified on furnace rating plate ± 0.1” WC.

6.5 Air temperature rise

At mid-point of temperature rise range on furnace rating plate, ± 2$^{o}$F.

6.6 External static pressure

Per Table 4 of ASHRAE Standard 103-1993. Voltage to the circulating blower is to be adjusted if necessary to provide required static pressure at required air temperature rise.

## 7. Testing - Baseline Gas (#1)

### 7.1 Setup run

Operate furnace on baseline gas for one hour at conditions per the preceding section. Fifteen minutes after starting, record firing rate data, $CO_2$ and carbon monoxide emission. Also record room ambient temperature, air temperature rise and stack temperature.

During operation, feel the furnace surfaces for hot spots and measure temperature of the hottest areas using a surface temperature probe and technique. Locate the three or four hottest spots.

If the furnace manufacturer has not provided heat exchanger thermocouples or specified thermocouple locations, disassemble the heat exchanger from the furnace after the one-hour period of firing. Examine the exchanger to locate hot spots as indicated by metal colorization. Install at least three thermocouples at the locations indicating the hottest temperatures, by spot welding. Route thermocouple leads along the exchanger surface out of direct air impingement to avoid fin effect cooling of the junction. Reassemble heat exchanger into furnace.

For a horizontal furnace, provide five or six thermocouples between the furnace and the plywood support surface. Locate the thermocouples near the outlet duct connection, adjacent to the burner and at the partition between the burner and heat exchanger compartments.

### 7.2 Rated input

Note: The purpose of this section is to provide reference information for the furnace at rated input – as opposed to the "as-shipped" condition. If gas injector orifices are too small to allow as-rated operation, these tests are to be postponed until all as-shipped testing is completed or until appropriate injectors are available.

Adjust furnace to operate at the rating plate input, holding manifold pressure within 10% of that specified on the rating plate. (If rated input cannot be achieved, postpone testing required in this section, per the preceding note.) After 15 minutes of operation, record input and combustion data ($CO_2$ & CO). Immediately thereafter adjust manifold pressure to fire at 112% of rated input. After 15 minutes, record input and combustion data ($CO_2$ & CO).

Return to the rated input condition and continue operation to steady state as required by the AQMD protocol and record data required by the protocol. After obtaining this data, record the heat exchanger temperatures and surface temperatures.

During the test observe flame and note yellow tipping and flame lifting phenomena or lack of same.

7.3 Basic operating condition

7.3.1 Steady operation

7.3.1.1 Category I Furnaces

Re-adjust unit to the basic operating condition. Determine input and combustion data ($CO_2$ & CO) at 15 minutes. Do not conduct "over fire" test and do not adjust firing rate. Continue operation to steady conditions as required by the AQMD protocol and record emission data required by the protocol. Record stack and heat exchanger temperatures and surface temperatures immediately after obtaining emission data.

During the test observe flame and note yellow tipping and flame lifting or flashback phenomena or lack of same.

If significant yellow tipping is noticed, an additional steady operation test is to be conducted with a suitable clean surface in the combustion product path. Placement of ceramic fiber paper at a flow impact point is a possible approach.

7.3.1.2 Category II and III Furnaces

Basic combustion quality and flame behavior are to be determined with the maximum-restriction vent. Upon completion of those tests, the five-foot vertical vent is to be installed on the furnace for NOx emission tests. Except for vent changes, the procedure is to be per the preceding section.

7.3.2 Burner and ignition operating characteristics

7.3.2.1 Vents

For Category I furnaces, these tests are to be conducted with the five foot vertical vent. For Category II and III furnaces, tests are to be conducted with the maximum restriction vent.

7.3.2.2 Cold operation

With the furnace adjusted to the basic operating condition and essentially at room temperature, initiate burner operation by means of a switch at the wall thermostat terminals. Allow the burners to operate for 5 seconds and turn them off. Repeat three times. Observe and record operation with respect to:

a. Immediate ignition and carryover to all burners

b. Flashback. If flashback is noted, allow burners to operate for 30 seconds to determine if clearing occurs.
c. Flame rollout
d. Instability of the main or pilot burner flames

Repeat the sequence with supply pressure at 4.0” WC.

Repeat the sequence with the gas valve knob throttled as necessary to fire the furnace at 1/3 of its normal firing rate, or at 87% of the minimum firing rate, whichever is less.

7.3.2.3 Hot operation

Repeat the testing of the previous section at all three supply pressure conditions with the furnace at steady state and at the basic operating condition. Observe and record the same phenomena.

7.4 Special tests

Special tests may be conducted to investigate phenomena of concern to the furnace manufacturer. The decision of whether or not to test and the design of appropriate tests will be discussed with the manufacturer.

## 8. Testing - Substitute Gases

For substitute gases #2, #3 and #4 conduct the following tests:

8.1 High-speed switch from baseline gas to substitute gas

Operate furnace on the baseline gas for 15 minutes at the basic operating condition. Conduct a high-speed switch to the substitute gas and record observations. Possible phenomena include flame color change, flame lifting, flashback or rollout, pilot burner instability or outage, etc.

Record emission data before, during and after changeover.

8.2 Steady operation

Conduct steady operation testing, as outlined for the baseline gas in section 7.3.1 preceding. Record input data, emission data, temperature and flame appearance data per that section. Do not adjust furnace operation except in minor ways to maintain the basic operating condition.

8.3 Burner and ignition operating characteristics

Conduct steady operation testing, as outlined for the baseline gas in section 7.3.2 preceding.

8.4 Special tests

Special tests, per section 7.4 preceding, will be conducted as appropriate.

8.5 High-speed switch from substitute gas to baseline gas

Operate furnace on the substitute gas for 15 minutes at the basic operating condition. Conduct a high-speed switch to the baseline gas and record observations and emission data per section 8.1.

## 9. Additional Testing

Conduct additional testing and/or testing with other gas blends, per the Phase II protocol, when test results or observations indicate it is necessary.

If indicated additional testing is outside of the project scope, include appropriate comment in the test report.

## 10. Calculations

NOX emission is to be calculated the AQMD protocol for Rule 1111, using the furnace AFUE rating as listed in the most recent directory of the Gas Appliance Manufacturers Association.

## Rationale - Test Setup and Procedure

Firing rate:

Most safety, performance and emission standards require that a gas appliance be operated at its rated input ± 2%. However a degree of de-rating is not uncommon because manufacturers must accommodate things beyond their control such as component and process tolerances and fuel gas property variation. Changing the as-shipped unit to fire at rated input would defeat the purpose of this study, i.e. to determine the effect of operation with different gas blends *without* adjustment.

The protocol requires that tests be run with provided gas injector orifices and at rated manifold pressure – as specified on the furnace rating plate. For reference, however, additional testing with the baseline gas (only) is required at rated input and at the “over fired” (112%) condition.

Burner and ignition operating characteristics:

While substitute gas compositions do not indicate likely problems, full-blown testing of burner and ignition systems per the safety standards would be more extensive than the program allows for. The testing specified in this protocol provides for observation of deviant phenomena, but does not include investigation of pilot and valve turndown characteristics, ignition system timing, etc.

Vent pipe choice:

Standards ANSI Z21.47, ASHRAE 103-1993 and SCAQMD Protocol for Rule 1111 differ with respect to the vent pipe. The specified pipe is basically per the SCAQMD convention, but has the addition of a thermocouple and insulation near the furnace collar to allow vent temperature measurement. Performance of a fan-assisted furnace is not significantly affected by the vent configuration provided that the provision of the thermocouple and sampling probe are such that substantially open flow area is maintained.

Backflow testing of down flow and horizontal furnaces:

Backflow tests (circulating blower failure and filter temperatures, etc) are not included in the test protocol because the imposed gas and firing rate changes are not expected to affect operation of the limit controls that protect against the condition. Accordingly, horizontal furnace test setup does not include an upturned inlet duct (which induces buoyancy-driven backflow when the blower motor is disabled).

Temperature of component and installation surfaces:

Setup and testing to determine temperature hazards with respect to heat exchangers, operating components and combustible surfaces is complex and time-consuming. The specified testing is limited to measurement of temperature at semi-subjectively determined “hot” areas. If there are adverse or unexpected findings, additional testing is to be recommended.

# Appendix B
# Equipment Schematics

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<u>Overall Setup for the Test Cell</u>

The overall setup of the equipment included a number of sub systems, including gas supply, gas composition blending and analysis, gas appliance, flue gas monitoring, and data acquisition. The overall schematic is shown in Figure B1 below. Gas analysis was accomplished with a residual gas analyzer (RGA), model QMS-300, from Stanford Research Systems, Inc. (Sunnyvale, CA). A schematic of the fully instrumented HC-FAU is shown in Figure B2.

Figure B1 – Overall Equipment Layout

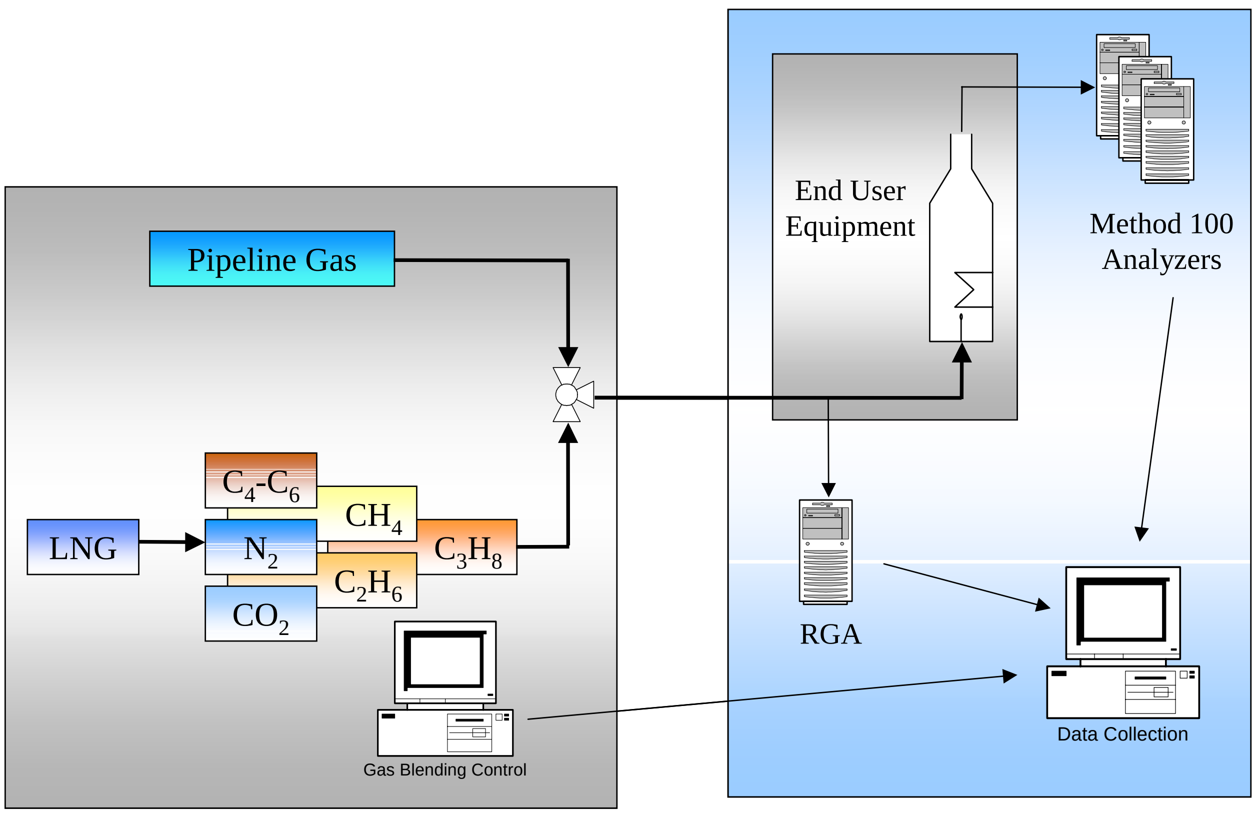
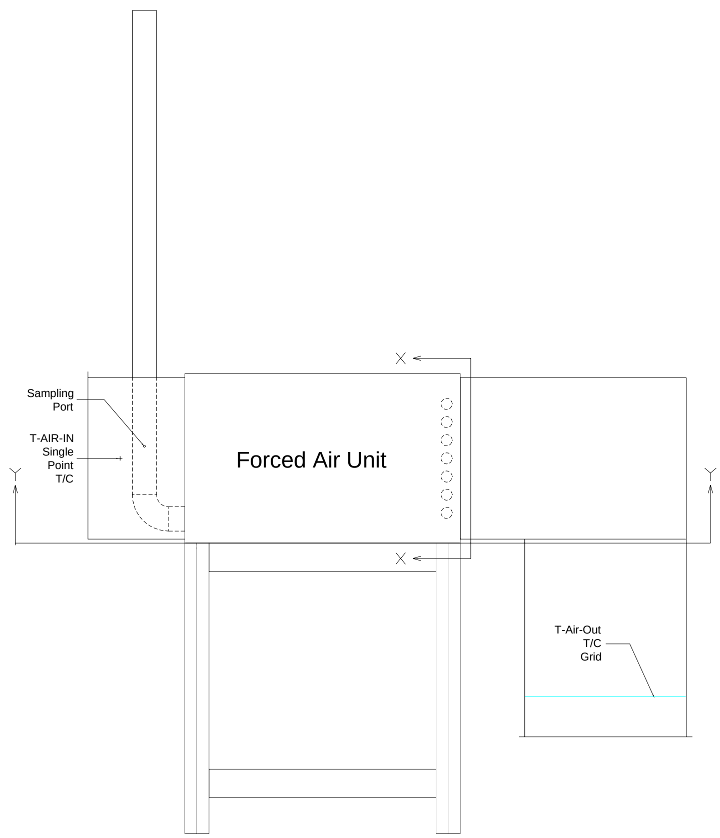


Figure B2 – HCFAU Schematic with Instrumentation




*The schematic shown above illustrates the ventilation used for the emissions tests. Performance tests were conducted using 65 ft. of external exhaust vent with six (6) “ells.” In both cases (emission and performance tests), the sample probe was located approximately two feet from the exhaust vent exit of the HCFAU.

## Appendix C
## Gas Composition and Blending

The project required testing the range of gas compositions shown in Table C1. As indicated in the Table, there were primary, secondary and tertiary gases. The primary gases included the baseline or set-up gas and others that outlined the boundary conditions for compositions determined by SCG. Secondary gases were intermediate gases within the boundary conditions and were used for processes that exhibit sensitivities to primary gases. Tertiary gas compositions depended on results from the secondary gases and had properties that were incremental changes in heat content or Wobbe number, depending on results from secondary gas.

**Table C1 - Range of Some Properties and Gas Compositions for This Study**

**Test Gas**

| Primary | | $CH_4$ | $C_2H_6$ | $C_3H_8$ | iso-$C_4H_{10}$ | n-$C_4H_{10}$ | iso-$C_5H_{12}$ | n-$C_5H_{12}$ | $C_6$ plus | $CO_2$ | $O_2$ | $N_2$ | Wobbe# | HHV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | Baseline, Line Gas | 96.08 | 1.78 | 0.37 | 0.06 | 0.06 | 0.01 | | 0.03 | 1.18 | | 0.44 | 1339 | 1022 |
| **2** | 970 Btu Gas | 96.00 | | | | | | | | 3.00 | | 1.00 | 1271 | 974 |
| | or 1000 Btu Gas | 97.00 | 0.75 | 0.10 | | | | | | 2.00 | | 0.15 | 1315 | 1000 |
| **3** | 1150 Btu Gas, Hi Wobbe | 87.03 | 9.23 | 2.76 | 0.99 | | | | | | | | 1437 | 1150 |
| **4** | 1150 Btu Gas, Lo Wobbe | 84.92 | 4.79 | 2.40 | 1.20 | 1.20 | 0.60 | 0.60 | 0.30 | 3.00 | 0.20 | 0.80 | 1375 | 1150 |
| **4a** | or 4 component mix | 84.45 | | 11.55 | | | | | | 3.00 | | 1.00 | 1375 | 1150 |
| Secondary | | | | | | | | | | | | | | |
| | *If fails test gas 4* | | | | | | | | | | | | | |
| **5** | 1100 Btu Gas, Avg. Wobbe | 88.88 | 5.28 | 2.61 | 0.34 | 0.50 | 0.11 | 0.06 | 0.06 | 1.40 | | 0.75 | 1376 | 1100 |
| **5a** | or 4 component mix | 90.85 | | 7.00 | | | | | | 1.40 | | 0.75 | 1376 | 1099 |

## Appendix D
## Equipment List

| Measurement | Equipment | Technology | Range |
|---|---|---|---|
| high CO concentration | Horiba VIA-50 | NDIR | 0-10% programmable |
| low CO concentration | Horiba CMA-331A | NDIR | 0-200 ppm, 0-1000 ppm |
| $O_2$ concentration | Horiba CMA-331A | para-magnetic pressure | 0-10%, 0-25% |
| $CO_2$ concentration | Horiba CMA-331A | NDIR | 0-5%, 0-2% |
| calibration gas divider | STEC SGD-710C | capillary | 10% increments |
| gas component flow | Unit Instruments 5301, 5361 | mass flow controllers | 0-50 lpm (5301),<br>0-100 lpm (5361) |
| total gas input | Rockwell R-275 | dry gas meter | 0-200 cfm |
| gas composition | Stanford Research Institute QMS-300 | quadrapole mass spectroscopy | 0-100% methane<br>0-15% non-methane |

# Appendix E
# Calculations

Emissions Concentrations

Corrected to 0% $O_2$

CO and $NO_x$ conc. (at 0% $O_2$) = $ppm \times \left[ \frac{20.9 - 0\%}{20.9 - \%O_2} \right]$

Where

ppm = measured CO or $NO_x$ concentration, ppmv
% $O_2$ = measured $O_2$ concentration, percent by volume

Corrected Fuel Flow Rate

$$SCFH = ACFH \times GMC \times \left[ \frac{FP + BP}{14.62\,psia} \right] \times \left[ \frac{519.67^o\,R}{FT + 459.67^o\,F} \right]$$

Where
SCFH = standard cubic feet per hour
ACFH = actual cubic feet per hour
FP = gas supply fuel pressure (psig)
BP = barometric pressure (psia)
14.62 psia = standard atmospheric pressure
519.67 $^oR$ = standard atmospheric temperature
FT = gas supply fuel temperature ($^oF$)

Input Rate

Input Rate (Btu/hr) = SCFH x HHV

Where

SCFH = standard cubic feet per hour of fuel gas
HHV = higher heating value of fuel gas (Btu/cf)

Wobbe

$$W_o = \frac{HHV}{\sqrt{SG}}$$

Where

$W_o$ = Wobbe number (Btu/cf)
HHV = higher heating value (Btu/cf)
SG = specific gravity of fuel gas

# Appendix F
# Tabulated Results

| Table of Averages<br>Horizontal Condensing FAU<br>As Found, Rated, and Overfired Test<br>04/27/2004 - 05/10/2004 | | | | |
|---|---|---|---|---|
| **Gases** | **As Found** | **Rated** | **Overfired** | **Rated** |
| HHV (Btu/cf) | 1,023 | 1,023 | 1,023 | 1,024 |
| Wobbe (Btu/cf) | 1,352 | 1,352 | 1,352 | 1,353 |
| Input Rate (Btu/hr) | 90,194 | 102,824 | 116,145 | 102,722 |
| Corrected SCFH | 88.2 | 100.5 | 113.5 | 100.4 |
| **Emissions (not from certified tests)** | | | | |
| Raw $O_2$ (%) | 4.30 | 5.69 | 3.06 | 5.11 |
| Raw $CO_2$ (%) | 8.93 | 8.11 | 9.61 | 8.54 |
| CO (ppm @ 0% $O_2$) | 533.9 | 204.2 | 348.2 | 182.0 |
| $NO_X$ (ppm @ 0% $O_2$) | 62.5 | 74.0 | 67.8 | 72.1 |
| **Temperatures (°F)** | | | | |
| Ambient | 81.7 | 77.2 | 78.1 | 77.9 |
| Avg. HX | N/A | 695.6 | 773.5 | 705.5 |
| Gas | 80.2 | 75.0 | 75.6 | 75.8 |
| Exhaust | 107.6 | 107.8 | 111.5 | 109.8 |
| Inlet Air | 82.0 | 77.5 | 78.2 | 78.4 |
| Outlet Air | 150.7 | 143.6 | 153.4 | 146.7 |
| **Pressures** | | | | |
| Supply (in. w.c.) | 7.15 | 7.10 | 7.08 | 7.11 |
| Manifold (in. w.c.) | 3.37 | 3.27 | 4.23 | 3.32 |

| Gas Composition<br>04/27/2004-5/10/2004<br>As Found, Rated, and Overfired Test | | | | |
|---|---|---|---|---|
| Component | As Found | Rated | Overfired | Rated |
| C1 | 97.9 | 97.8 | 97.9 | 97.9 |
| C2 | 1.2 | 1.3 | 1.3 | 1.3 |
| C3 | 0.2 | 0.2 | 0.2 | 0.2 |
| iC4 | 0.0 | 0.0 | 0.0 | 0.0 |
| nC4 | 0.2 | 0.2 | 0.2 | 0.2 |
| iC5 | 0.0 | 0.0 | 0.0 | 0.0 |
| nC5 | 0.0 | 0.0 | 0.0 | 0.0 |
| C6 | 0.0 | 0.0 | 0.0 | 0.0 |
| CO2 | 0.6 | 0.5 | 0.5 | 0.5 |
| O2 | 0.0 | 0.0 | 0.0 | 0.0 |
| N2 | 0.3 | 0.3 | 0.3 | 0.3 |
| Total Mole % | 100.4 | 100.4 | 100.4 | 100.4 |

| Table of Averages<br>Horizontal Condensing FAU<br>Performance Tests<br>05/19/2004 - 05/20/2004 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Gases** | **Base** | **2** | **Base** | **Base** | **3** | **Base** | **4a** | **Base** |
| HHV (Btu/cf) | 1,020 | 978 | 1,020 | 1,022 | 1,136 | 1,022 | 1,309 | 1,020 |
| Wobbe (Btu/cf) | 1,354 | 1,274 | 1,354 | 1,356 | 1,426 | 1,356 | 1,507 | 1,354 |
| Input Rate (Btu/hr) | 106,528 | 101,090 | 106,524 | 107,497 | 114,358 | 107,592 | 130,880 | 107,398 |
| Corrected SCFH | 104.4 | 103.4 | 104.4 | 105.2 | 100.7 | 105.2 | 101.4 | 105.3 |
| **Emissions (not from certified tests)** | | | | | | | | |
| Raw $O_2$ (%) | 6.01 | 6.77 | 6.05 | 5.64 | 4.19 | 5.74 | 4.63 | 5.68 |
| Raw $CO_2$ (%) | 8.07 | 7.79 | 8.11 | 8.27 | 9.17 | 8.14 | 9.46 | 8.14 |
| CO (ppm @ 0% $O_2$) | 225.7 | 260.0 | 226.9 | 219.6 | 188.8 | 202.2 | 178.9 | 205.7 |
| $NO_X$ (ppm @ 0% $O_2$) | 79.3 | 76.5 | 76.6 | 75.9 | 74.9 | 76.3 | 72.6 | 75.0 |
| **Temperatures (°F)** | | | | | | | | |
| Ambient | 81.7 | 79.0 | 79.0 | 77.7 | 77.5 | 77.0 | 78.3 | 79.0 |
| Avg. HX | 676.6 | 655.3 | 673.6 | 696.7 | 736.3 | 696.4 | 726.1 | 683.1 |
| Gas | 78.8 | 78.5 | 78.4 | 74.8 | 75.4 | 75.5 | 76.2 | 77.2 |
| Exhaust | 114.3 | 113.1 | 112.4 | 112.2 | 115.6 | 111.7 | 115.4 | 114.8 |
| Inlet Air | 83.6 | 81.6 | 81.6 | 78.3 | 78.7 | 78.6 | 79.7 | 80.7 |
| Outlet Air | 146.9 | 141.8 | 144.3 | 143.7 | 149.1 | 143.9 | 148.9 | 145.8 |
| **Pressures** | | | | | | | | |
| Supply (in. w.c.) | 6.91 | 7.01 | 6.92 | 6.90 | 6.86 | 6.90 | 6.95 | 6.91 |
| Manifold (in. w.c.) | 3.29 | 3.28 | 3.28 | 3.28 | 3.28 | 3.28 | 3.28 | 3.28 |

| Gas Composition<br>05/19/2004-5/20/2004<br>Performance Test | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Component | Base | Gas 2 | Base | Base | Gas 3 | Base | Gas 4a | Base |
| C1 | 97.9 | 95.8 | 97.9 | 97.8 | 87.3 | 97.8 | 79.1 | 98.0 |
| C2 | 0.9 | 0.0 | 0.9 | 1.1 | 9.3 | 1.1 | 0.2 | 0.9 |
| C3 | 0.1 | 0.0 | 0.1 | 0.1 | 2.7 | 0.1 | 19.5 | 0.1 |
| iC4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| nC4 | 0.3 | 0.3 | 0.3 | 0.3 | 0.5 | 0.3 | 0.3 | 0.2 |
| iC5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| nC5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| C6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| CO2 | 0.0 | 2.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| O2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| N2 | 0.8 | 1.0 | 0.8 | 0.8 | 0.2 | 0.8 | 1.0 | 0.8 |
| Total Mole % | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

# Gas Quality and LNG Research Study
## Appendix A - 1

| Table of Averages<br>Horizontal Condensing FAU<br>Emissions Test<br>05/24/2004 - 05/25/2004 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Gases** | **Base** | **2** | **3** | **Base** | **4a** | **Base** | **5a** | **Base** |
| HHV (Btu/cf) | 1,023 | 978 | 1,145 | 1,027 | 1,155 | 1,026 | 1,098 | 1,026 |
| Wobbe (Btu/cf) | 1,351 | 1,274 | 1,433 | 1,354 | 1,379 | 1,353 | 1,372 | 1,353 |
| Input Rate (Btu/hr) | 106,972 | 100,434 | 113,406 | 108,129 | 110,720 | 108,190 | 109,469 | 107,807 |
| Corrected SCFH | 104.6 | 102.7 | 99.1 | 105.3 | 95.8 | 105.4 | 99.7 | 105.1 |
| **Emissions (not from certified tests)** | | | | | | | | |
| Raw $O_2$ (%) | 6.34 | 7.64 | 4.91 | 6.54 | 6.11 | 6.43 | 6.11 | 6.44 |
| Raw $CO_2$ (%) | 8.26 | 7.74 | 9.49 | 8.21 | 8.83 | 8.18 | 8.60 | 8.19 |
| CO (ppm @ 0% $O_2$) | 243.1 | 333.4 | 162.2 | 224.6 | 187.5 | 217.2 | 200.0 | 221.2 |
| $NO_X$ (ppm @ 0% $O_2$) | 73.6 | 71.9 | 74.2 | 78.8 | 75.2 | 77.1 | 75.5 | 76.9 |
| **Temperatures (°F)** | | | | | | | | |
| Ambient | 76.1 | 76.5 | 78.6 | 70.3 | 70.5 | 71.0 | 72.0 | 72.9 |
| Avg. HX | 659.9 | 621.9 | 725.5 | 710.1 | 691.1 | 685.4 | 694.3 | 683.4 |
| Gas | 75.5 | 75.5 | 76.8 | 69.7 | 69.8 | 69.9 | 70.7 | 71.4 |
| Exhaust | 112.3 | 110.1 | 115.9 | 107.3 | 107.9 | 107.8 | 108.8 | 109.5 |
| Inlet Air | 77.8 | 78.1 | 79.3 | 72.1 | 72.5 | 72.7 | 73.9 | 74.8 |
| Outlet Air | 142.1 | 136.9 | 148.1 | 136.4 | 138.5 | 137.7 | 139.5 | 138.9 |
| **Pressures** | | | | | | | | |
| Supply (in. w.c.) | 7.18 | 7.23 | 7.27 | 7.16 | 7.20 | 7.16 | 7.22 | 7.17 |
| Manifold (in. w.c.) | 3.27 | 3.27 | 3.27 | 3.24 | 3.24 | 3.25 | 3.25 | 3.25 |

| Gas Composition<br>05/24/2004-5/25/2004<br>Emissions Test | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Component | Base | Gas 2 | Gas 3 | Base | Gas 4a | Base | Gas 5a | Base |
| C1 | 97.9 | 96.3 | 87.9 | 97.7 | 84.7 | 97.7 | 91.2 | 97.8 |
| C2 | 1.2 | 0.0 | 9.4 | 1.4 | 0.1 | 1.3 | 0.1 | 1.3 |
| C3 | 0.2 | 0.0 | 2.6 | 0.3 | 11.5 | 0.3 | 6.7 | 0.3 |
| iC4 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| nC4 | 0.2 | 0.1 | 0.5 | 0.3 | 0.2 | 0.3 | 0.2 | 0.3 |
| iC5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| nC5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| C6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| CO2 | 0.5 | 2.9 | 0.0 | 0.6 | 2.8 | 0.6 | 1.4 | 0.5 |
| O2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| N2 | 0.3 | 1.0 | 0.0 | 0.3 | 1.1 | 0.3 | 0.9 | 0.3 |
| Total Mole % | 100.4 | 100.4 | 100.7 | 100.5 | 100.4 | 100.5 | 100.5 | 100.5 |