LNG Research Study

Steam Boiler with Premixed Gun-Type Power Burner

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Disclaimer

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Results Summary

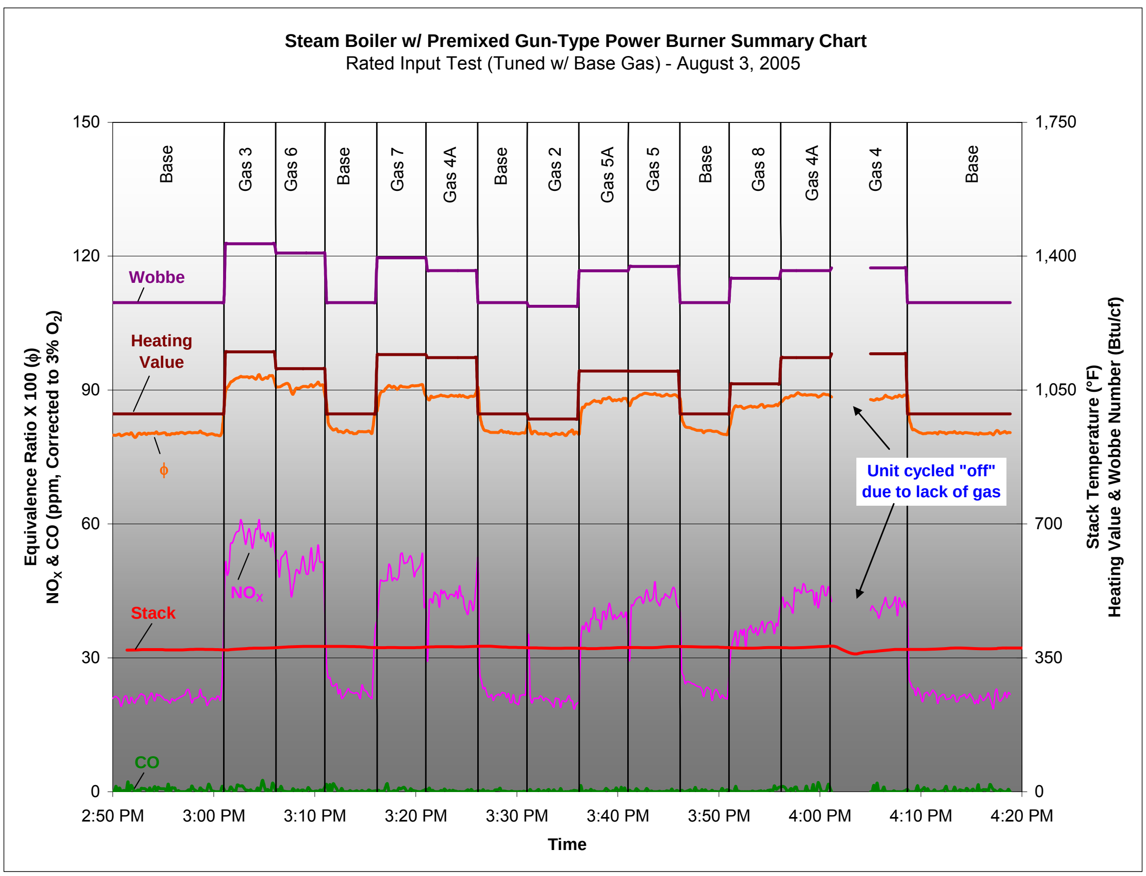
Results obtained from all tests conducted reveal that (a) there were no operational, ignition, flame stability, flame lifting, flashback, yellow tipping or safety problems with the different gases or during transitioning; (b) CO emissions were low; and (c) NO_X emissions and equivalence ratio followed the same pattern as the Wobbe Number.

Before each test, the manufacturer's representative tuned this appliance with either Base Gas or Gas 8 to ~350,000 Btu/hr; which is ~12 percent below the rated input.

After testing was concluded, the manufacturer reviewed the test results and expressed concerns with high NO_X emissions and low O_2 levels when the unit operated with richer gases.

Rated Input Test (Tuned w/ Base Gas)

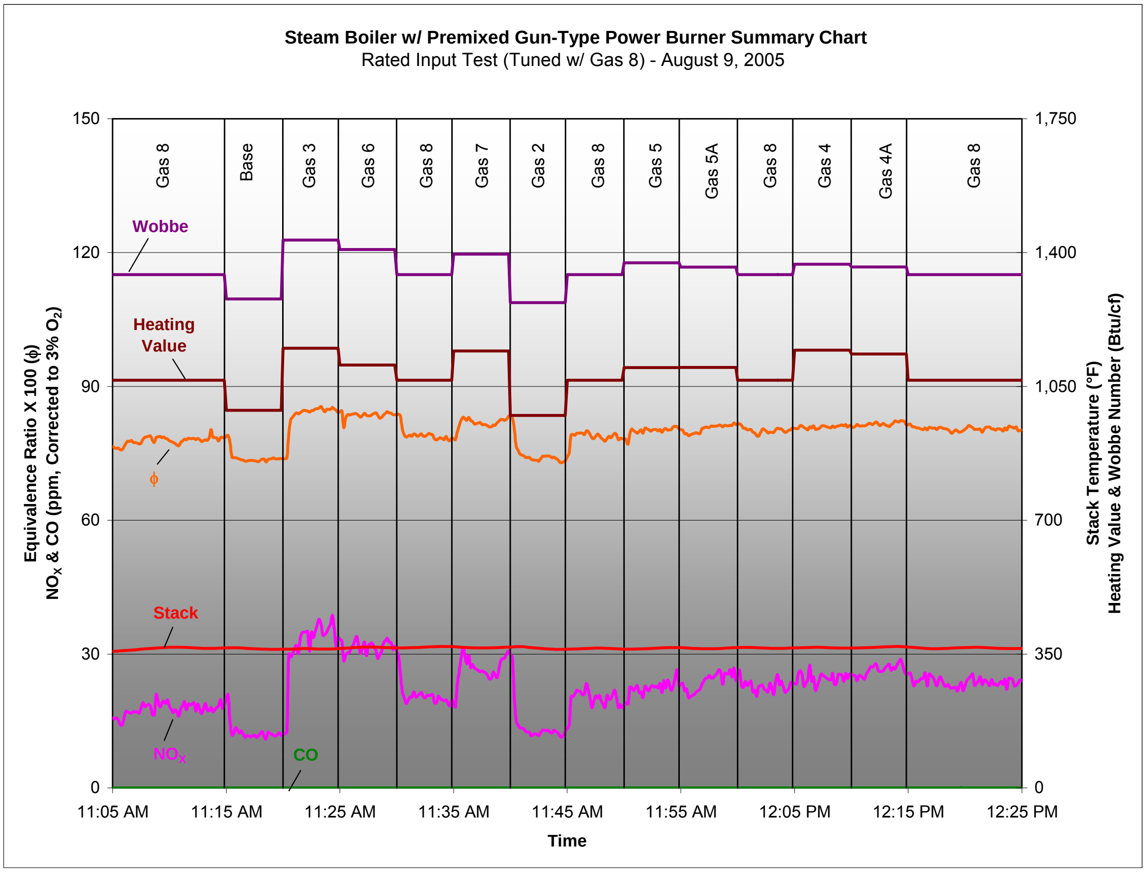
When tuned with Base Gas, NO_X emissions (corrected to 3% O_2) were below 57 ppm for all test gases. Base Gas NO_X emissions averaged 22.7 ppm. Changes in NO_X emissions correlated directly with changes in Wobbe Number and equivalence ratio. CO emissions (corrected to 3% O_2) were negligible throughout the course of the test.



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

Rated Input Test (Tuned w/ Gas 8)

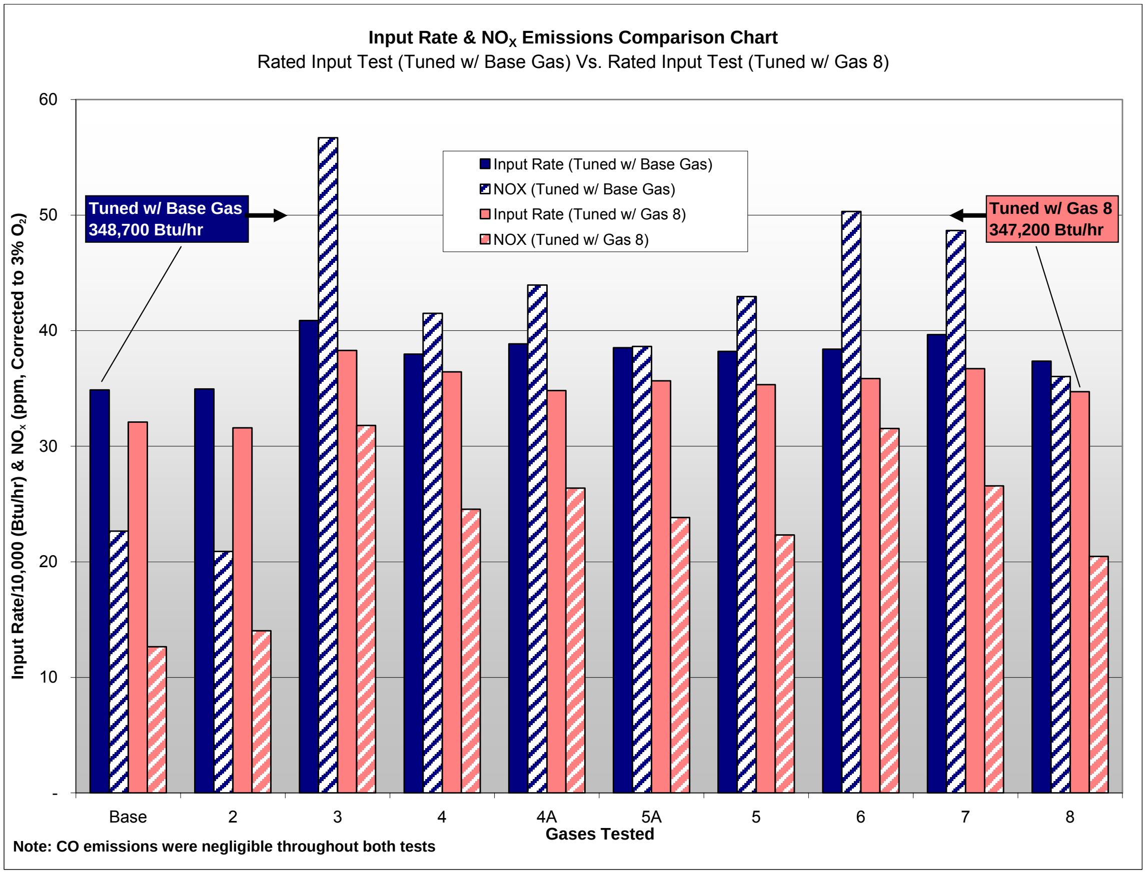
When tuned with Gas 8, results revealed that NO_X emissions (corrected to 3% O_2) stayed below 32 ppm for all test gases. Gas 8 NO_X emissions averaged 20.5 ppm and Base Gas NO_X emissions averaged 12.6 ppm. CO emissions (corrected to 3% O_2) were negligible throughout the entire test run.



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

Rated Input & NO_X Emissions Comparison Chart

When tuned with Gas 8, the NO_X emissions and input rate were lower than when tuned with Base Gas. On both tests, NO_X emissions and input rate were highest with Gas 3 and CO emissions were negligible with all gases tested.



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

Equipment Selection Criteria

This unit was selected because a) it uses a premixed gun-type power burner that several industry experts claimed might be sensitive to rich gases; b) both the boiler manufacturer and the burner system are regularly used in our service territory; c) it has been complex for boiler and burner manufacturers to meet SCAQMD emissions rules while adhering to the Gas-Fired Low Pressure Steam and Hot Water Boilers Standard (ANSI Z21.13) and/or the Commercial-Industrial Gas Heating Equipment Standard (UL–795) from the Underwriters Laboratory. SCAQMD rules limit the NO_X and CO emissions for Type 1 boilers (from 75,000 Btu/hr up to and including 400,000 Btu/hr). The ANSI Z21.13 and UL standards cover safety, construction and performance, with each having combustion tests that limit CO emissions.

In addition, this unit was selected because industry experts were concerned about how the unit will react to the richer gases.

Equipment Specifications

Description	9.5 (boiler) HP Low NO_X Steam Boiler
Burner	Premixed gun-type power burner
Maximum rated input	397,000 Btu/hr
Type of fuel	Natural Gas
Required supply pressure	7 – 14 in w.c.

Standards

A description of the test protocol and rationale used to develop testing procedures are included in Appendix A. Test protocol development was based on the following test standards.

UL 795	Commercial-Industrial Gas Heating Equipment
ANSI Z21.13-2000	Gas-Fired Low-Pressure Steam and Hot Water Boilers
SCAQMD Protocol	Nitrogen Oxides Compliance Testing for Natural Gas - Fired Water Heaters and Small Boilers (last amended January 1998)
SCAQMD Rule 1146.2	Emission of Oxides of Nitrogen From Large Water Heaters and Small Boilers (adopted January 9, 1998)
SCAQMD Method 100.1	Instrumental Analyzer Procedure for Continuous Gaseous Emissions

Installation

The manufacturer installed the boiler according to their specifications for outdoor installation. The outlet steam valve was adjusted to maintain between 30 to 60 psig of pressure inside the boiler. This allowed the boiler to run continuously without opening the pressure relief valve.

Instrumentation was installed following the above test standards and input from the manufacturer and a consultant. Thermocouples were installed to measure make-up water, steam, flue gas, ambient and gas temperatures. Pressure transducers were installed to measure gas manifold, gas delivery system, gas supply and steam pressures. A gas meter was installed to measure the gas flow and an emissions probe was installed in the flue vent of the boiler.

Test Gases

The following gases have been specifically formulated to cover the range of gas compositions and calorific values of natural gases that could be delivered in the Southern California Gas Company territory by current natural gas suppliers and future LNG suppliers. Gas composition details are specified in Appendix C.

Gas	**Wobbe Number** (Btu/cf)	**Heating Value** (Btu/cf)
Base	1,278 (Low Wobbe)	987 (Low heat content)
2	1,269 (Lowest Wobbe)	974 (Lowest heat content)
3	1,433 (Highest Wobbe)	1,150 (Highest heat content)
4	1,370 (Medium Wobbe)	1,145 (Highest heat content)
4A	1,362 (Medium Wobbe)	1,135 (High heat content)
5	1,374 (Medium Wobbe)	1,100 (High heat content)
5A	1,362 (Medium Wobbe)	1,100 (High heat content)
6	1,408 (High Wobbe)	1,106 (High heat content)
7	1,395 (High Wobbe)	1,142 (Highest heat content)
8	1,342 (Medium Wobbe)	1,066 (Medium heat content)

Test Procedure

Test procedures were developed based on the above test standards. However, due to differences between test standards, time limitations, and facility restrictions, the test procedures were simplified. Test procedure simplification was done with input from manufacturers and consultants in the context of developing and maintaining a sound test procedure.

This test was divided in to two series of tests. The first series of tests was with the boiler tuned to Base Gas (low heating value and low Wobbe Number) and the second was with the boiler tuned to Gas 8 (medium heating value and medium Wobbe Number gas). These tests were intended to determine how the boiler will react to numerous test gases when tuned to these two gases.

Due to the manufacturer's concerns with low O_2 levels while running with rich gases, the test duration for each gas was reduced to 5 minutes. Preliminary tests with this boiler and previous tests on other boilers have shown that, in most cases, combustion stability due to switching gases is achieved during the first minute of operation.

Before every test, the following steps were performed:

- All emissions analyzers were calibrated and linearity was checked.
- Data loggers were checked and temperatures, pressures, and gas flow readings were verified.

During every test, the following steps were performed:

- Base Gas and Test Gases were run continuously with switching between gases taking less than 14 seconds.
- Emissions, pressures, temperatures and combustion stability were monitored, during and after changeover.

After every test, the following steps were performed:

- Flue vent was inspected for soot formation.
- Test data was downloaded.
- Linearity and drift inspections were performed on all emissions analyzers.

Rated Input Test (Tuned w/ Base Gas)

Using Base Gas as the setup gas, the manifold pressure was adjusted and the highest input rate achieved was 352,909 BTU/hr, which is 11.1% less than the manufacturer input rate. Once readings were stable, data collection began and the gases were run in the following order:

- Base Gas for 10 minutes.
- Gas 3 for 5 minutes.
- Gas 6 for 5 minutes.
- Reestablish Base Gas for 5 minutes.
- Gas 7 for 5 minutes.
- Gas 4A for 5 minutes.
- Reestablish Base Gas for 5 minutes.
- Gas 2 for 5 minutes.
- Gas 5A for 5 minutes.
- Gas 5 for 5 minutes.
- Reestablish Base Gas for 5 minutes.
- Gas 8 for 5 minutes.
- Gas 4A for 5 minutes.
- Gas 4 for 5 minutes.
- Conclude testing with Base Gas for 10 minutes.

Rated Input Test (Tuned w/ Gas 8)

Using Gas 8 as the setup gas, the manifold pressure was adjusted by the manufacturer's representative to achieve an input rate as close as possible to the input rate attained in the previous test with Base Gas. Once readings were stable, data collection began and the gases were run in the following order:

- Gas 8 for 10 minutes.
- Base Gas for 5 minutes.
- Gas 3 for 5 minutes.
- Gas 6 for 5 minutes
- Reestablish Gas 8 for 5 minutes
- Gas 7 for 5 minutes.
- Gas 2 for 5 minutes.
- Reestablish Gas 8 for 5 minutes.
- Gas 5 for 5 minutes.
- Gas 5A for 5 minutes.
- Reestablish Gas 8 for 5 minutes.
- Gas 4 for 5 minutes.
- Gas 4A for 5 minutes.
- Conclude testing with Gas 8 for 10 minutes.

Cold Ignition Test

The unit was tuned with each setup gas. With appliance's components at ambient temperature, three ignition tests were conducted following the protocol detailed in §7.1 & §7.2 of Appendix A.

Hot Ignition Test

The unit was tuned with each setup gas. After steady-state operating conditions were achieved, three ignition tests were conducted following the protocol detailed in §7.3 & §7.4 of Appendix A.

Inlet Pressure Test

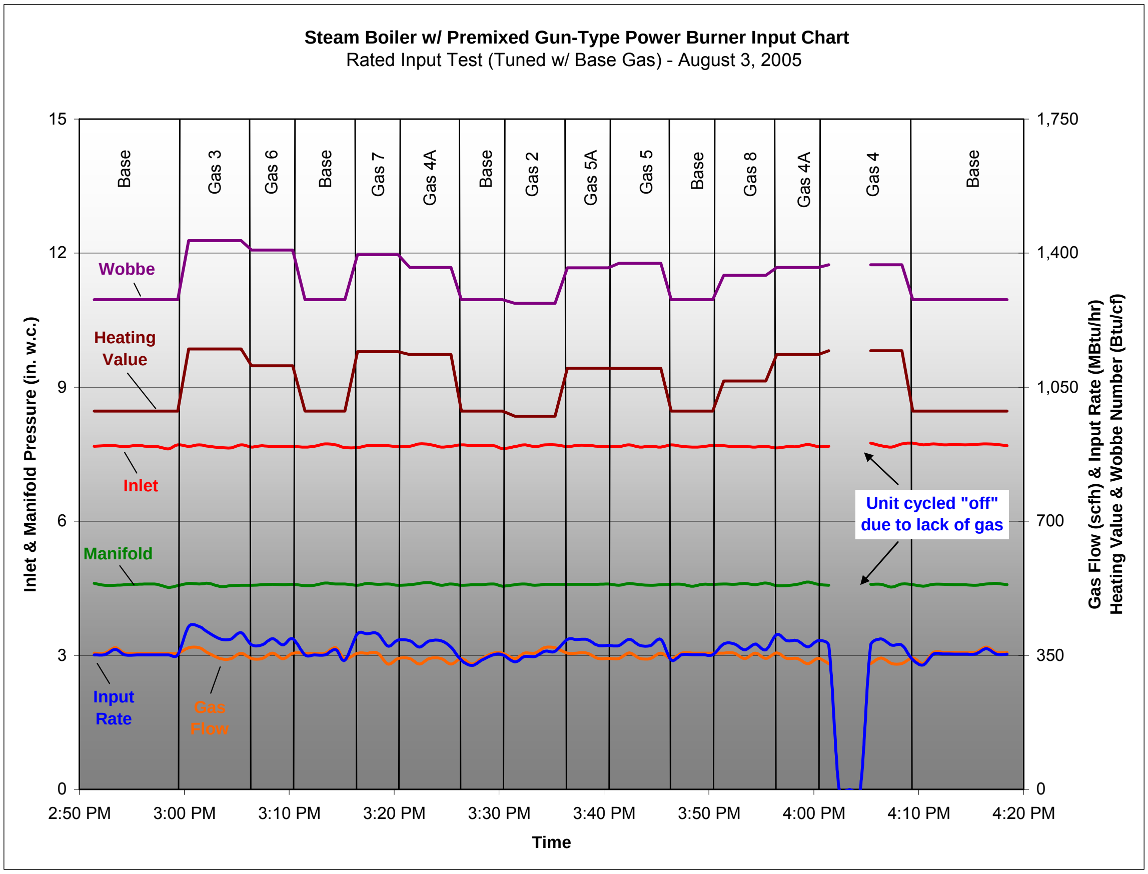
High and low inlet pressure tests were not conducted because of concerns by the manufacturer regarding O_2 percentage.

Results[1,2,3]

Rated Input Test (Tuned w/ Base Gas)

Input

The minimum and maximum input rate achieved during this test was 348,758 Btu/hr (Base Gas) and 408,904 Btu/hr (Gas 3). In most cases, variations of input rate during the test corresponded with changes in Wobbe Number. Inlet and manifold pressures remained stable at 7.7 in w.c. and 4.6 in. w.c., respectively.



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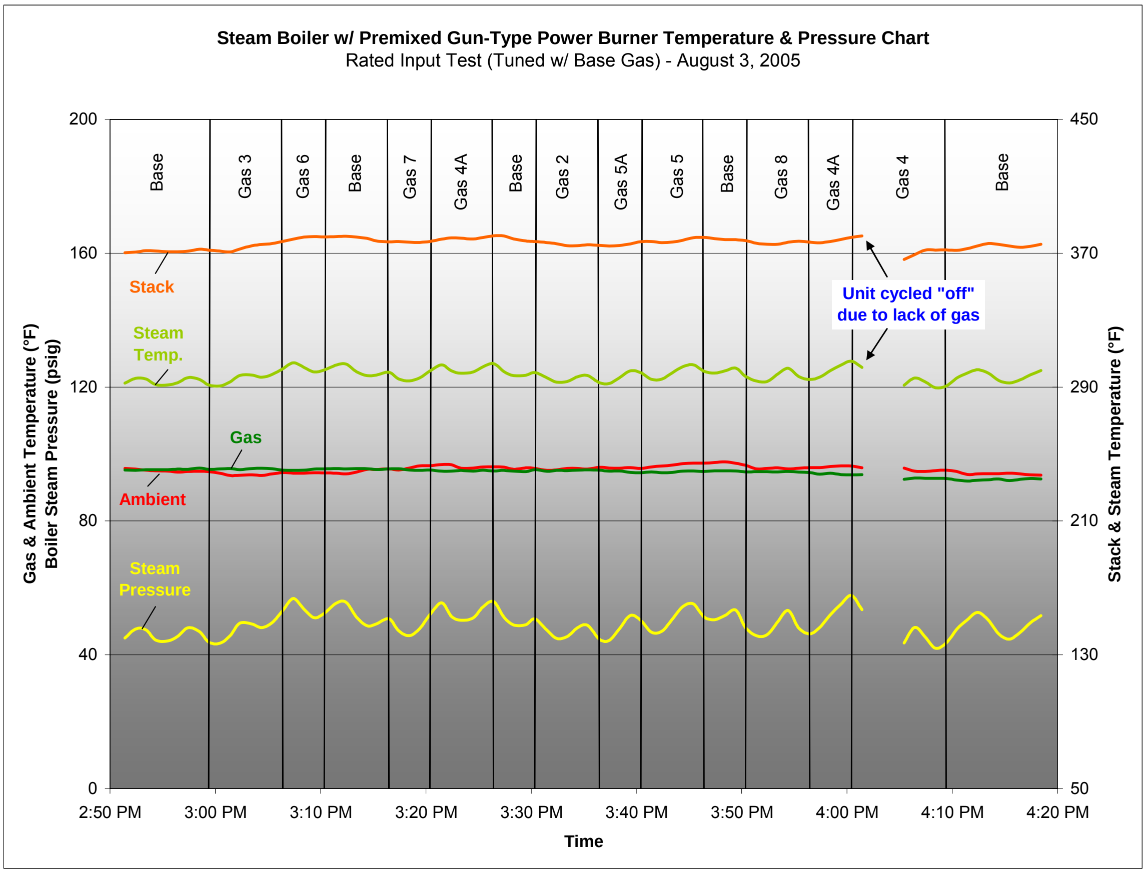
1 All emissions, temperature and input values mentioned throughout the results section are average values.
2 CO, HC & NO_X emissions values are corrected to 3% O_2.
3 When either Base Gas or Gas 8 is used as the set-up gas, the values reported for the set-up gas are the average values of all runs for that gas during each test.

Temperatures

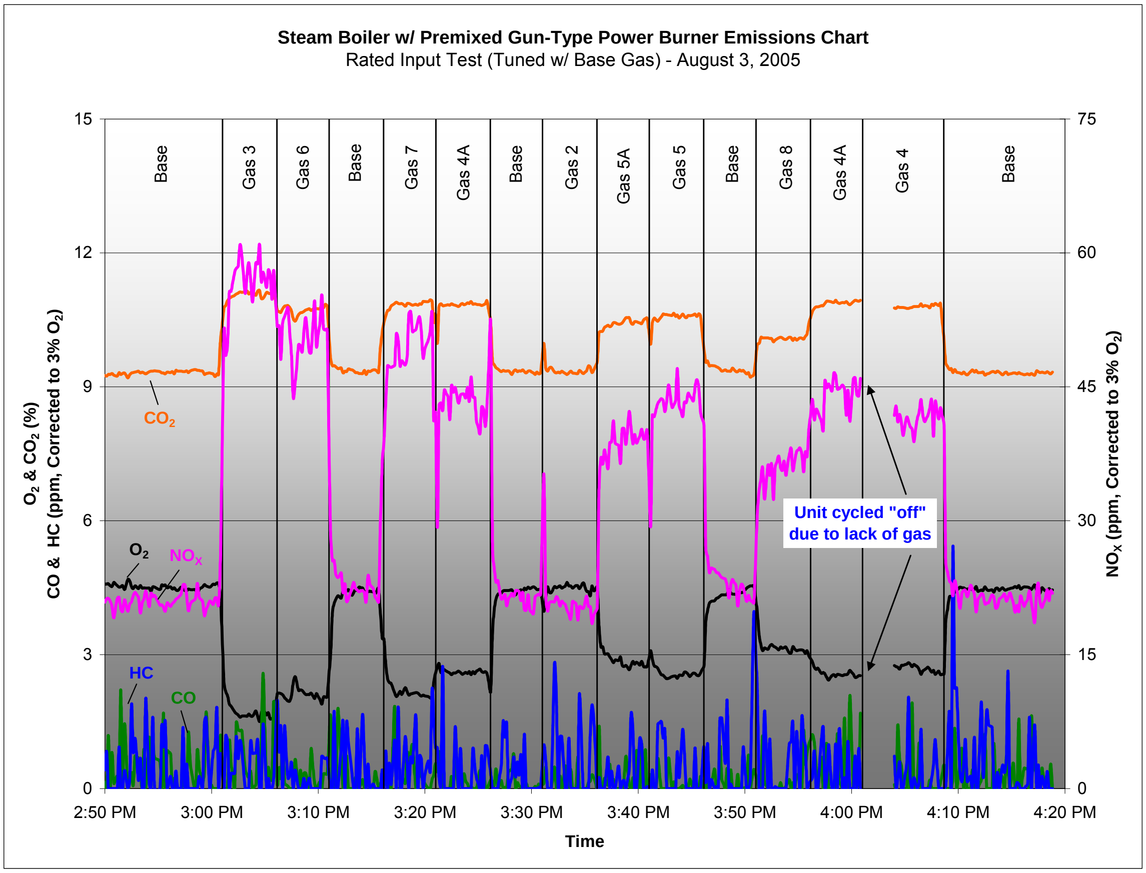
Steam pressure ranged from 49.7 to 53.4 psig, steam temperature varied between 295°F and 301°F and stack temperature varied between 373°F and 379°F throughout the test. Ambient and gas temperatures remained stable throughout the course of the test.

Results reflect that steam pressure, steam temperature, and stack temperature rose during periods using high Wobbe number gases (Gas 3 and Gas 6), and dropped with lower Wobbe number gases (Base Gas and Gas 2).



Emissions

NO_X emissions were highest with Gas 3 (56.7 ppm) and lowest with Base Gas (22.7 ppm). The test shows O_2 percentage had a reverse trend with NO_X emissions and CO_2 percentage. CO and HC emissions were negligible throughout this test.

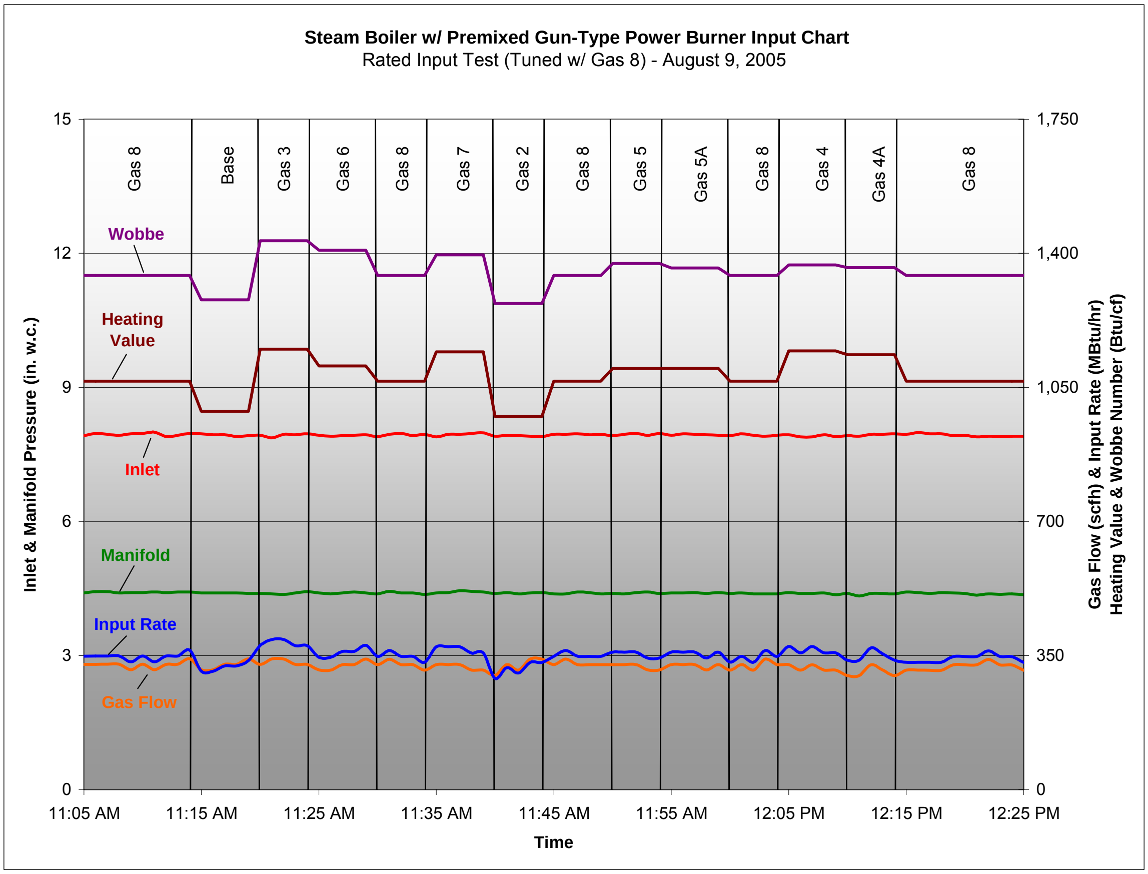


NOTE: Emission test results are for information purposes. They were not the result of certified tests.

Rated Input Test (Tuned w/ Gas 8)

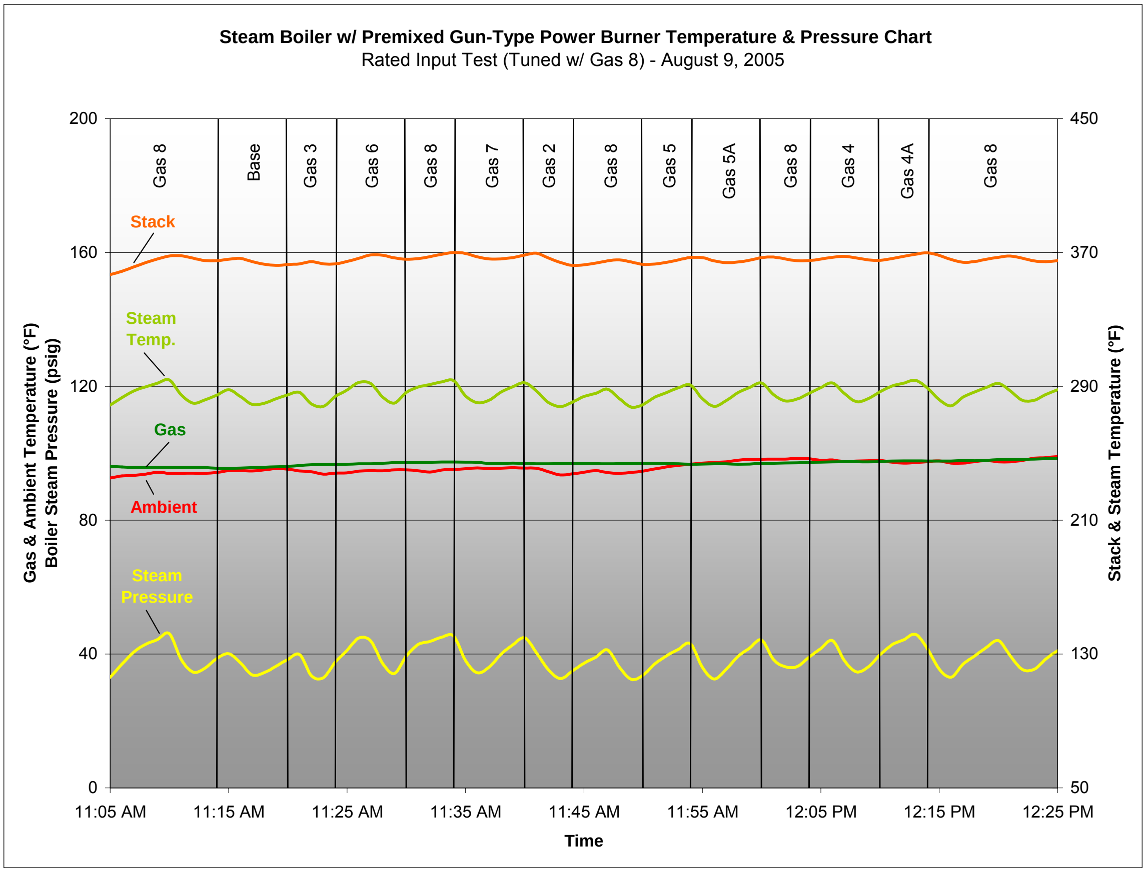
Input

The minimum and maximum input rates achieved during this test were 315,309 Btu/hr (Gas 2) and 382,278 Btu/hr (Gas 3). In most cases, variations of input rate during the test corresponded with changes in Wobbe Number. Inlet and manifold pressures remained stable at 7.9 ± 0.1 in w.c. and 4.4 in. w.c., respectively.



Temperatures

Steam pressure ranged from 36.4 to 42.9 psig, steam temperature varied between 282°F and 291°F and stack temperature varied between 363°F and 368°F throughout the test. Ambient and gas temperatures increased slightly throughout the course of test but remained fairly stable.

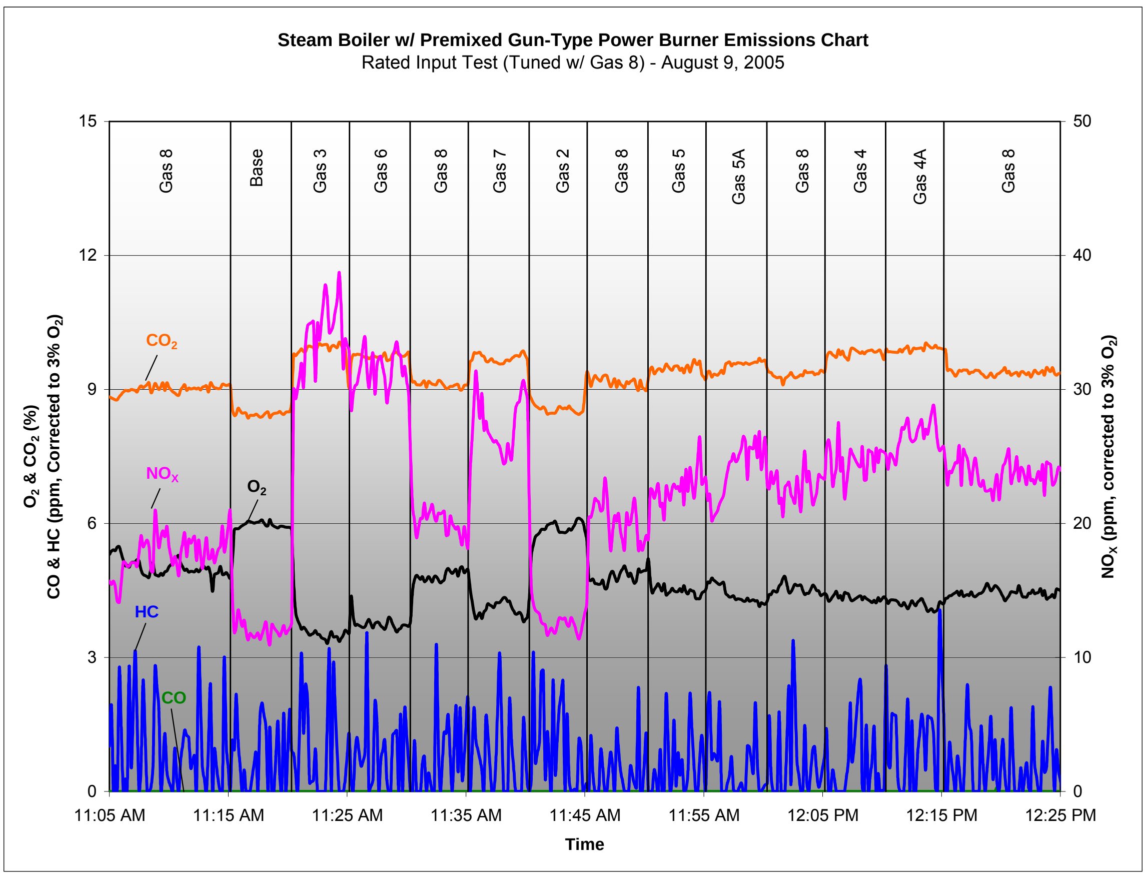


Emissions

NO_X emissions were highest with Gas 3 (31.8 ppm) and Gas 6 (31.5 ppm). For the remaining gases, NO_X emissions were below 27 ppm, with the lowest value observed with Base Gas (12.7 ppm).

Unlike results from most of our previous tests, NO_X emissions with the Set-up Gas (Gas 8) were inconsistent - increasing in the last three runs. The temperature, input and pressure data collected didn't show any indication of why such discrepancies occurred.

The test shows O_2 percentage had a reverse trend with NO_X emissions and CO_2 percentage. CO and HC emissions remained low throughout the entire test.



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

Cold Ignition Test
For each set-up gas (Base Gas and Gas 8), the boiler turned “on” without any problems for all ignition tests. After ignition, flames were stable and there was no flame lifting, flashback or yellow tipping.

Rated Input Test (Tuned w/ Base Gas)		
Gas	Start-Up #	Comment & Observation
Base	1	Normal and without delays
	2	Normal and without delays
	3	Normal and without delays
3	1	Normal and without delays
	2	Normal and without delays
	3	Normal and without delays
Rated Input Test (Tuned w/ Gas 8)		
Gas	Start-Up #	Comment & Observation
8	1	Normal and without delays
	2	Normal and without delays
	3	Normal and without delays
3	1	Normal and without delays
	2	Normal and without delays
	3	Normal and without delays

Hot Ignition Test

For each set-up gas (Base Gas and Gas 8), the boiler turned “on” without any problems for all ignition tests. After ignition, flames were stable and there was no flame lifting, flashback or yellow tipping.

Rated Input Test (Tuned w/ Base Gas)		
Gas	Start-Up #	Comment & Observation
Base	1	Normal and without delays
	2	Normal and without delays
	3	Normal and without delays
3	1	Normal and without delays
	2	Normal and without delays
	3	Normal and without delays
Rated Input Test (Tuned w/ Gas 8)		
Gas	Start-Up #	Comment & Observation
8	1	Normal and without delays
	2	Normal and without delays
	3	Normal and without delays
3	1	Normal and without delays
	2	Normal and without delays
	3	Normal and without delays

Appendix A: Test Protocol

1. Standards

The test protocol for this appliance is based on the following test standards:

UL 795	Commercial-Industrial Gas Heating Equipment
ANSI Z21.13-2000	Gas-Fired Low-Pressure Steam and Hot Water Boilers
SCAQMD Protocol	Nitrogen Oxides Compliance Testing for Natural Gas - Fired Water Heaters and Small Boilers (last amended January 1998)
SCAQMD Rule 1146.2	Emission of Oxides of Nitrogen From Large Water Heaters and Small Boilers (adopted January 9, 1998)
SCAQMD Method 100.1	Instrumental Analyzer Procedure for Continuous Gaseous Emissions

2. Equipment Information

Description	9.5 (boiler HP) Low NO_X Steam Boiler
Burner	Premixed gun-type power burner
Maximum rated input	397,000 Btu/hr
Type of fuel	Natural Gas
Required supply pressure	7 – 14 in w.c.

3. Test Arrangement

3.1. Basic Setup

The boiler is to be tested outdoors on a level surface. The boiler will be mounted on a skid and delivered to the Engineering Analysis Center. Natural gas, electrical power, and water are to be provided at rates and conditions according to manufacturer specifications.

3.2. Water Flow and Piping

Provide water at the flow rate, conditions (water softener required) and temperature as close as possible to those required by the test standards and manufacturer specifications. Maintain satisfactory water level in the steam drum by means of wake up water.

3.3. Vent Pipe

The vent pipe used must meet SCAQMD Protocol requirements for outdoor testing. For all testing, a straight vertical vent pipe (at least three feet in length and of the diameter of the boiler vent collar) is to be provided. The emissions sample probe and three-point thermocouple grid (wired as a thermopile) must be constructed per SCAQMD Protocol. The following is a description of the vent pipe:

Diameter	8 inches
Length	50 inches
Material	Sheet metal
Thermocouple Location	32 inches from the bottom
Emissions Sample Probe Location	32 inches from the bottom

3.4. Electrical Power Electrical power is to be provided per manufacturer specifications.

3.5. Testing Instrumentation

Instrumentation must adhere as close as possible to the SCAQMD Protocol for Rules 1121/1146.2 and SCAQMD Method 100.1.

3.6. Temperatures and Pressures

Provide instrumentation to measure ambient, fuel (natural gas), steam, stack and inlet water temperatures. In addition, also provide instrumentation to measure inlet, manifold and steam pressures.

Provide thermocouples in other locations as appropriate to record possible effects of gas blend changes. If possible, seek assistance from the manufacturer selecting locations.

3.7. Special Measures - Windows & camera access

Windows or openings for viewing the flame will not be available due to burner type and boiler configuration.

4. Test Gases

All test gases will adhere to the Southern California Gas Company's Gas Quality Specification (Rule 30), which is approved by the California Public Utilities Commission (CPUC).

The following gases have been specifically formulated to cover the range of gas compositions and calorific values of natural gases that could be delivered in the Southern California Gas Company territory by current natural gas suppliers and future LNG suppliers.

Gas	**Wobbe Number** (Btu/cf)	**Heating Value** (Btu/cf)
Base	1,278 (Low Wobbe)	987 (Low heat content)
2	1,269 (Lowest Wobbe)	974 (Lowest heat content)
3	1,433 (Highest Wobbe)	1,150 (Highest heat content)
4	1,370 (Medium Wobbe)	1,145 (Highest heat content)
4A	1,362 (Medium Wobbe)	1,135 (High heat content)
5	1,374 (Medium Wobbe)	1,100 (High heat content)
5A	1,362 (Medium Wobbe)	1,100 (High heat content)
6	1,408 (High Wobbe)	1,106 (High heat content)
7	1,395 (High Wobbe)	1,142 (Highest heat content)
8	1,342 (Medium Wobbe)	1,066 (Medium heat content)

5. Basic Operating Conditions

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

5.1. Ambient Temperature

Due to outdoor testing, it is not feasible to control ambient temperature. Ambient temperature must be measured 6 feet away from the boiler and elevated to approximately the mid-height of the boiler and shielded from abnormal radiation and convective effects as per SCAQMD Protocol.

5.2. Inlet and Manifold Pressures

Inlet pressure will be measured just before the boiler gas control and manifold pressure will be measured after the boiler gas control or at the supplied pressure taps.

5.3. Setup Gas Input Rate

The input rate is to be that combination of gas orifice size, inlet gas pressure and manifold pressure required to deliver the as received and/or appliance input rate with the Setup Gas. Input rate, inlet gas pressure and manifold pressure are to be within the tolerances specified by testing standards and/or manufacturers specifications. The appliance input rate will be verified after the appliance has been operated for 15 minutes from a cold start (i.e. all parts of the appliance are at room temperature). With gases other than the Setup Gas, the firing rate generally will *not* be at rated input.

5.4. Steam Flow, Temperature and Pressure

Provide instrumentation to measure the steam temperature and pressure in outlet steam piping as illustrated in Figure #8 of the SCAQMD protocol. Set steam pressure as high as possible to maintain steady-state and consistent operating conditions without shut-off.

5.5. Flame Temperature

Due to the difficulties and cost involved in accurately measuring flame temperature continuously during each test, a simplistic method for measuring flame temperature will be used. This method requires the installation of a thermocouple tip inside the outer mantel of the flame such that it is fixed throughout the length of the test. Due to measurement method and changes in both flame shape and flame length, readings simply indicate temperature treads in the flame zone.

6. Testing

6.1. Rated Input Test (Tuned w/ Base Gas)

Operate the boiler with Base Gas as received or as tuned by the manufacturer/vendor (i.e. with boiler gas regulator and manifold pressure as set by manufacturer). Also, begin collecting temperature, pressure and emissions data while verifying proper operation of all equipment and instrumentation. (**NOTE:** If break-in of the unit is required, this will be done prior to testing until it is evident that all manufacturing oils, insulation binder or any other materials that may generate additional emissions are burned off. After break-in, allow the unit to cool to ambient temperature).
Continue steady boiler operation with Base Gas for a specified duration and conduct a high-speed switch to the first test gas. Record data before, during and after changeover and observe transient phenomena. Possible phenomena include flame flashback, noise, instability or outage, etc. (**NOTE:** The firing rate is not to be adjusted and the boiler controls must not be allowed to adjust firing rate in response to a water temperature change).

With the boiler continuing to operate at steady state on the first test gas, conduct a high-speed switch to another test gas and record observations and data.

Conduct a high-speed switch to the Base Gas and record observations and data per above. Continue testing by reestablishing steady state conditions with the Base Gas after two or three runs with test gases.

When testing has been conducted with all gases, shut down boiler and examine flue collector and vent connection area for presence of soot by means of the swab technique. 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.

6.2. Rated Input Test (Tuned w/ Gas 8)

Tune the appliance with Gas 8 to achieve the same input rate and similar performance (including emissions, temperatures, etc.) as with Base Gas. Follow the same procedures as specified in §6.1.

7. Ignition Tests

Shortly after and during ignition, observe flames and note yellow tipping, flame lifting, flashback phenomena or lack of same.

7.1. Cold Ignition Test (Tuned w/ Base Gas)

With the appliance at room temperature and at the maximum allowable input rate achieved during initial tuning with Base Gas, purge the gas delivery system with Base Gas. Using Base Gas, turn the appliance "ON" and document any combustion, ignition or flame irregularities. Allow the appliance to cool down to room temperature then repeat this procedure 2 more times.

Purge the gas delivery system with Gas 3. Using Gas 3, turn the appliance "ON" and document any combustion, ignition or flame irregularities. Allow the appliance to cool down to room temperature then repeat this procedure 2 more times.

7.2. Cold Ignition Test (Tuned w/ Gas 8)

Follow the same procedure as Cold Ignition Test (Tuned w/ Base Gas) using Gas 8 as the Setup Gas.

7.3. Hot Ignition Test (Tuned w/ Base Gas)

With the appliance at steady state temperatures and at the maximum allowable input rate achieved during initial tuning with Base Gas, purge the gas delivery system with Base Gas. Using Base Gas, turn the appliance "ON" and document any combustion, ignition or flame irregularities. Repeat this procedure 2 more times without allowing the appliance to cold down.

Purge the gas delivery system with Gas 3. Using Gas 3, turn the appliance "ON" and document any combustion, ignition or flame irregularities. Repeat this procedure 2 more times without allowing the appliance to cool down.

7.4. Hot Ignition Test (Tuned w/ Gas 8)

Follow the same procedure as Cold Ignition Test (Tuned w/ Base Gas) using Gas 8 as the Setup Gas.

8. Special Tasks
Special tests may be conducted to investigate phenomena of concern to the boiler manufacturer. The decision of whether to test and the design of appropriate tests are to be discussed with the manufacturer.

9. Additional Testing
Conduct additional testing and/or testing with other gas blends when test results or observations indicate it is necessary. If indicated, additional testing outside of the project scope must be included in the test report.

10. Calculations
CO and NO_X emissions (ppm, Corrected to 3% O_2) are to be calculated per the AQMD protocol for Rule 1146.2.

11. Rationale – Test Setup and Procedures

Firing Rate
A degree of de-rating by manufacturers is not uncommon because they must accommodate for things beyond their control such as component and process tolerances and fuel gas property variation. Allowing boiler 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 practice might affect conclusions.

Burner and Ignition Operating Characteristics
Test 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.

Appendix B: Table of Averages
Rated Input Test (Tuned w/ Base Gas)

Table of Averages Steam Boiler w/ Premixed Power Burner Rated Input Test (Tuned w/ Base Gas) August 3, 2005															
Gases	**Base**	**3**	**6**	**Base**	**7**	**4A**	**Base**	**2**	**5A**	**5**	**Base**	**8**	**4A**	**4**	**Base**
HHV (Btu/cf)	988	1,150	1,106	988	1,143	1,135	988	974	1,100	1,099	988	1,066	1,135	1,145	988
Wobbe (Btu/cf)	1,279	1,433	1,408	1,279	1,396	1,362	1,279	1,269	1,362	1,373	1,279	1,342	1,362	1,370	1,279
Input Rate (Btu/hr)	352,909	408,904	383,965	351,246	396,664	381,418	340,308	349,578	385,319	382,127	348,849	373,660	388,535	379,597	350,479
Corrected Gas Flow (scfh)	357.3	355.6	347.2	355.6	347.2	336.0	344.5	358.8	350.4	347.6	353.2	350.4	342.2	331.5	354.8
Emissions (not from certified tests)															
O_2 (%)	4.5	1.7	2.1	4.3	2.2	2.6	4.3	4.5	2.9	2.6	4.3	3.2	2.6	2.7	4.4
CO_2 (%)	9.3	11.1	10.7	9.4	10.8	10.8	9.4	9.4	10.4	10.5	9.4	10.1	10.9	10.8	9.3
CO (ppm @ 3% O_2)	0.5	0.6	0.3	0.3	0.3	0.2	0.1	0.1	0.3	0.1	0.2	0.2	0.5	0.3	0.3
HC (ppm @ 3% O_2)	0.5	0.5	0.4	0.5	0.6	0.4	0.3	0.6	0.3	0.4	0.7	0.5	0.4	0.3	0.6
NO_X (ppm @ 3% O_2)	21.3	56.7	50.3	23.5	48.7	43.0	23.0	20.9	38.6	42.9	23.7	36.0	43.9	41.5	21.8
Ultimate CO_2 (%)	11.9	12.1	11.9	11.8	12.1	12.4	11.8	11.9	12.1	12.0	11.8	11.9	12.4	11.4	11.8
Equivalence Ratio (Φ)	0.8	0.9	0.9	0.8	0.9	0.9	0.8	0.8	0.9	0.9	0.8	0.9	0.9	0.8	0.8
Temperatures (°F)															
Ambient	95.0	93.8	94.4	94.8	95.9	96.3	95.9	95.4	95.9	96.7	97.3	95.7	96.2	95.3	94.2
Gas	95.4	95.6	95.3	95.6	95.3	95.0	95.0	95.1	94.8	94.7	94.9	94.7	94.1	92.9	92.3
Stack	371.3	373.4	379.0	379.2	376.8	378.9	378.8	375.2	375.2	377.5	378.4	376.1	377.6	371.9	374.0
Steam	293.3	295.2	301.3	300.0	296.5	300.5	299.2	295.0	295.7	298.8	299.1	296.5	299.8	294.2	296.1
Pressures															
Supply (in. w.c.)	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
Manifold (in. w.c.)	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
Steam (psig)	45.9	47.6	53.4	52.0	48.7	52.5	51.1	46.9	47.7	50.8	51.0	48.5	51.9	46.5	48.4

Rated Input Test (Tuned w/ Gas 8)

Table of Averages Steam Boiler w/ Premixed Gun-Type Power Burner Rated Input Test (Tuned w/ Gas 8) August 9, 2005														
Gases	**8**	**Base**	**3**	**6**	**8**	**7**	**2**	**8**	**5**	**5A**	**8**	**4**	**4A**	**8**
HHV (Btu/cf)	1,066	988	1,150	1,106	1,066	1,143	974	1,066	1,099	1,100	1,066	1,145	1,135	1,066
Wobbe (Btu/cf)	1,342	1,279	1,433	1,408	1,342	1,396	1,269	1,342	1,373	1,362	1,342	1,370	1,362	1,342
Input Rate (Btu/hr)	347,284	320,328	382,278	357,857	347,831	366,361	315,309	351,151	352,659	355,943	344,916	363,659	347,515	341,872
Corrected Gas Flow (scfh)	325.7	324.3	332.4	323.6	326.2	320.6	323.6	329.3	320.8	323.7	323.5	317.6	306.1	320.6
Emissions (not from certified tests)														
O_2 (%)	5.0	5.9	3.8	3.7	4.7	4.2	5.7	5.3	4.5	4.4	4.5	4.3	4.2	4.4
CO_2 (%)	9.0	8.5	9.8	9.7	9.2	9.7	8.6	8.9	9.4	9.5	9.3	9.8	9.9	9.4
CO (ppm @ 3% O_2)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HC (ppm @ 3% O_2)	0.9	0.7	0.9	0.8	0.7	0.9	1.0	0.7	0.6	0.6	0.7	0.5	1.0	0.6
NO_X (ppm @ 3% O_2)	17.7	12.6	31.8	31.5	21.0	26.6	14.0	16.9	22.3	23.8	22.9	24.5	26.4	23.8
Ultimate CO_2 (%)	11.9	11.8	12.0	11.8	11.8	12.1	11.9	11.9	12.1	12.1	11.9	12.3	12.4	11.9
Equivalence Ratio (Φ)	0.78	0.74	0.83	0.84	0.79	0.82	0.75	0.79	0.80	0.81	0.80	0.81	0.82	0.81
Temperatures (°F)														
Ambient	93.8	95.0	94.5	94.7	94.9	95.6	94.6	94.3	95.8	97.6	98.3	97.8	97.4	97.8
Gas	95.8	95.7	96.5	96.9	97.3	97.1	96.9	96.9	96.9	96.8	97.1	97.5	97.7	98.0
Stack	364.0	364.5	363.4	367.0	367.8	367.3	366.3	364.3	364.6	365.2	366.2	366.7	367.7	366.0
Steam	285.7	282.7	282.6	287.1	290.6	284.6	283.6	283.7	285.8	283.6	285.3	286.1	290.3	285.1
Pressures														
Supply (in. w.c.)	8.0	7.9	7.9	7.9	7.9	7.9	7.9	8.0	7.9	7.9	7.9	7.9	7.9	7.9
Manifold (in. w.c.)	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
Steam (psig)	39.2	36.4	36.4	40.2	43.3	38.3	37.6	37.2	39.0	37.0	38.8	38.9	42.9	38.3

Appendix C: Test Gases

Gas Sample Date	Baseline 8/1/2005	2 8/5/2004	3 7/1/2005	4 8/5/2004	4A 7/15/2005	5 8/18/2004	5A 7/19/2004	6 7/1/2005	7 6/20/2005	8 8/5/2005
COMPONENTS	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**
METHANE	93.393	95.871	86.549	84.971	85.103	88.814	90.809	91.168	86.466	89.998
ETHANE	1.454	0.000	9.480	4.785	0.000	5.299	0.023	5.747	0.312	0.000
PROPANE	0.321	0.014	2.725	2.402	10.588	2.605	6.918	1.727	9.946	5.997
i-BUTANE	0.062	0.000	1.034	1.194	0.044	0.002	0.011	0.534	0.094	0.041
n-BUTANE	0.059	0.000	0.000	1.207	0.025	0.842	0.005	0.531	0.061	0.000
i-PENTANE	0.019	0.000	0.000	0.594	0.004	0.157	0.000	0.000	0.019	0.001
n-PENTANE	0.013	0.000	0.000	0.600	0.004	0.000	0.000	0.000	0.016	0.001
C6 + 57/28/14	0.025	0.031	0.000	0.186	0.014	0.074	0.044	0.000	0.023	0.001
NITROGEN	2.704	1.087	0.128	1.061	1.117	0.800	0.778	0.274	3.025	3.839
CARBON DIOXIDE	1.595	2.997	0.035	3.001	3.079	1.407	1.413	0.003	0.034	0.120
OXYGEN	0.356	0.000	0.049	0.000	0.021	0.000	0.000	0.016	0.004	0.003
TOTAL	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**
Compressibility Factor	0.9979	0.9980	0.9972	0.9969	0.9970	0.9974	0.9974	0.9975	0.9971	0.9976
HHV (Btu/real cubic foot)	**987.80**	**974.40**	**1,150.00**	**1,145.13**	**1,135.30**	**1,099.38**	**1,099.82**	**1,106.00**	**1,142.00**	**1,066.30**
LHV (Btu/real cubic foot)	890.00	877.27	1039.90	1035.92	1027.50	993.10	993.61	998.90	1033.40	963.10
Specific Gravity	0.5968	0.5895	0.6442	0.6989	0.6946	0.6407	0.6410	0.6167	0.6697	0.6312
Wobbe Index	**1,278.66**	**1,269.12**	**1,432.81**	**1,369.72**	**1,362.21**	**1,373.49**	**1,373.72**	**1,408.37**	**1,395.49**	**1,342.13**

Appendix D: Zero, Span and Linearity Tables

August 3, 2005 Rated Input Test (Tuned w/ Base Gas)

	Zero, Span & Linearity Data Steam Boiler w/ Premixed Gun-Type Power Burner Rated Input Test (Tuned w/ Base Gas) August 3, 2005	O_2 (%)	CO_2 (%)	CO (ppm)	HC (ppm)	NO_x (ppm)
	Analyzer Emission Ranges	**0 - 25**	**0 - 20**	**0 - 200**	**0 - 1000**	**0 - 100**
Zero	**Zero Calibration Gas (Low-Range Values)**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
	Allowable Zero Drift (Less Than ± 3% of Range)	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
	Zero Calibration - 2:23:46 PM	0.11	0.01	0.12	0.02	0.32
	Zero Drift Check - 4:23:32 PM	0.08	0.01	0.41	0.03	0.70
	Total Drift Over Test Period	**0.03**	**0.00**	**0.29**	**0.01**	**0.38**
	Was the Zero Drift Within Allowable Deviation?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Span	**Span Calibration Gas (High-Range Values)**	**20.10**	**12.07**	**182.40**	**443.00**	**85.20**
	Allowable Span Drift (Less Than ± 3% of Range)	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
	Span Calibration -2:33:36 PM	9.05	12.17	80.90	432.55	17.02
	Span Drift Check - 4:28:15 PM	9.03	12.12	79.72	436.58	16.60
	Total Drift Over Test Period	**0.02**	**0.05**	**1.18**	**4.03**	**0.42**
	Was the Span Drift Within Allowable Deviation?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

August 9, 2005 Rated Input Test (Tuned w/ Gas 8)

	Zero, Span & Linearity Data Steam Boiler w/ Premixed Gun-Type Power Burner Rated Input Test (Tuned w/ Gas 8) August 9, 2005	O_2 (%)	CO_2 (%)	CO (ppm)	HC (ppm)	NO_x (ppm)
	Analyzer Emission Ranges	**0 - 25**	**0 - 20**	**0 - 200**	**0 - 1000**	**0 - 100**
Zero	**Zero Calibration Gas (Low-Range Values)**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
	Allowable Zero Drift (Less Than ± 3% of Range)	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
	Zero Calibration - 10:31:57 AM	0.09	0.03	0.12	0.36	0.16
	Zero Drift Check - 12:35:06 PM	0.08	0.12	-0.18	0.44	1.98
	Total Drift Over Test Period	**0.01**	**0.09**	**0.30**	**0.08**	**1.82**
	Was the Zero Drift Within Allowable Deviation?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Span	**Span Calibration Gas (High-Range Values)**	**20.10**	**12.07**	**182.40**	**443.00**	**85.20**
	Allowable Span Drift (Less Than ± 3% of Range)	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
	Span Calibration - 10:42:55 AM	8.99	12.06	79.97	443.82	16.31
	Span Drift Check - 12:28:43 PM	8.98	12.16	78.59	449.22	18.36
	Total Drift Over Test Period	**0.01**	**0.10**	**1.38**	**5.40**	**2.05**
	Was the Span Drift Within Allowable Deviation?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

Appendix E: Calculations

Emission Concentrations

Corrected to O_2 Standard (3% O_2)

$$\text{CO, HC \& NO}_x \text{ Concentrations (corrected to 3\% O}_2\text{)} = \text{Raw Concentrations (ppm)} \times \left[\frac{20.9 - 3}{20.9 - \%\text{O}_2} \right]$$

Where

Raw Concentration = Measured CO, HC & NO_x concentrations, by volume (ppm)

% O_2 = Measured O_2 Concentration

Ultimate CO_2

$$\text{Ultimate CO}_2\ (\%) = \text{Raw CO}_2 \times \left[\frac{20.9}{20.9 - \text{Raw O}_2} \right]$$

Where

Raw CO_2 = Measured CO_2 Concentration (%)

% O_2 = Measured O_2 Concentration (%)

% Excess Air

To determine the % 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 natural gas, the balanced chemical equations for each constituent and their respective theoretical air and theoretical flue gas values (expressed in moles).

Constituent	Balanced Chemical Composition	Theo. Air	Theo. Flue Gas
Methane (CH_4)	$CH_4 + 2O_2 + 2(3.78)N_2 \Rightarrow 1CO_2 + 2H_2O + 2(3.78)N_2$	9.56	8.56
Ethane (C_2H_6)	$C_2H_6 + 3.5O_2 + 3.5(3.78)N_2 \Rightarrow 2CO_2 + 3H_2O + 3.5(3.78)N_2$	16.73	15.23
Propane (C_3H_8)	$C_3H_8 + 5O_2 + 5(3.78)N_2 \Rightarrow 3CO_2 + 4H_2O + 5(3.78)N_2$	23.90	21.90
i-Butane (C_4H_{10})	$C_4H_{10} + 6.5O_2 + 6.5(3.78)N_2 \Rightarrow 4CO_2 + 5H_2O + 6.5(3.78)N_2$	31.07	28.57
n-Butane (C_4H_{10})	$C_4H_{10} + 6.5O_2 + 6.5(3.78)N_2 \Rightarrow 4CO_2 + 5H_2O + 6.5(3.78)N_2$	31.07	28.57
i-Pentane (C_5H_{12})	$C_5H_{12} + 8O_2 + 8(3.78)N_2 \Rightarrow 5CO_2 + 6H_2O + 8(3.78)N_2$	38.24	35.24
n-Pentane (C_5H_{12})	$C_5H_{12} + 8O_2 + 8(3.78)N_2 \Rightarrow 5CO_2 + 6H_2O + 8(3.78)N_2$	38.24	35.24
Hexanes (C_6H_{14})	$C_6H_{14} + 9.5O_2 + 9.5(3.78)N_2 \Rightarrow 6CO_2 + 7H_2O + 9.5(3.78)N_2$	45.41	41.91

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 (ex: For Methane, 2 moles of O_2 plus 7.56 moles of N_2 = 9.56 moles of Theoretical Air). The theoretical flue 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 (ex: For Methane, 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), the % composition of each gas is used to determine the theoretical air and theoretical flue gas values for each gas tested. Thus,

$$\text{Theoretical Air} = \sum C_1P + C_2P + \ldots + C_nP$$

$$\text{Theoretical Flue} = \sum D_1P + D_2P + \ldots + D_nP$$

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 as a decimal, not a percentage). Therefore, the % Excess Air is calculated as follows:

$$\%\,\text{Excess Air} = \left[\text{Theoretical Flue Value} \times \frac{\text{Ultimate } CO_2 - \text{Raw } CO_2}{\text{Theoretical Air Value} \times \text{Raw } CO_2}\right] \times 100$$

Air/Fuel Ratio

$$\text{Air/Fuel Ratio} = \text{Theoretical Air Value} + \frac{\text{Theoretical Air Value} \times \%\,\text{Excess Air}}{100}$$

Equivalence Ratio (ϕ)

$$\text{Equivalence Ratio}\,(\phi) = \frac{100}{100 + \%\,\text{Excess Air}}$$

Gas Meter Accuracy Table

The gas meter used during testing was compared to a certified bell prover to determine its accuracy (error percentage) at various flow rates.

The gas meter accuracy table (below) shows the prover flow rates that the meter was tested, error percentage for each accuracy test and meter error.

Also included on the table is a gas meter flow rate. The gas meter flow rate is the meter's reading at each prover flow rate when the meter error is factored in. This flow rate was calculated using the meter accuracy equation:

$$\%\,\text{Error} = \left(\frac{\text{Gas Meter Flow - Prover Flow}}{\text{Prover Flow}} \right) \times 100$$

Through algebraic manipulation, the gas meter flow is determined using the following equation:

$$\text{Gas Meter Flow} = \text{Prover Flow} \times \left(1 + \frac{\%\,\text{Error}}{100} \right)$$

A negative error percentage indicates the gas meter flow rate was below the prover flow rate whereas a positive error percentage indicates the gas meter flow rate was above the prover flow rate.

TESTS WERE CONDUCTED USING 20 CU. FT. BELL PROVER #3226		
Model Number: 8C **Meter Number:** 11335393 **Date:** September 22, 2004		
Prover Flow cfh	**Meter Error**	**Gas Meter Flow** cfh
800	**0.10%**	**799.20**
700	**0.20%**	**698.60**
600	**0.10%**	**599.40**
500	**-0.30%**	**501.50**
400	**-0.30%**	**401.20**
200	**-0.10%**	**200.20**
100	**-0.10%**	**100.10**

Actual Gas Flow with Meter Correction (acfh)

To correct the actual gas flow that was measured during testing, a gas meter flow rate range is selected from the meter accuracy table. The gas meter flow rates and meter error (divided by 100) will be used to calculate the meter correction factor at any given gas flow rate.

Setting y = average meter error (divided by 100) and x = gas meter flow rate, the error can be calculated using the following equation:

$$\frac{y - y_0}{y_1 - y_0} = \frac{x - x_0}{x_1 - x_0}$$

Manipulating the right side of the equation algebraically:

$$\alpha = \frac{x - x_0}{x_1 - x_0}$$

The equation would then simplify into:

$$y = \frac{y_1 - y_0}{x_1 - x_0}\left(x - x_0\right) + y_0$$

If the appliance has an actual gas flow rate (F_A) of 672.0 actual cubic feet per hour (acfh), the gas meter flow rate range would be 599.40 to 698.60 acfh and the meter error range (divided by 100) would be 0.0010 to 0.0020. Using this information, the meter error (y) is:

$$y = \frac{0.0020 - 0.0010}{698.60\text{ acfh} - 599.40\text{ acfh}}\left(672.0\text{ acfh} - 599.40\text{ acfh}\right) + 0.0010 = 0.001732$$

Once the meter error is known, the actual gas flow rate with meter correction ($F_{meter.}$) can be calculated using the following equation:

$$F_{meter} = \frac{F_A}{\left(1 + y\right)}$$

$$F_{meter} = \frac{672.0\text{ acfh}}{\left(1 + 0.001732\right)} = 670.8382\text{ acfh}$$

Corrected Gas Flow (scfh)

$$F_{corrected} = F_{meter} \times \left[\frac{P_{Fuel}\ (psig) + P_1\ (psia)}{P_{standard}} \right] \times \left[\frac{T_{standard}}{T_{Fuel}\ (^\circ F) + 459.67} \right]$$

Where

$F_{corrected}$ = Gas flow corrected to standard temperature and pressure (scfh)
F_{meter} = Actual gas flow with meter correction (acfh)
P_{Fuel} = Natural gas inlet pressure (psig)
P_1 = Average pressure in Pico Rivera at an average elevation of 161 ft (psia)
$P_{standard}$ = Standard atmospheric pressure (14.735 psia @ 60°F)
$T_{standard}$ = Standard atmospheric temperature (519.67 R @ 1 atm)
T_{Fuel} = Fuel temperature (°F)

Input Rate (Btu/cf)

$$\text{Input Rate} = \text{Corrected Gas Flow} \times \text{HHV}$$

Where

HHV = Higher Heating Value (Btu/cf)

Wobbe Number (Btu/cf)

$$W_0 = \frac{HHV}{\sqrt{G}}$$

Where

W_0 = Wobbe Number (Btu/cf)
HHV = Higher Heating Value (Btu/cf)
G = Specific gravity of gas sample

Appendix F: Test Equipment

All emissions analyzers, analyzer calibration gases and instrumentation meet CARB and SCAQMD standards.

Emissions Analyzer				
Analyzer	**Manufacturer**	**Model**	**Type**	**Accuracy**
NO/NO_X	Thermo Environmental Instruments Inc.	10AR	Chemiluminescent	± 1% of full scale
CO	Thermo Environmental Instruments Inc.	48	Nondispersive infrared (NDIR) gas analyzer	± 1% of full scale
CO_2	Fuji	ZRH	Nondispersive infrared (NDIR) gas analyzer	± 1% of full scale
HC	California Analytical Instruments, Inc.	300 HFID	Flame ionization detector (FID)	± 1% of full scale
O_2	Teledyne	326RA	Electrochemical cell	± 1% of full scale

Calibration & Span Gases			
Gas	**Manufacturer**	**Type**	**Accuracy**
Calibration	Scott Specialty Gases	Certified Master Class - 0 %	± 2%
NO/NO_X	Scott Specialty Gases	Certified Master Class - 18.95 ppm	± 2%
CO	Scott Specialty Gases	Certified Master Class - 79.3 ppm	± 2%
CO_2	Scott Specialty Gases	Certified Master Class -12.1 %	± 2%
HC	Scott Specialty Gases	Certified Master Class - 0.5 ppm	± 2%
O_2	Scott Specialty Gases	Certified Master Class - 9.1 %	± 2%

Test Equipment			
Equipment	**Manufacturer**	**Model**	**Accuracy**
Datalogger	Delphin	D51515	n/a
Gas Chromatograph	Agilent	6890	± 0.5 BTU/scf
K	Omega Engineering Co.	KMQSS	2.2°C or 0.75%
J	Omega Engineering Co.	JMQSS	2.2°C or 0.75%
R	Omega Engineering Co.	RMQSS	2.2°C or 0.75%
T	Omega Engineering Co.	TMQSS	2.2°C or 0.75%
Drytest Gas Meter 800 cf/h max	Roots Meter	8C175	n/a
Gas Meter Pulser 2 pulses per 1/10 cf	Rio Tronics	4008468	n/a
Gas Pressure Regulator	Fisher	299H	± 1.0 %
Differential Pressure Transmitter	Dwyer	607-4	±0.25 -0.50%
Pressure Transducer	Omega	PX205-100GI	±0.25% of full scale

Appendix G: Test Set-Up/Schematic

Equipment utilized for testing adheres to industry standards for testing laboratories that certify such equipment. The test rig is transportable and includes a data logger, emissions cart, gas meter, thermocouples and pressure transducers; plus, a gas regulation system that can take natural gas from 3,000 psig and deliver up to 2,000 cubic feet per hour (cfh) at low pressure (approx. 8 in w.c.). The test rig is illustrated below.