Gas Quality and LNG Research Study
Appendix A - 7

LNG Research Study

Testing of a Pool Heater with a Pre-Mix Burner

Prepared for
The Southern California Gas Company

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Table of Contents

Table of Figures

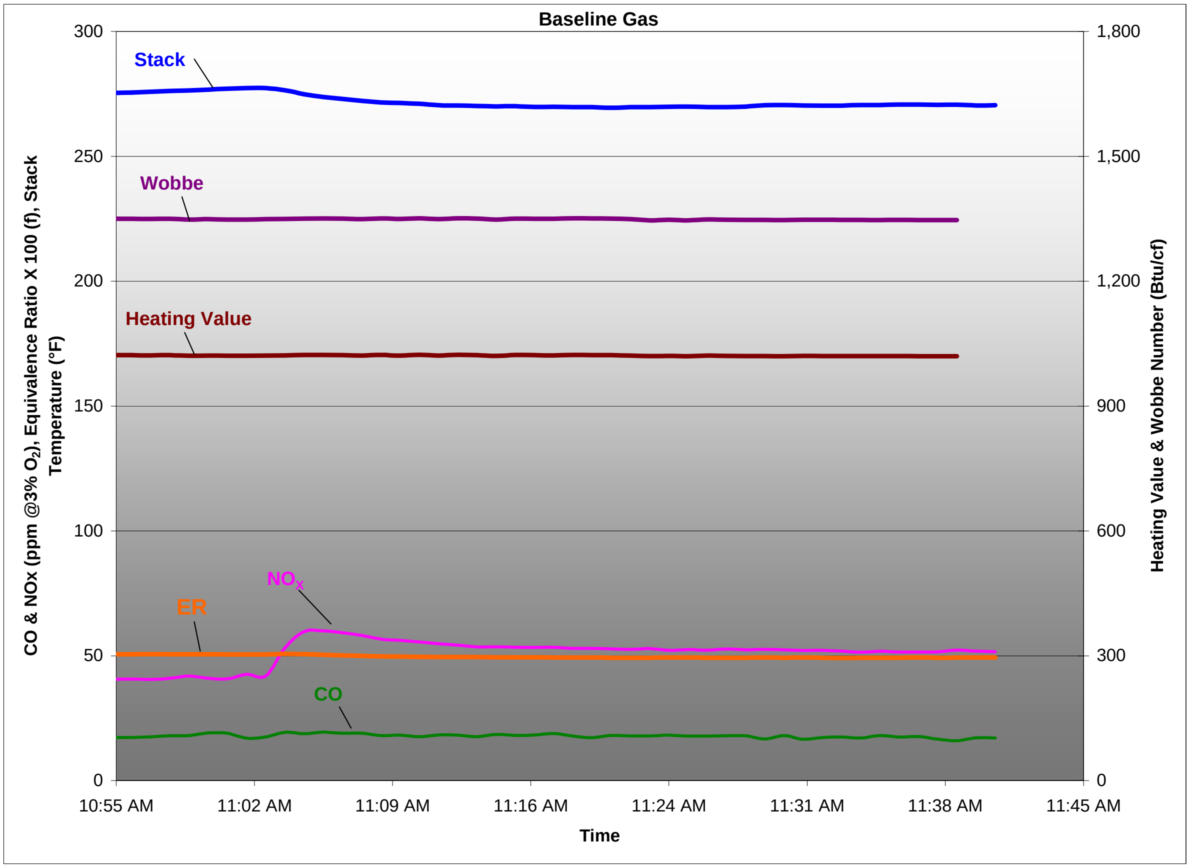
RESULTS SUMMARY

The residential pre-mix pool heater was tested over a wide range of operating conditions, gas properties and composition and showed some sensitivities to the gas blends tested with regard to 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 Test

NO_x emissions during the test sequence, corrected to 3% oxygen, averaged 52.8 ppm. Corrected CO emissions averaged 17.8 ppm. The as-found firing rate was 91.4% rated input. This was conducted with baseline gas. A summary of the continuous test data and calculations for the as-found test is shown in Figure 1.

Figure 1 – Summary of Pre-Mix Pool Heater As-Found Testing

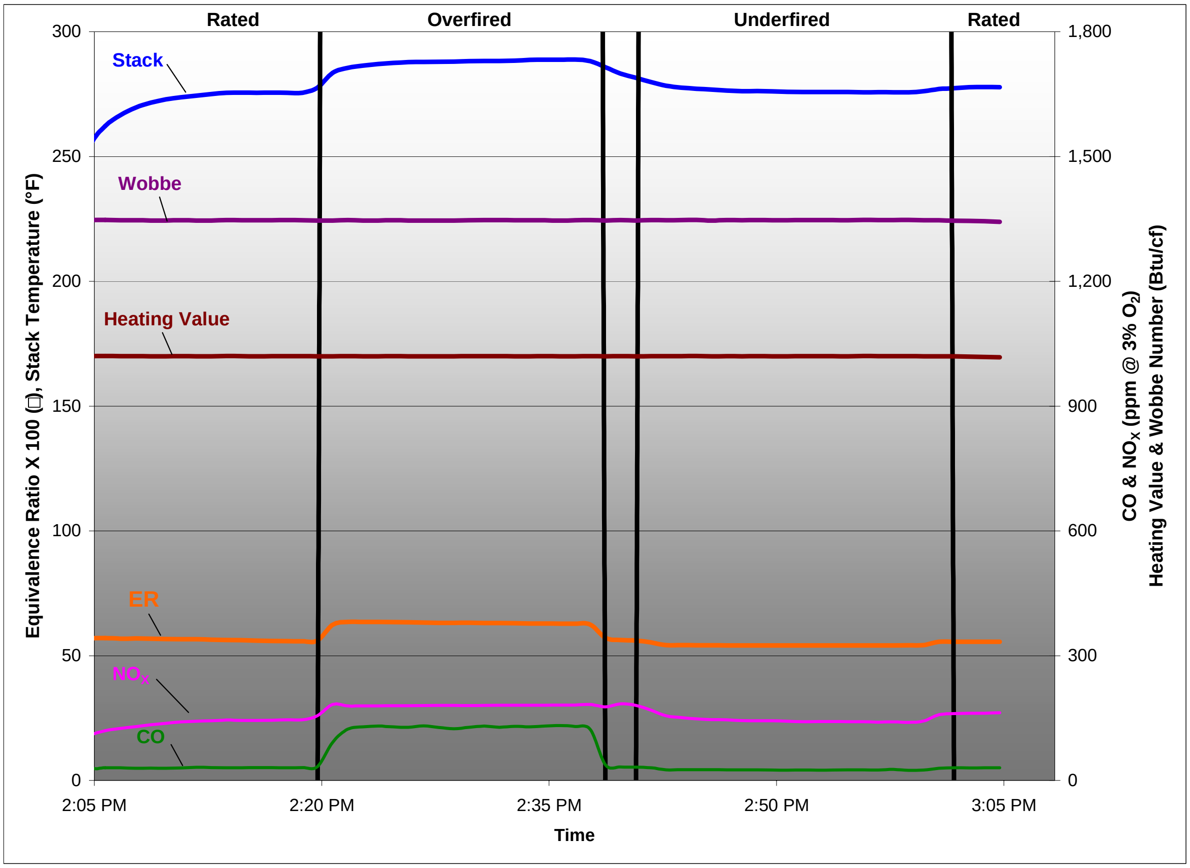


[1] Emission test results are for information purposes only. They are not the results of certified tests

Rated Input, Overfired, and Underfired Test
NO_x emissions during the test sequence, corrected to 3% oxygen, ranged from 141 ppm (underfired) to 181 ppm (overfired). Corrected CO emissions ranged from 25.4 ppm (underfired) to 130 ppm (overfired). The initial baseline firing rate was 101.3% of the rated input. The overfired and underfired firing rates averaged 112.6% to 98.2%, respectively. These tests were conducted with baseline gas.

Stack temperatures were slightly higher when operating in the overfired condition compared with those measured during the underfired and rated input conditions. Overfired and underfired conditions were achieved by changing the gas pressure. A summary of the continuous test data and calculations for the rated input, overfired, and underfired test is shown in Figure 2.

Figure 2 – Summary of Pre-Mix Pool Heater Rated Input, Overfired, and Underfired Testing

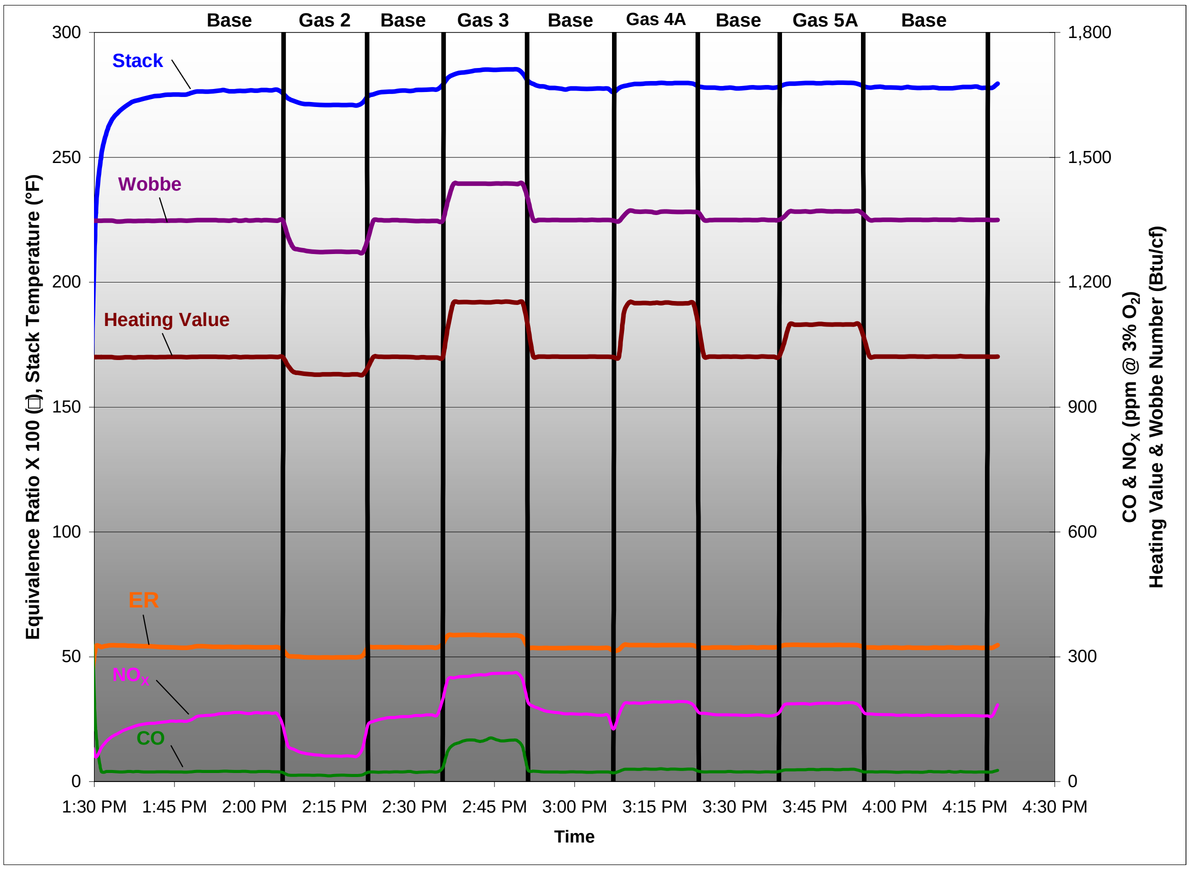


[1] Emission test results are for information purposes only. They are not the results of certified tests

Emissions Test

NO_x emissions during the test sequence, corrected to 3% oxygen, ranged from 65.5 ppm (Gas #2) to 257 ppm (Gas #3). CO emissions, corrected to 3% oxygen, ranged from 15.3 ppm (Gas #2) to 95.4 ppm (Gas #3). The average baseline firing rate was 98.1% of the rated input. A summary of the continuous test data and calculations for the emissions test is shown in Figure 3.

Figure 3 – Summary of Pre-Mix Pool Heater Emissions Testing



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

EQUIPMENT SELECTION CRITERIA

The particular features of the heater that make it an appropriate subject is that it incorporates a premix burner technology that may be sensitive to changes in gas composition. The protocol development was guided by the ANSI standard and the regulations of the South Coast Air Quality Management District.

EQUIPMENT SPECIFICATIONS

Description:	Gas-fired residential pre-mix pool heater
Burner Type:	Pre-mix, multiple tubular punched-port burners operated by induced draft
Input rating:	250,000 Btu/hr
Type of fuel:	Natural gas
Required fuel inlet supply pressure:	5.0 – 10.5” W.C.
Gas manifold pressure:	3.0” W.C.

STANDARDS

A test protocol was developed based on the following standards:

- ANSI Z21.56-2001, Standard for Gas-Fired Pool Heaters.
- South Coast Air Quality Management District Rule 1146.2, Emission of NOx from Large Water Heaters and Small Boilers, adopted January 9, 1998.
- South Coast Air Quality Management District Protocol, NOx Compliance Testing for Natural Gas-fired Water Heaters and Small Boilers, last amended January 1998.

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 pool heater 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 water in and out, flue gas, and selected burner surfaces. Pressure transducers were installed to measure supply, gas meter, manifold, atmospheric, and water pressures. A schematic of the instrumented pool heater is shown in Appendix B (Figure B2).

Once instrumentation was installed, the pool heater was operated on pipeline gas to verify that the heater 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 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

Three types of tests were conducted in evaluating the pre-mix pool heater:

1) As-found
2) Rated input, overfired, and underfired
3) Emissions

Testing of the pool heater 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 pool heater was turned "on" and allowed to heat up to an "idle" 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 20 minutes with the burner at a specified power level and gas with all temperature, emissions and gas compositions being recorded. 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. Phenomena of interest included: flame color change, flame lifting, flashback or rollout, pilot burner instability or outage, etc.

As-Found Test
The water heater was fired from a cold (ambient) condition, with the outlet water valve set to provide a 40 ^{o}F rise across the pool heater. This series consisted of a continuous one-hour test run where the heater was operated at the manufacturer's gas supply specifications with the orifice set provided. This test was conducted with baseline gas.

Rated Input, Overfired, and Underfired Tests

The orifice set was replaced to allow for 100% rated gas input at the manufacturer's nameplate manifold pressure. These tests were conducted with baseline gas. The pool heater was fired from a cold (ambient) condition, with the outlet water valve set to provide a 40 ^{o}F rise across the pool heater. This series consisted of a continuous test run, with three distinct operating conditions:

1) "Rated Input" condition, where the heater was operated at the manufacturer's gas supply specifications
2) "Overfired" condition, where the manifold pressure was increased to a point approximating 112% rated input
3) "Underfired" condition, where the main gas supply pressure was reduced to 4" W.C. (from normal supply pressure of 7.0" W.C.)

Emissions Tests

The emissions tests consisted of 15 minute periods of operation from a stable operating condition with each gas tested. Emissions measurements for calculation purposes were based on the last five minutes of operation for each gas. Emissions tests were conducted using baseline gas, Gas #2 (low heating value, low Wobbe), Gas #3 (high heating value, high Wobbe), Gas #4a (high heating value, medium Wobbe) and Gas #5a (medium heating value, medium Wobbe).

RESULTS

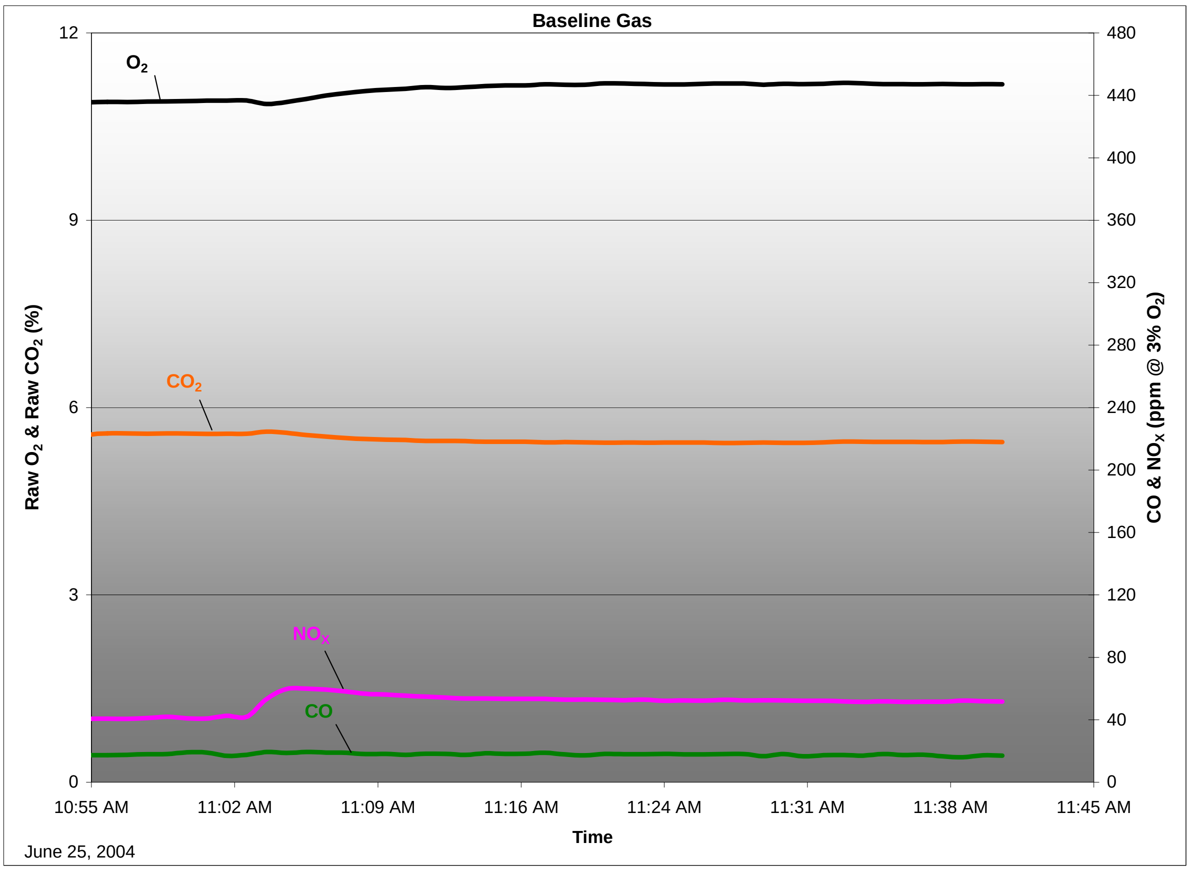
As-Found Test

Emissions
NO_x emissions concentrations for the as-found condition averaged 52.8 ppm (corrected to 3% O_2).

CO emissions for the as-found condition averaged 17.8 ppm (@ 3% O_2).

Figure 4 presents the continuous raw emissions concentration measurement data for this test sequence.

Figure 4 – Emissions Data (As-found Test)



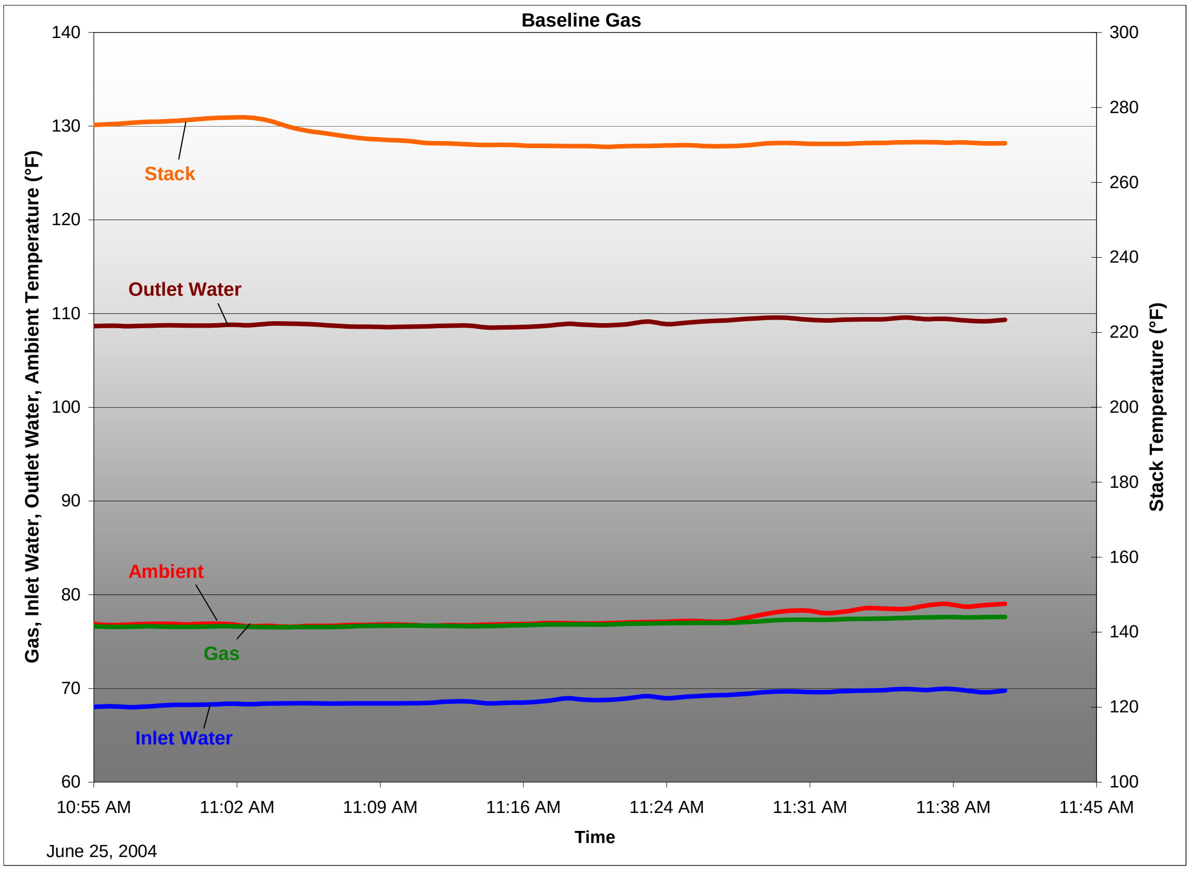
Emission test results are for information purposes only. They are not the results of certified tests.

Temperatures

The average outlet water temperature during the test sequence was 108.9 ^{o}F, providing a 40 ^{o}F temperature rise with an average inlet water temperature of 68.9 ^{o}F. The average stack temperature was 269.7 ^{o}F.

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

Figure 5 – Temperature Data (As-Found Test)

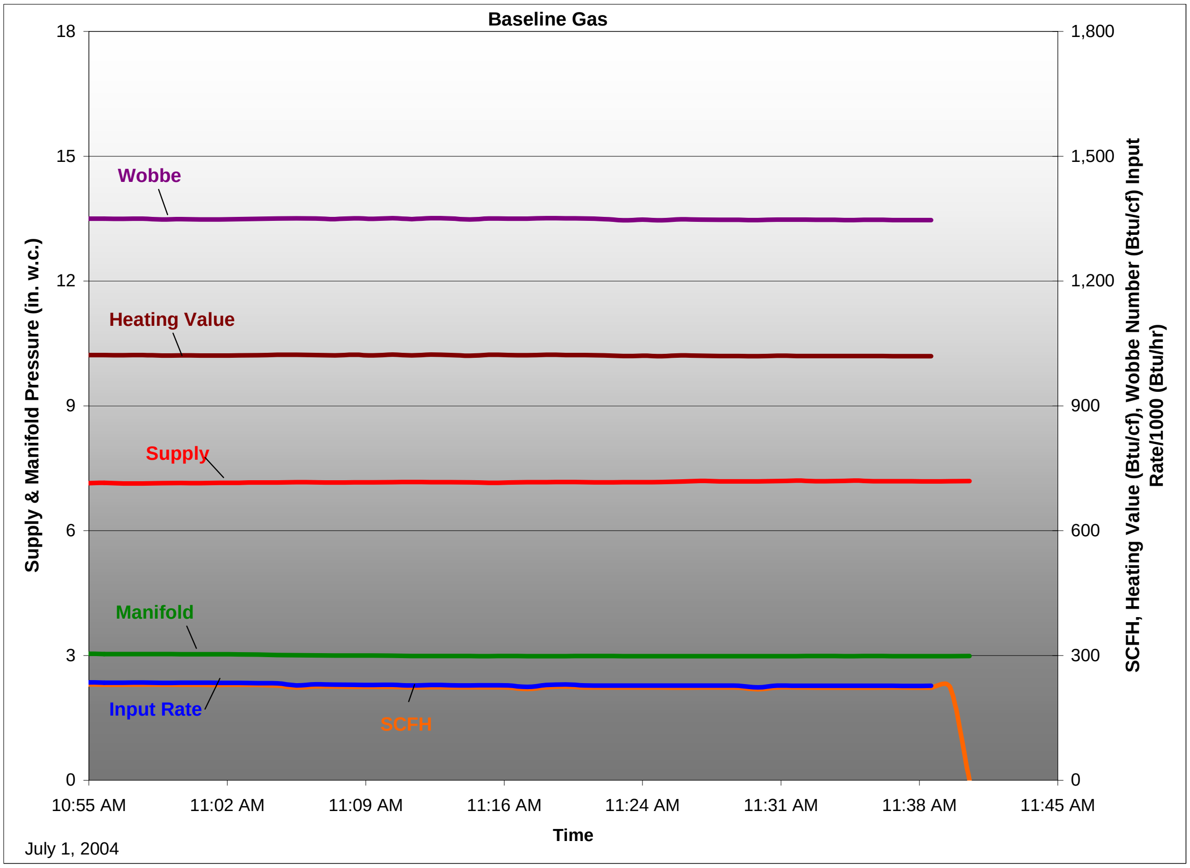


Emission test results are for information purposes only. They are not the results of certified tests.

Gas Input
The pool heater was operated at the manufacturer's rated manifold pressure in the as-found condition for this test sequence, yielding a firing rate of 91.4% of the nameplate rating. Fuel gas analyses show a steady 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 Test)



Rated Input, Overfired, and Underfired Test

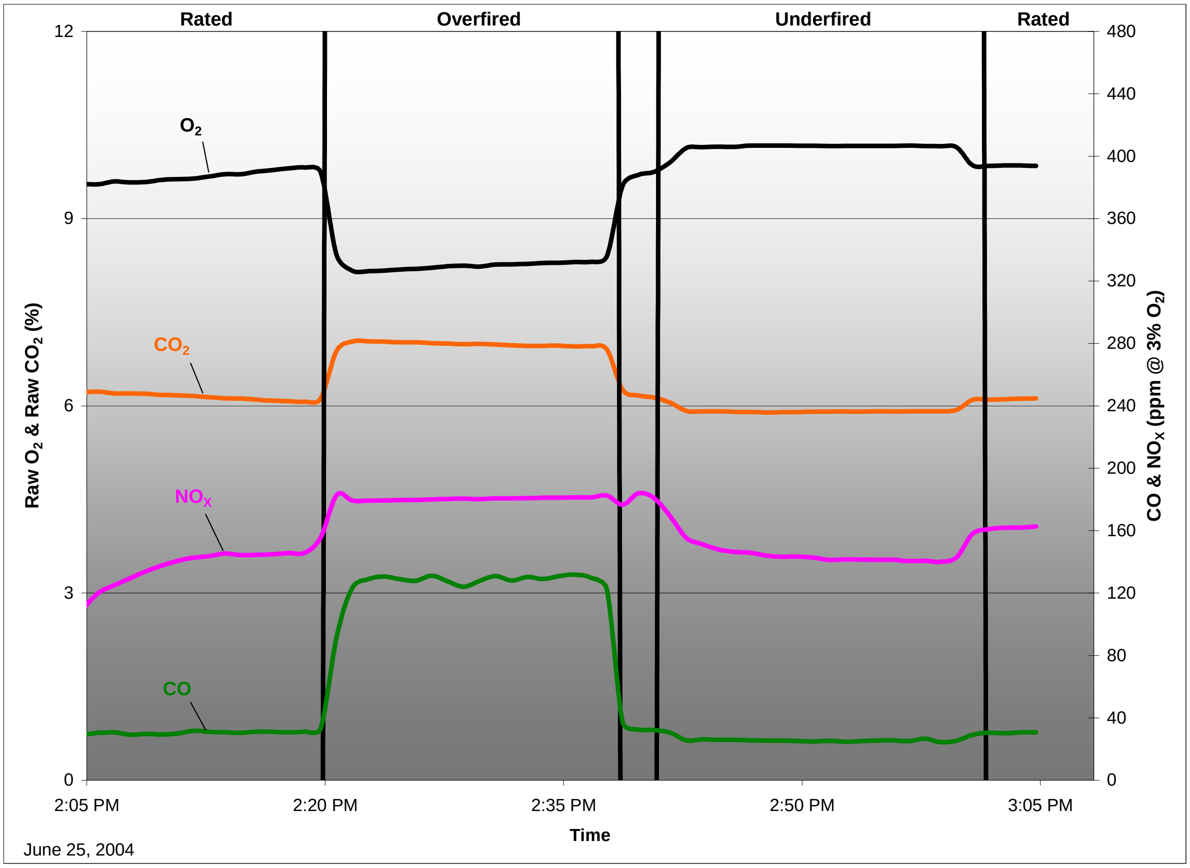
Emissions

NO_x emissions concentrations for the rated input condition averaged 145 ppm (corrected to 3% O_2). The average NO_x concentration increased to 181 ppm (@ 3% O_2) after switching to the overfired condition. The lowest levels of NO_x, measured during the test sequence [141 ppm (@ 3% O_2)], were seen during the underfired test. These tests were conducted with baseline gas.

CO emissions for the rated input condition averaged 30.7 ppm (@ 3% O_2). The CO emissions increased to 130 ppm (@ 3% O_2) during the overfired condition, and decreased to 25.4 ppm (@ 3% O_2) during the underfired condition.

Figure 7 presents the continuous raw emissions concentration measurement data for this test sequence.

Figure 7 – Emissions Data (Rated Input, Overfired, and Underfired Test)



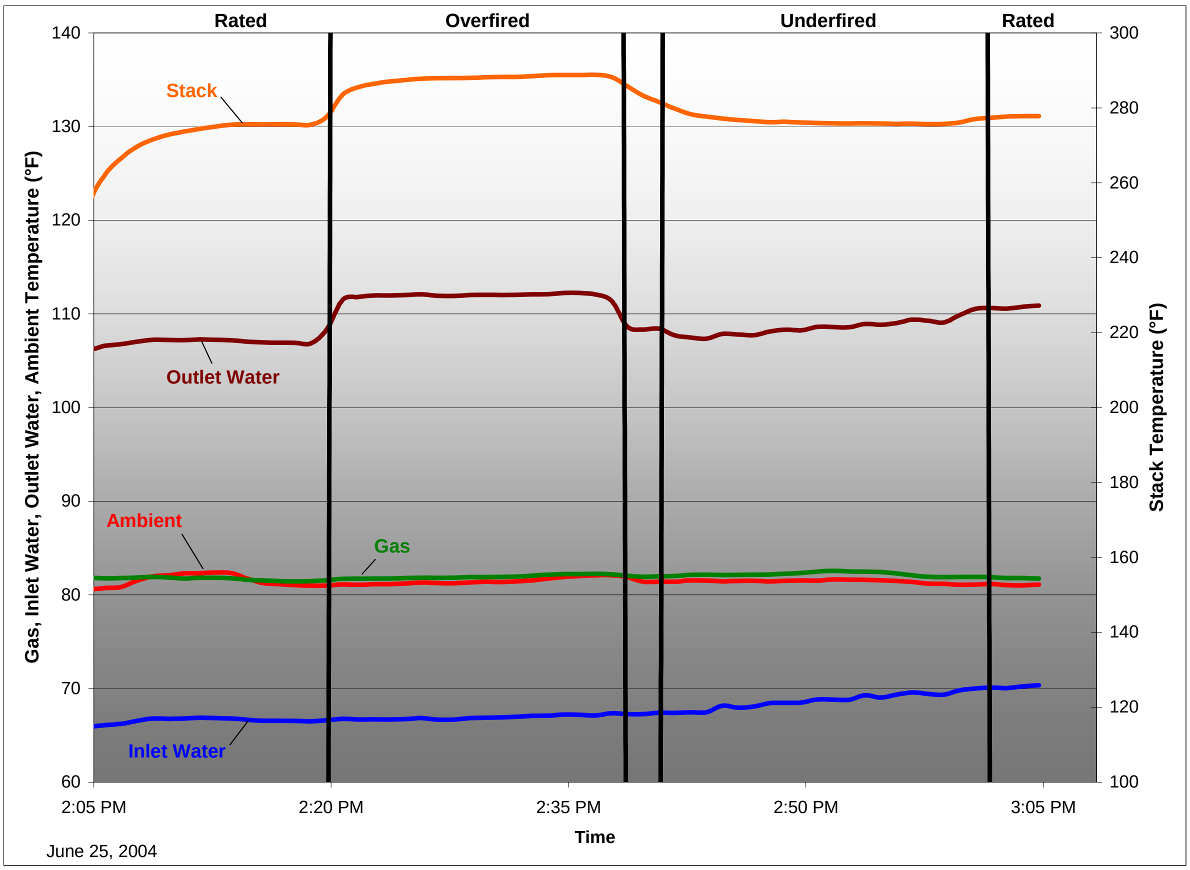
Emission test results are for information purposes only. They are not the results of certified tests.

Temperatures
The average outlet water temperature during the rated input condition was 107 ^oF, providing a 40.4 ^oF temperature rise with an average inlet water temperature of 66.6 ^oF. The average temperature rise increased to 45 ^oF during the overfired condition. The average temperature rise slightly decreased to 39.8 ^oF during the underfired condition. There was a gradual increase in inlet water temperature (66.6 ^oF to 70.2 ^oF) over the test sequence due to hot ambient conditions.

The average stack temperature during both the rated input and underfired conditions was 276 ^oF. The average stack temperature increased to 289 ^oF during the overfired condition.

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

Figure 8 – Temperature Data (Rated Input, Overfired, and Underfired Test)

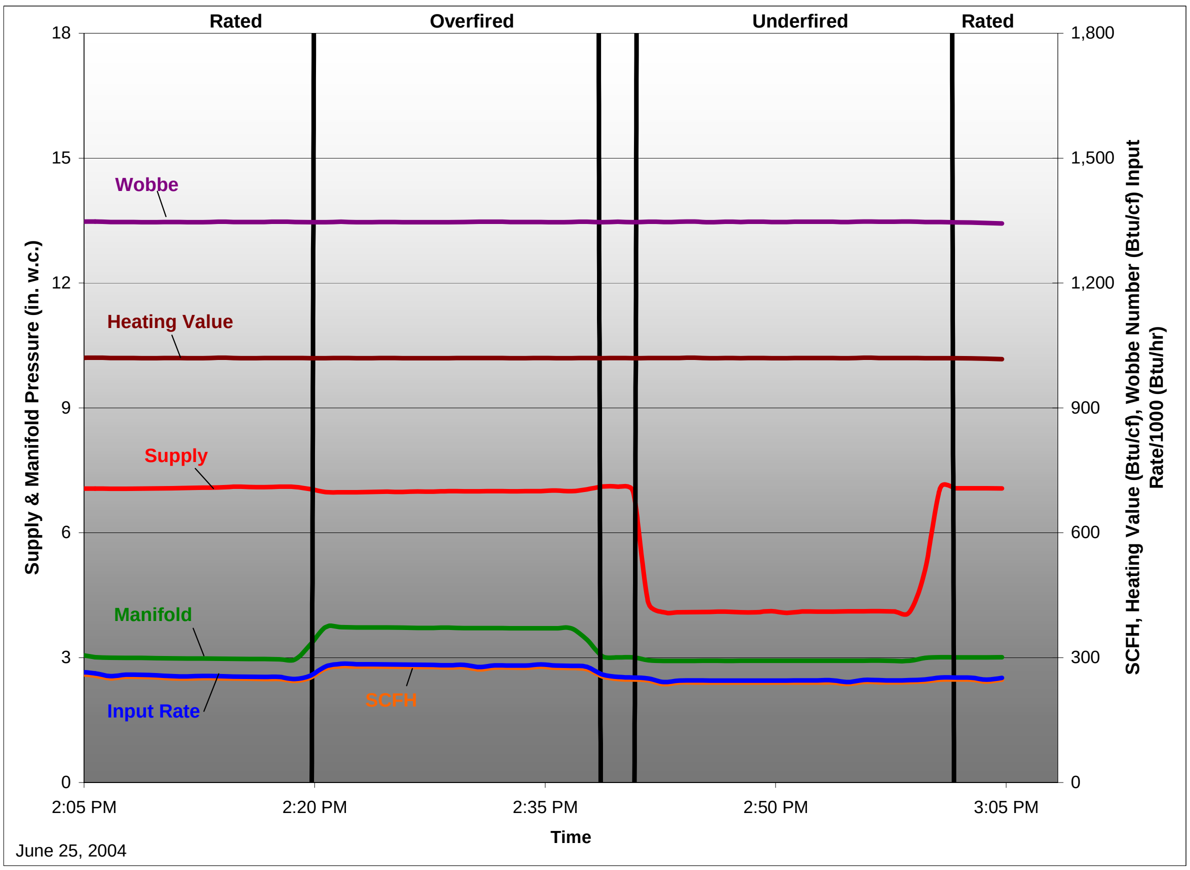


Gas Input

The pool heater was operated at three distinct gas supply conditions using baseline gas for this test sequence. The rated input condition yielded a firing rate of 101.3% of the nameplate rating. The overfired condition (achieved by increasing gas manifold pressure from 3.0 in. to 3.7 in W.C.) resulted in a firing rate of 112.6% of the nameplate. The underfired condition (achieved by reducing the gas supply pressure from 7.0 in. to 4.3 in. W.C.) resulted in a firing rate of 98.2% of the nameplate. Fuel gas analyses show a steady heating value and Wobbe over the course of the test sequence. These tests were conducted with baseline gas.

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

Figure 9 - Gas Input Data (Rated Input, Overfired, and Underfired Test)

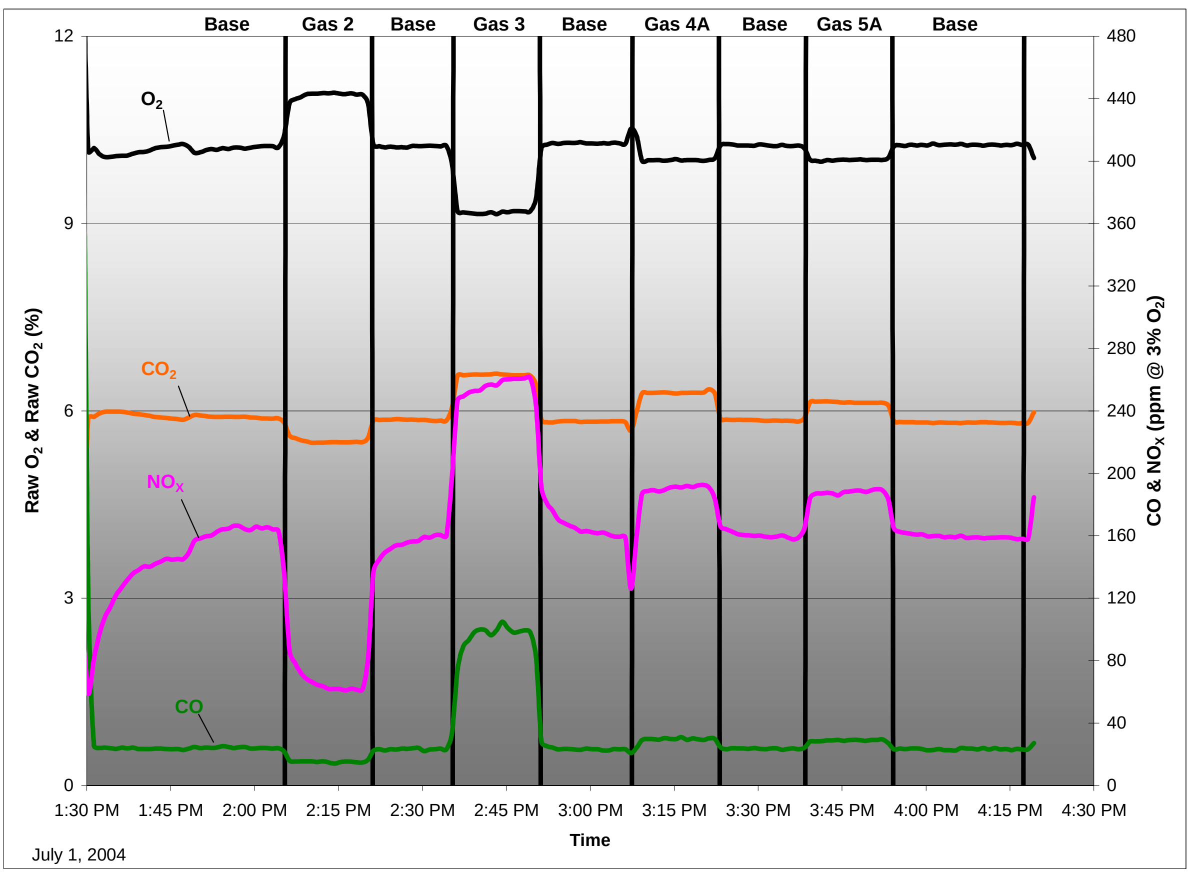


Emissions Test

Emissions
For the pool heater tested, results indicate that NO_x emissions concentrations are affected by the gas compositions used in this study. NO_x emissions concentrations for the base gas condition averaged 161 ppm (corrected to 3% O_2). The average NO_x concentration was lowest (65.5 ppm @ 3% O_2) after switching to Gas #2. The average NOx concentration was highest (257 ppm @ 3% O_2) using Gas #3. The intermediate gases (Gas #4a and Gas # 5a) yielded corrected NOx emissions concentrations of 190 ppm and 188 ppm, respectively.

CO emissions over the entire test ranged from 15 ppm (@ 3% O_2) to 30 ppm (@3% O_2) for all Gases, except for Gas #3 (95 ppm @ 3% O_2). Figure 10 presents the continuous emissions measurement data for this test sequence.

Figure 10 – Emissions Data (Emissions Test)



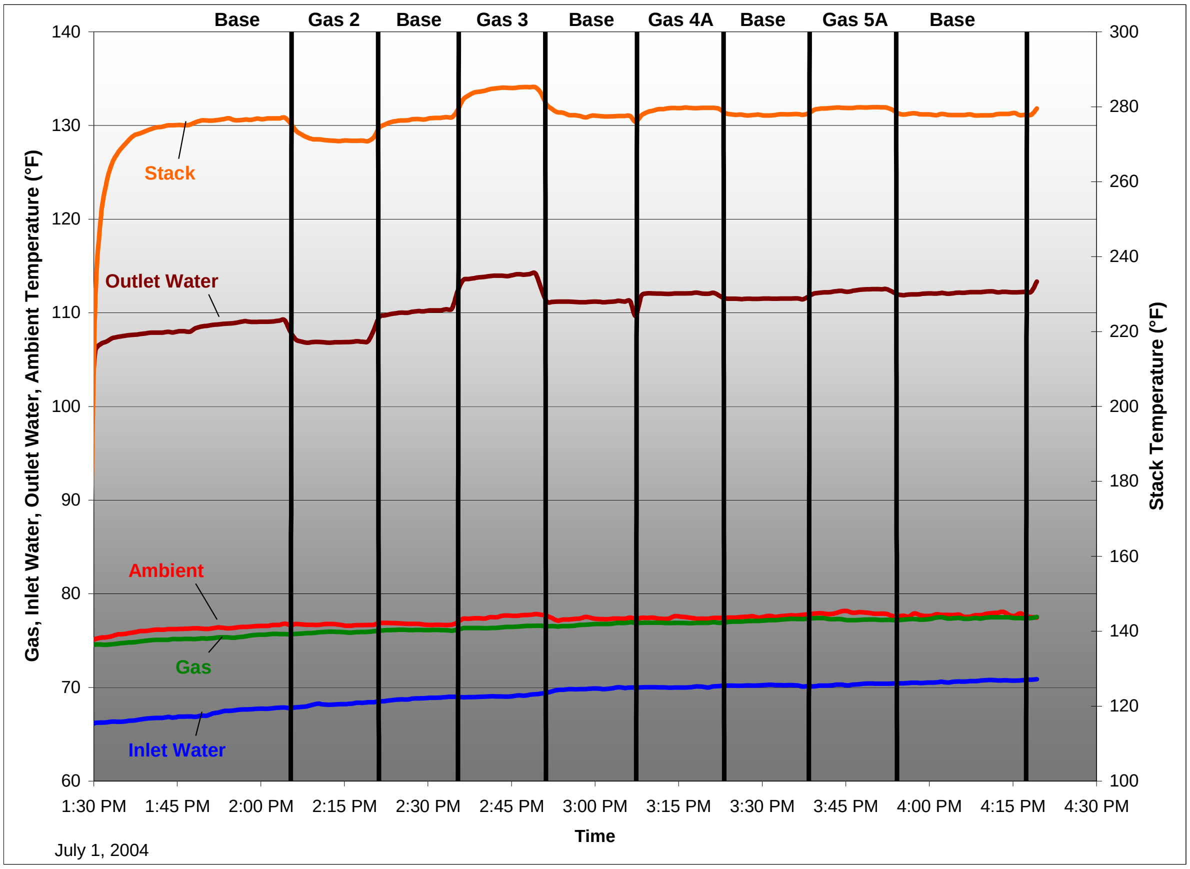
Emission test results are for information purposes only. They are not the results of certified tests.

Temperatures

The average stack temperature using Base Gas was 278 ^oF. Average stack temperatures ranged from 271 ^oF (Gas #2) to 285 ^oF (Gas #3). Likewise, maximum temperature rise for all gases ranged from 38.8 ^oF (Gas #2) to 44.6 ^oF (Gas #3).

Figure 11 presents the continuous temperature measurement data for this test sequence.

Figure 11 – Temperature Data (Emissions Test)

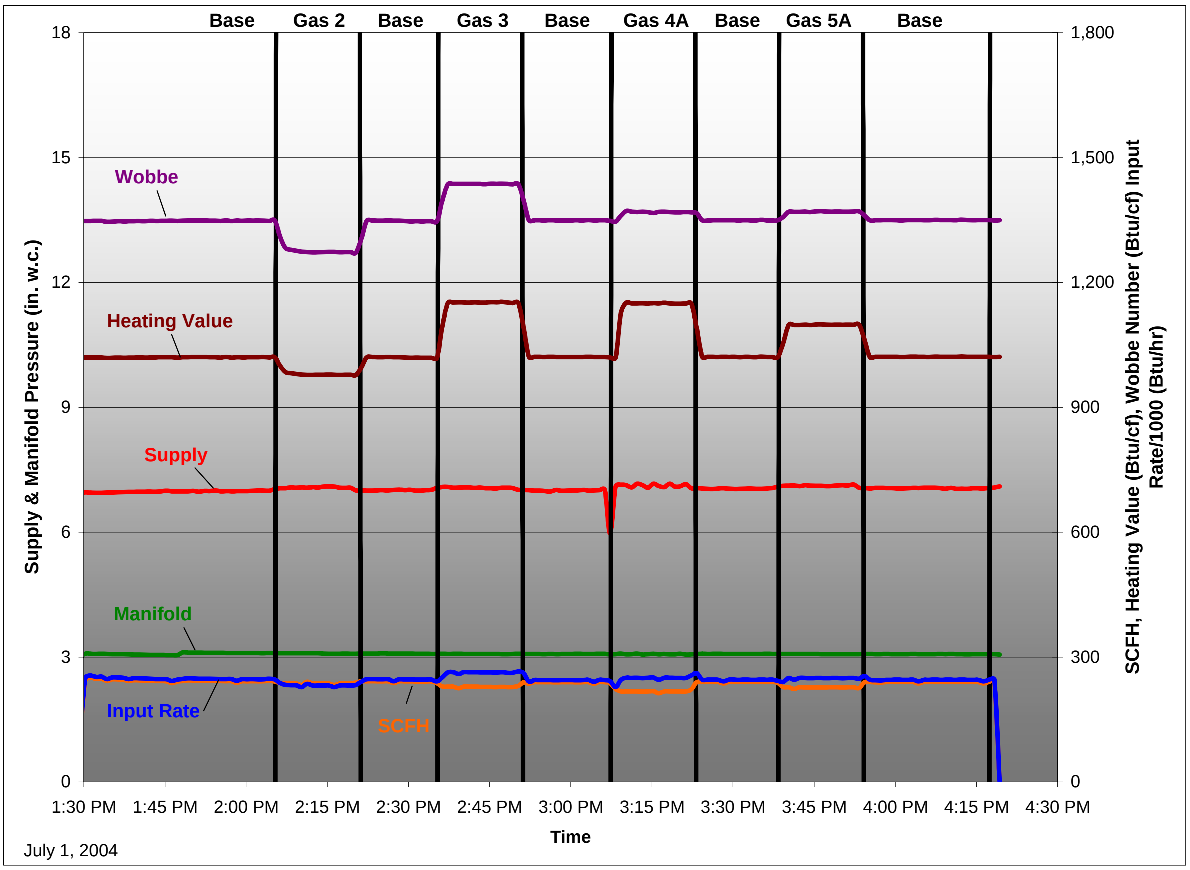


Gas Input

The average Base gas firing rate (5 tests) was 98.1% of the nameplate rating. The minimum firing rate observed (92.5% nameplate) occurred when using Gas #2. The maximum firing rate observed (105.3% nameplate) occurred when using Gas #3. Gas #4a and Gas #5a yielded firing rates of 100.5% and 99.7% of nameplate rating, respectively. Fuel gas analyses show a steady 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 Test

The manufacturer indicated that there were no ignition issues in its own testing of the heater over a wide range of firing rates and conditions. Ignitions conducted during the course of other testing (as found, rated, overfired, underfired) showed no anomalies. Therefore, no tests specific to ignitions were conducted.

Appendix A

Test Protocol – Gas-Fired Pool Heaters

1. Objective and General Approach

This protocol specifies procedures for conducting and reporting tests of gas-fired pool heaters with respect to their operation with liquefied natural gas (re-gasified). The study is to evaluate the ability of a heater to operate through a change to or from LNG and the effect of LNG on the operation, safety, combustion emissions or other aspects of heater 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 heater 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 LNG Research Study White Paper developed in Phase I of the study.

2. Standards

- ANSI Z21.56-2001, Standard for Gas-Fired Pool Heaters.
- South Coast Air Quality Management District Rule 1146.2, Emissions of NO_X from Large Water Heaters and Small Boilers, adopted January 9, 1998.
- South Coast Air Quality Management District Protocol, NO_X Compliance Testing for Natural Gas-fired Water Heaters and Small Boilers, last amended January 1998.

3. Heater Data

Record descriptive and technical data, including the following:

3.1 Heater rating plate data

a. Model number
b. Serial number
c. Rated input
d. Manifold pressure

3.2 Efficiency 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 heater.

3.5 Photograph the heater and significant design/construction features.

4. Test Arrangement

4.1 Basic setup

The heater is to be tested on the concrete laboratory floor. Fuel gas, electrical power, and water are to be provided at rates and conditions required by the test standards and manufacturer specifications. Combustion products are to be sampled in a vent stack constructed per emission measurement standards.

4.2 Water flow and piping

If the heater has a water flow bypass mechanism, block it in the closed position as required in Section 7.3.3 of the AQMD Protocol. Provide water at the flow rate and temperature required by the test standards and manufacturer specifications. If necessary, provide a supply water pump, a recirculating pump and valving necessary to adjust water flow rate and temperatures. Maintain water pressure at a level sufficient to assure proper heater operation.

4.3 Vent pipe

For all testing, a straight vertical vent pipe, five feet in length and of the diameter of the heater vent collar, is to be provided. Provide the pipe with insulation of resistance rating 4 hr-ft-^{o}F/Btu or greater. Provide an integrated sampling probe, constructed per the AQMD protocol, six inches from the top of the vent pipe. Twelve inches from the bottom of the pipe, provide a nine-point thermocouple grid, wired as a thermopile.

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 heater gas control.

4.5 Electrical power

Electrical power is to be provided at the voltage specified on the heater rating plate ± 1%.

4.6 Instrumentation

Instrumentation is to be per the SCAQMD Protocol for Rule 1146.2.

4.7 Special measures – thermocouples

As appropriate, provide thermocouples on burners and/or combustion chamber surfaces subject to high temperature stress. If possible, obtain components with pre-installed thermocouples from the heater manufacturer or obtain the manufacturer's advice as to where temperature stress is likely to be greatest.

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 heater operation.

5. Test Gases

Gas composition is specified in Appendix B of the Phase II Scope of Work:

#1 Baseline gas

#2 Low-Wobbe low-heat content gas

#3 High-Wobbe high-heat content gas

#4 Medium-Wobbe high-heat content gas

Additional gases, consistent with the Phase II protocol are to be used when results of testing with the preceding gases indicate additional investigation is necessary.

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 Sections 7.3.6 & 7.1.6 of the AQMD Protocol.

6.2 Gas supply pressure

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

6.3 Basic firing setup

The basic firing setup is to be that combination of gas orifice size and manifold pressure required to deliver rated input with the baseline gas. Manifold pressure is to be within ± 10% of that specified on the rating plate. With gases other than the baseline gas the firing rate generally will *not* be at rated input.

6.4 Water flow, temperature and pressure

Unless the manufacturer's specifications are more restrictive, provide water flow and treat inlet water as necessary to maintain heater inlet temperature at 65^{o}F ± 5^{o}F and water temperature rise at 40^{o}F ± 5^{o}F. Maintain adequate water pressure to assure proper operation of the heater.

7. Testing – Startup Run

Operate heater on baseline gas for one hour as-received – i.e. with gas orifices received in the heater and manifold pressure at the rating plate value ± 0.2" WC. 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. (Note: If it is evident that manufacturing oils, insulation binder, etc. are not totally driven off at 15 minutes, delay data acquisition until "break-in" is complete. After break-in, allow unit to cool one-half hour with water flowing through the heat exchanger, and re-start to obtain "startup" data.)

Verify proper operation of all equipment and instrumentation.

8. Steady operation testing

8.1 Base case at rated input

Adjust heater to operate at the rating plate input, holding manifold pressure within 10% of that specified on the rating plate and changing gas orifices if necessary. This establishes and defines the "basic firing setup" referred to in Section 6.3 above.

From a cold start, record input and combustion data (CO_2 & CO) at 15 minutes and verify that the firing rate is within 2% of rated input. Immediately thereafter adjust manifold pressure to fire at 112% of rated input. After 15 minutes record input and combustion data (CO_2 & CO). Thereafter re-adjust manifold pressure to the basic firing setup. Then reduce the gas supply pressure to 4.0" WC and record firing rate and combustion data.

During the testing observe flames and note yellow tipping and flame lifting or flashback phenomena or lack of same. Record these observations. If significant yellow tipping was observed, inspect vent connection area and swab with a white cloth to determine if soot has been deposited. If soot is present, remove it prior to continuation of testing.

8.2 Steady operation tests – baseline and substitute gases

8.2.1 Steady operation with baseline gas

Starting with the baseline gas, operate heater at the basic operating condition. Verify that firing rate is at ± 2% of rated input at 15 minutes and record combustion data (CO_2 & CO). Do not conduct "overfire" test.

Continue operation to establish that stack temperature changes by no more than ± 5^{o}F in 15 minutes and that inlet and outlet water temperatures remain within acceptable limits. Record stack temperature and that of burners and/or the combustion chamber components identified in Section 4.7 preceding.

Continue operation and record NO_X emission data as required by the AQMD Protocol.

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

8.2.2 Gas changeover and steady operation with substitute gases

Continue steady heater operation with baseline gas and conduct a high-speed switch to the substitute gas. Record data before, during and after changeover and observe transient phenomena. Note that the firing rate is not to be adjusted. Possible phenomena include flame color change, flame lifting, flashback or rollout, pilot burner instability or outage, etc.

When steady state is achieved record all operating data including firing rate, stack temperature and component temperatures per section 8.2.1. Continue operation and determine NO_X emission per the AQMD protocol.

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

With the heater continuing to operate at steady state on the substitute gas, conduct a high-speed switch to the baseline gas and record observations and data per above.

Continue testing by reestablishing steady state conditions with the baseline gas and repeat the test sequence for each of the remaining substitute gas blends.

When testing has been conducted with all gases, shut down heater and examine vent connection area for presence of soot by means of the swab technique specified in section 8.1. If soot is found, clean surfaces and repeat testing with suspect gas blend(s), selected on the basis of earlier yellow tipping observations. Establish which gas(es) tends to burn with soot deposition.

9. Burner and ignition operating characteristics

9.1 Operation with baseline gas

9.1.1 Cold operation

Verify or adjust heater operation to the basic operating condition with baseline gas. Allow heater to cool to room temperature and initiate burner operation by means of the heater temperature control switch. Allow the burners to operate at normal manifold pressure 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.

9.1.2 Hot operation

Repeat the testing of the previous section at both supply pressure conditions, starting with the heater at steady state operation. Observe and record the same phenomena.

9.2 Operation with substitute gases

Without adjustment of heater, operate to steady state on the baseline gas and successively with the substitute gases. When steady state conditions are achieved with each gas, turn the burners off and on three times, each time allowing progression through an ignition sequence. Observe and record observations per preceding section. In particular, note variation from operation with baseline gas and behavior with respect to areas that were of concern with the baseline gas.

If unusual phenomena are noted with any of the gases, conduct cold operation testing with that gas, per section 9.1.1.

10. Special tests

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

11. 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.

12. Calculations

NO_X emission is to be calculated per the AQMD protocol for Rule 1146.2 in terms of PPM at 3% oxygen. Calculate stack efficiency using the ANSI Z21 alignment chart (Ref: ANSI Z21.13) or the algorithm of ASHRAE Standard 103-1993.

Rationale - Test Setup and Procedure

Firing rate:

A degree of de-rating by manufacturers is not uncommon because they must accommodate things beyond their control such as component and process tolerances and fuel gas property variation. Such de-rating is to be evaluated in a “startup run” during which the heater will be operated “as shipped” on baseline gas. After the startup, “base case” data is to be obtained with the heater adjusted to its rated input. The gas orifice size and manifold pressure required to achieve that condition with baseline gas are to be maintained during operation with the various gas blends being evaluated.

Allowing heater operation to “float” with gas blend makes it possible to associate performance change with only the gas change. Existence of “as shipped” startup data allows inference as to how a factory de-rate practices might affect conclusions.

Burner and ignition operating characteristics:

Substitute gas compositions do not indicate likely problems and 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:

Most pool heaters are designed for installation either indoors or outdoors. Usually they are shipped in the outdoor configuration and accessory parts are used for conversion for indoor use. Outdoor configurations are notoriously difficult to test because combustion products are dispersed and diluted within the vent terminal in ways that defeat attempts to obtain representative samples. Because of that problem, third-party laboratories have often conducted emission tests with the indoor configuration and that approach has likewise been specified in this protocol. This choice results in higher data quality. In any case, the effect of gas fuel blend is evaluated on a consistent and comparable basis.

Efficiency:

Pool heater efficiency test standards require a “heat-to-water” measurement, i.e. the heat delivered to the water is compared with the fuel energy provided. This procedure requires substantial equipment and water handling capability and test time. For that reason, efficiency is to be evaluated by means of stack loss measurement, which can be done quickly in the context of other tests. An algorithm for calculation of stack efficiency is not provided in the pool heater standards, so the ANSI Z21 and ASHRAE Standard 103 algorithms are specified.

Appendix B

Equipment Schematics

Overall Setup for the Test Cell

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 Pool Heater is shown in Figure B2.

Figure B1 – Overall Equipment Layout

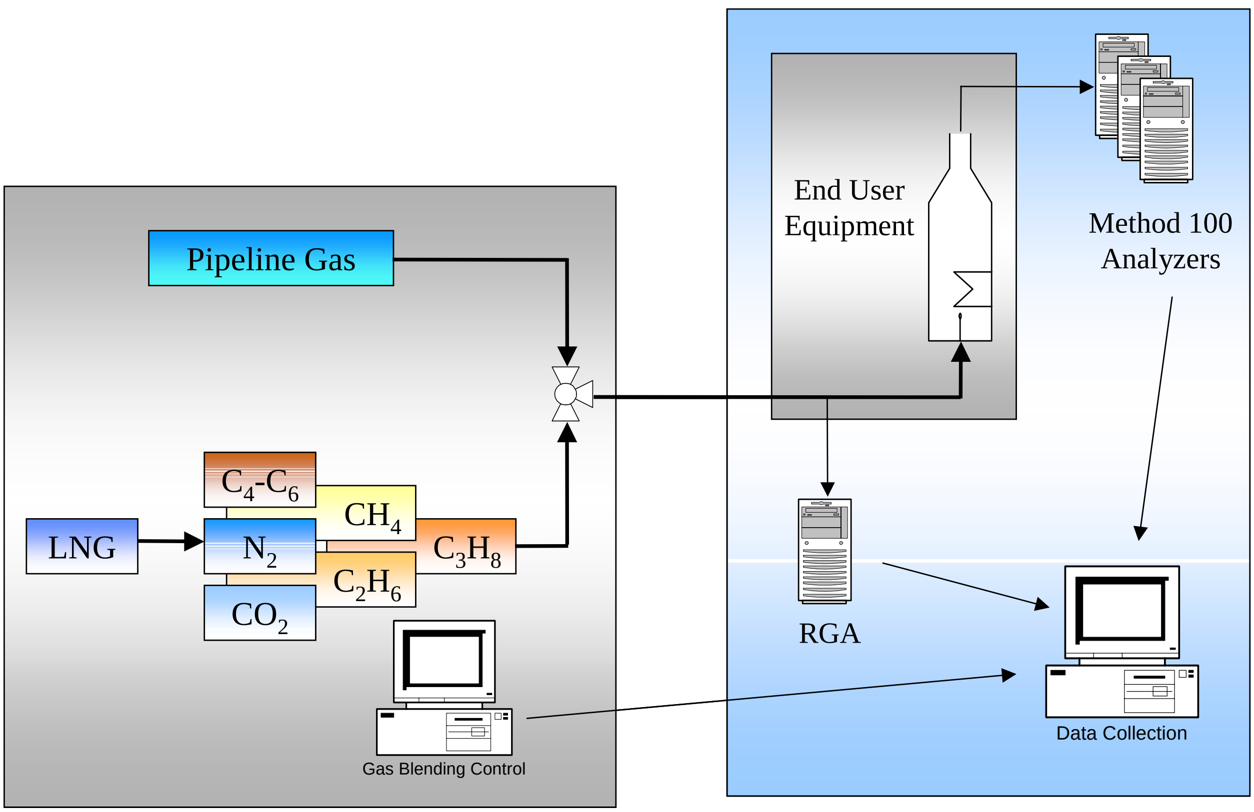
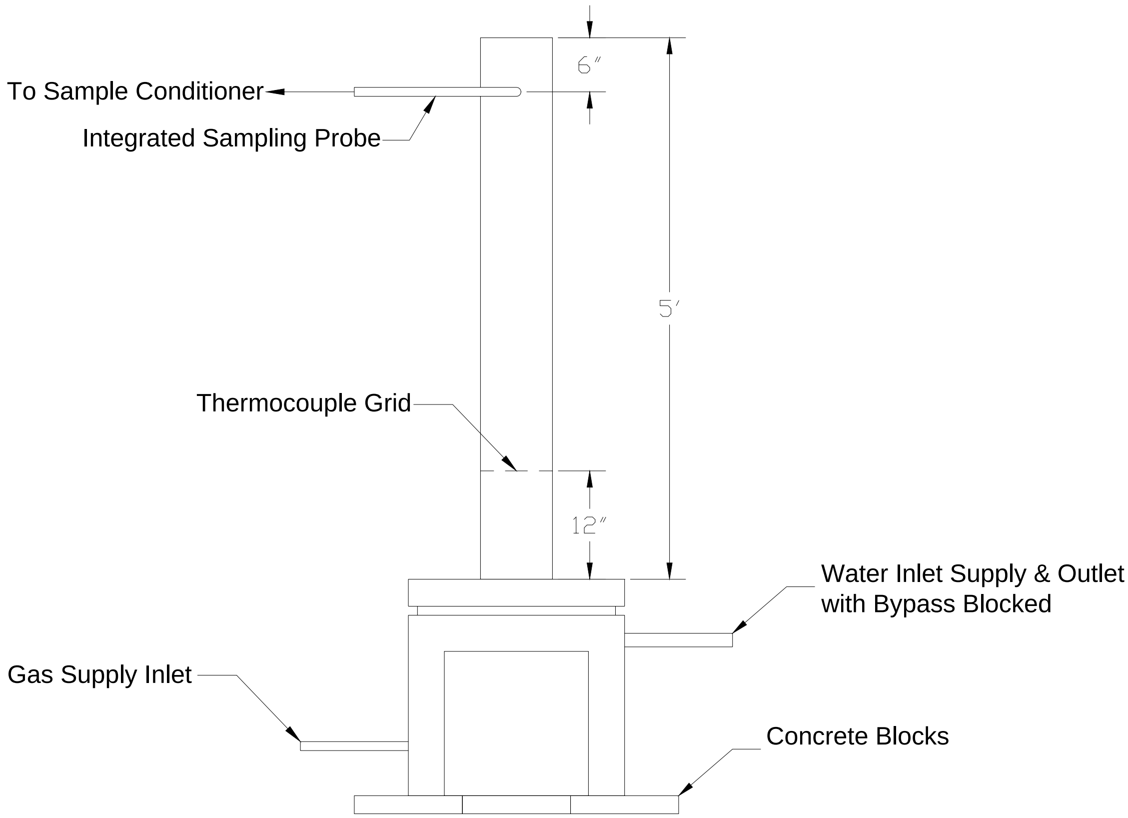


Figure B2 – Pre-Mix Pool Heater Test Schematic



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		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
Primary														
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), 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 0-15% non-methane

Appendix E

Calculations

Emissions Concentrations

Corrected to 3% O_2

CO and NO_x conc. (at 3% O_2) = $ppm \times \left[\frac{20.9 - 3\%}{20.9 - \%O_2} \right]$

Where

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

Ultimate CO_2

Ult. CO_2 = $RawCO_2 \times \left[\frac{20.9}{20.9 - RawO_2} \right]$

Where

Ult. CO_2 = Ultimate CO_2 (%)
Raw CO_2 = Measured CO_2 Concentration (%)
Raw O_2 = Measured O_2 Concentration (%)

Percent Excess Air

Constituent	Balanced Chemical Composition	Theo. Air	Theo. Flue Gas
Methane (CH_4)	$CH_4 + \mathbf{2}O_2 + \mathbf{2(3.78)}N_2 \rightarrow \mathbf{1}CO_2 + \mathbf{2}H_2O + \mathbf{2(3.78)}N_2$	9.56	8.56
Ethane (C_2H_6)	$C_2H_6 + \mathbf{3.5}O_2 + \mathbf{3.5(3.78)}N_2 \rightarrow \mathbf{2}CO_2 + \mathbf{3}H_2O + \mathbf{3.5(3.78)}N_2$	16.73	15.23
Propane (C_3H_8)	$C_3H_8 + \mathbf{5}O_2 + \mathbf{5(3.78)}N_2 \rightarrow \mathbf{3}CO_2 + \mathbf{4}H_2O + \mathbf{5(3.78)}N_2$	23.90	21.90
i-Butane (C_4H_{10})	$i\text{-}C_4H_{10} + \mathbf{6.5}O_2 + \mathbf{6.5(3.78)}N_2 \rightarrow \mathbf{4}CO_2 + \mathbf{5}H_2O + \mathbf{6.5(3.78)}N_2$	31.07	28.57
n-Butane C_4H_{10})	$n\text{-}C_4H_{10} + \mathbf{6.5}O_2 + \mathbf{6.5(3.78)}N_2 \rightarrow \mathbf{4}CO_2 + \mathbf{5}H_2O + \mathbf{6.5(3.78)}N_2$	31.07	28.57

To determine the percent Excess Air, the theoretical air and theoretical flue gas values for each gas tested must be calculated. The table above lists the constituents found in the gas blends tested, the balanced chemical equations for each constituent, and their respective theoretical air and theoretical flue gas values (expressed in moles).

The theoretical air value for each constituent is the sum of moles for both O_2 and N_2 on the reactants side of the balanced chemical equation (e.g. methane requires 2 moles of O_2 plus 7.56 moles of N_2 = 9.56 moles of theoretical air). The theoretical flue gas value for each constituent is the sum of moles for both CO_2 and N_2 on the product side of the balanced chemical equation (e.g. combustion of 1 mole of methane produces 1 mole of CO_2 plus 7.56 moles of N_2 = 8.56 moles of theoretical flue gas).

Once the test gases have been analyzed (via gas chromatography or quadropole mass spectroscopy), the % composition of each test gas is used to determine the theoretical air and theoretical flue gas values for each gas tested. Thus,

Theoretical Air = $\sum C_1P + C_2P + \ldots + C_nP$

And

Theoretical Flue = $\sum D_1P + D_2P + \ldots + D_nP$

Where C is the theoretical air value for each constituent, D is the theoretical flue gas value for each constituent and P is the percent composition for each constituent (expressed in decimal, rather than percentage form). Therefore, the % excess air is calculated as follows:

$$\% \text{ Excess Air} = \left[Theo.FlueValue \times \frac{Ult.CO_2 - RawCO_2}{Theo.AirValue \times RawCO_2} \right] \text{X } 100\%$$

Air/Fuel Ratio = $\left[Theo.AirValue \times \frac{Theor.AirValue \times \%ExcessAir}{100} \right]$

Equivalence Ratio (ϕ)

Equivalence Ratio (ϕ) = $\frac{100}{100 + \%ExcessAir}$

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 ^{o}R = standard atmospheric temperature
FT = gas supply fuel temperature (^{o}F)

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 Pre-Mix Pool Heater As-Found, Rated Input, Overfired, and Underfired Test June 25, 2004					
Gases	**As-Found**	**Rated**	**Overfired**	**Underfired**	**Rated**
HHV (Btu/cf)	1,022	1,020	1,020	1,020	1,018
Wobbe (Btu/cf)	1,349	1,347	1,347	1,347	1,344
Input Rate (Btu/hr)	228,428	253,350	281,435	245,435	250,199
Corrected SCFH	223.6	248.4	276.0	240.6	245.7
Emissions (not from certified tests)					
Raw O_2 (%)	11.18	9.76	8.29	10.16	9.85
Raw CO_2 (%)	5.44	6.09	6.96	5.92	6.11
CO (ppm @ 3% O_2)	17.8	30.9	130.0	25.4	30.5
NO_X (ppm @ 3% O_2)	52.8	145.1	181.1	141.1	162.2
Ultimate CO_2 (%)	11.70	11.44	11.54	11.52	11.56
Equivalence Ratio (ER)	0.49	0.56	0.63	0.54	0.56
Temperatures (°F)					
Ambient	77.0	81.4	81.8	81.3	81.1
Gas	76.9	81.5	82.1	82.1	81.8
Inlet Water	68.9	66.6	67.1	69.4	70.2
Outlet Water	108.9	107.0	112.1	109.2	110.8
Stack	269.7	275.6	288.6	275.8	277.8
Pressures					
Supply (in. w.c.)	7.16	7.10	7.00	4.28	7.07
Manifold (in. w.c.)	2.99	2.97	3.71	2.94	3.01

Table of Averages Pre-Mix Pool Heater Emissions Test July 1, 2004									
Gases	**Base**	**2**	**Base**	**3**	**Base**	**4A**	**Base**	**5A**	**Base**
HHV (Btu/cf)	1,020	978	1,019	1,152	1,021	1,149	1,021	1,098	1,021
Wobbe (Btu/cf)	1,348	1,273	1,347	1,437	1,349	1,369	1,349	1,370	1,350
Input Rate (Btu/hr)	247,031	231,325	245,077	263,358	243,713	251,173	245,090	249,321	195,678
Corrected SCFH	242.1	236.5	240.5	228.6	238.7	218.6	240.1	227.0	191.6
Emissions (not from certified tests)									
Raw O_2 (%)	10.27	11.04	10.19	9.24	10.33	10.02	10.24	10.03	10.12
Raw CO_2 (%)	5.87	5.51	5.88	6.54	5.80	6.30	5.85	6.12	5.84
CO (ppm @ 3% O_2)	23.5	15.3	25.3	95.4	22.6	29.8	23.5	28.7	23.9
NO_X (ppm @ 3% O_2)	158.7	65.5	167.3	257.4	152.9	190.1	160.2	187.8	163.5
Ultimate CO_2 (%)	11.54	11.69	11.48	11.72	11.47	12.10	11.46	11.77	11.43
quivalence Ratio (ER)	0.54	0.50	0.54	0.58	0.53	0.55	0.54	0.55	0.54
Temperatures (°F)									
Ambient	76.7	76.7	76.7	77.8	77.4	77.4	77.7	77.8	77.6
Gas	75.7	75.9	76.1	76.6	76.9	76.9	77.3	77.2	77.4
Inlet Water	67.8	68.4	69.0	69.2	70.0	70.1	70.2	70.4	70.8
Outlet Water	108.9	107.2	110.7	113.8	110.9	112.0	111.6	112.5	112.4
Stack	276.7	271.1	277.5	284.9	277.2	279.7	278.0	279.7	278.3
Pressures									
Supply (in. w.c.)	7.01	7.06	7.02	7.05	6.80	7.12	7.06	7.12	7.07
Manifold (in. w.c.)	3.10	3.08	3.08	3.07	3.08	3.08	3.08	3.07	3.07

Gas Analysis - July 1, 2004					
Gases	**Base**	**2**	**3**	**4A**	**5A**
Methane	98.1230	96.2767	87.3941	84.1545	90.9300
Ethane	0.9393	0.0244	9.3035	0.1319	0.1082
Propane	0.2567	0.0603	2.8601	11.5671	6.8647
iso-Butane	0.0000	0.0000	0.5332	0.0000	0.0000
n-Butane	0.2071	0.1161	0.5004	0.0724	0.1271
iso-Pentane	0.0000	0.0000	0.0000	0.0000	0.0000
n-Pentane	0.0000	0.0000	0.0000	0.0000	0.0000
C6 Plus	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.6376	2.9950	0.0000	3.1092	1.5086
O2	0.0000	0.0000	0.0000	0.0000	0.0000
N2	0.3131	0.9951	0.0000	1.2337	0.8707
Total Mole %	100.4768	100.4676	100.5915	100.2687	100.4093