LNG Research Study

Low NO_X Steam Boiler

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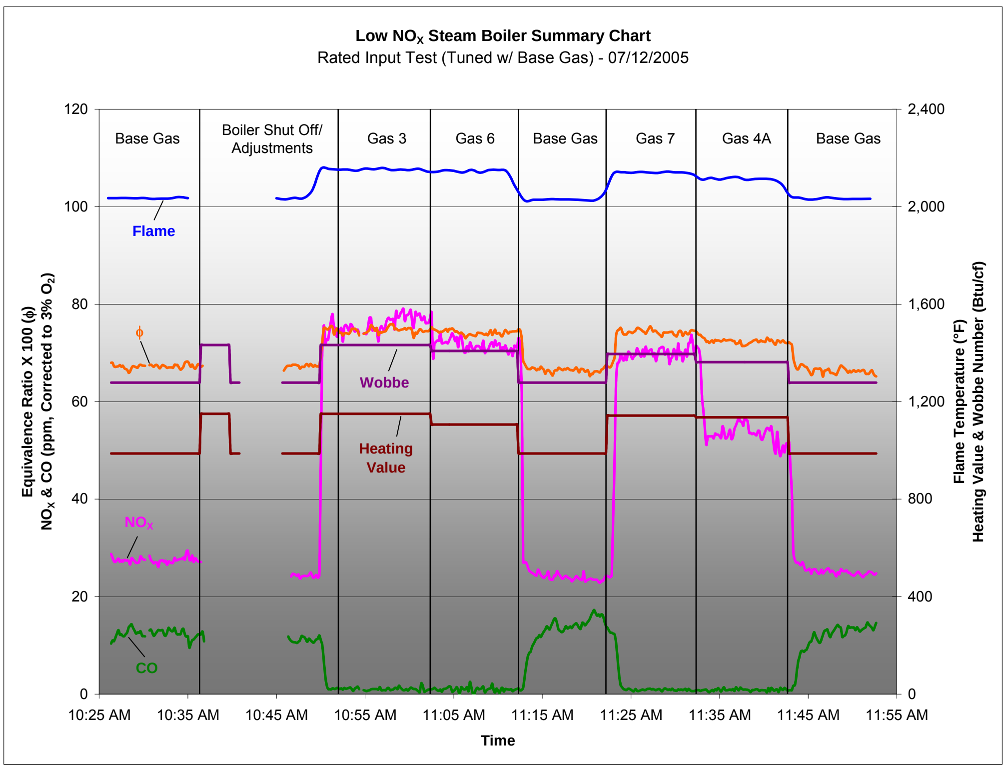
Results Summary

Results obtained from all tests conducted revealed that (a) there were no operational, ignition or flame stability problems with the different gases or during transitioning; (b) after tuning the appliance with Gas 3 (highest heating value and Wobbe Number) CO emissions were 325.4 ppm (corrected to 3% O_2) with Base Gas and (c) flame temperature, partial orange tinting of the flame, NO_X, and equivalence ratio followed the same pattern as the Wobbe Number. Results while boiler was tuned with Base Gas corroborate results from test conducted in September 2004.

After the manufacturer representatives reviewed the data, they expressed concerns with higher NO_X emissions observed with richer gases when tuned with Base Gas and the high CO emissions observed with Base Gas when tuned with Gas 3.

Rated Input Test (Tuned w/ Base Gas)

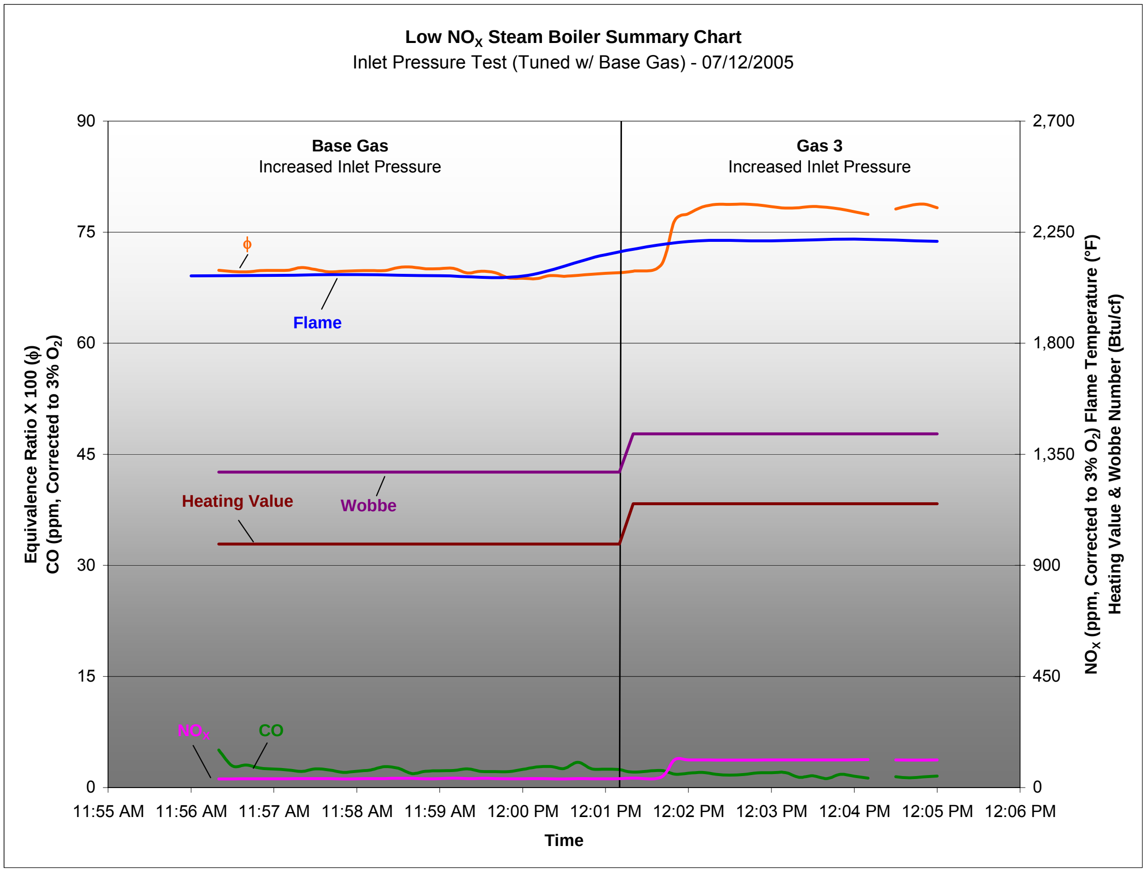
Prior to testing, the manufacturer's representative tuned the appliance with Base Gas to an input rate of 587,225 Btu/hr; which is 8.96% below rated input. NO_X emissions (corrected to 3% O_2) were 25.6 ppm for Base Gas and highest with Gas 3 (76.0 ppm) and Gas 6 (71.7 ppm). CO emissions (corrected to 3% O_2) were low throughout the test. Higher Wobbe Number gases (Gases 3 & 6) generated high flame temperatures averaging 2,150°F, while Base Gas and medium Wobbe Number gases (Gases 4A & 7) had flames temperatures, which averaged 2,036°F and 2,125°F, respectively.



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

Increased Inlet Pressure Test (Tuned w/ Base Gas)

NO_X emissions (corrected to 3% O_2) were 36.1 ppm with Base Gas and increased to 112.2 ppm with Gas 3. CO emissions (corrected to 3% O_2) was 2.5 ppm for Base Gas but decreased slightly with Gas 3 to 1.7 ppm. Flame temperature was 2,074°F with Base Gas and increased to 2,204°F with Gas 3.



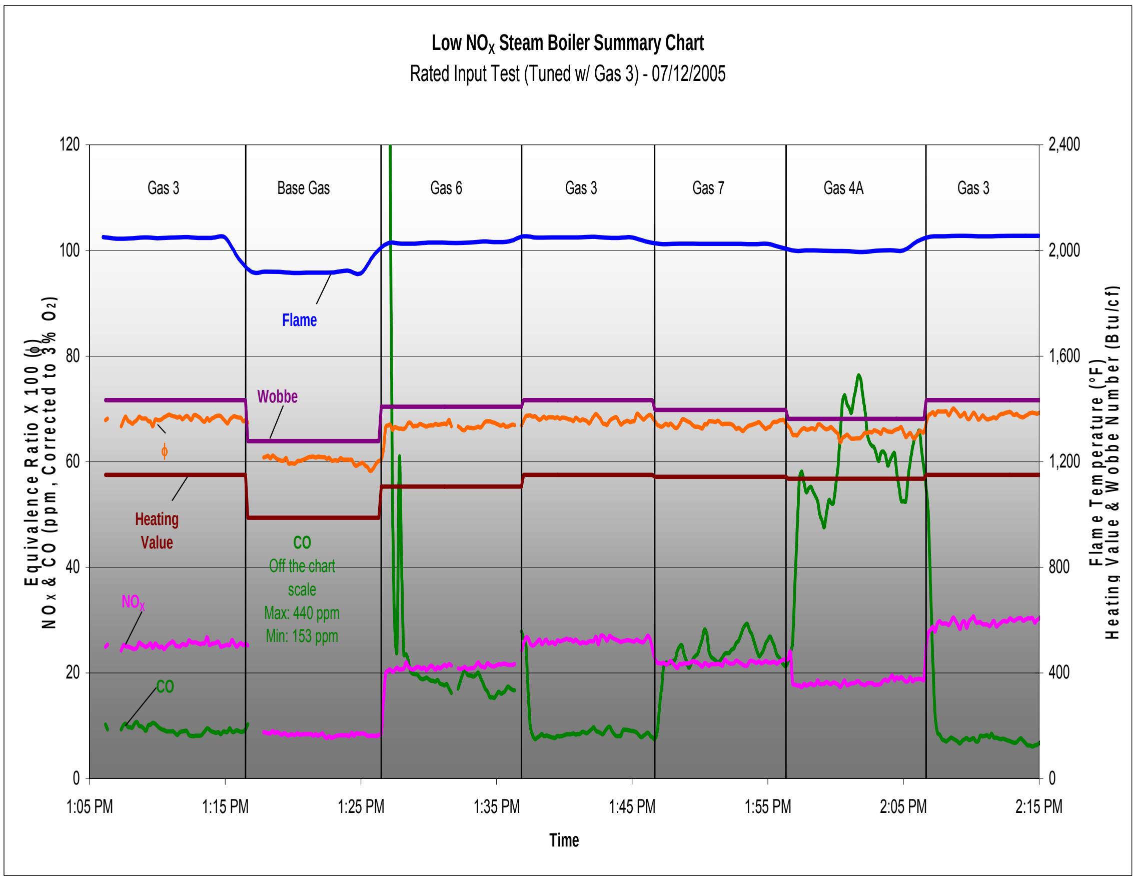
NOTE: Emission test results are for information purposes. They were not the result of certified tests.

Rated Input Test (Tuned w/ Gas 3)

Prior to testing, the manufacturer's representative tuned this appliance with Gas 3 to an input rate of 594,977 Btu/hr; which is 7.76% below rated input. NO_X emissions (corrected to 3% O_2) were 27.0 ppm for Gas 3 and lowest with Base Gas at 8.3 ppm. NO_X emissions for Base Gas and Gas 3 where lower for this test than when the appliance was tuned with Base Gas.

In contrast, CO emissions (corrected to 3% O_2) were higher during this test compared to the emissions values obtained when the appliance was tuned with Base Gas. CO emissions were highest with Base Gas (325.4 ppm – off the chart scale) and lowest with Gas 3 (8.3 ppm).

Average flame temperature was highest with Gas 3 (2,049°F) and lowest with Base Gas (1,922°F). These temperatures were lower than the values obtained when the appliance was tuned with Base Gas - Gas 3 (2,153°F) and Base Gas (2,035°F).

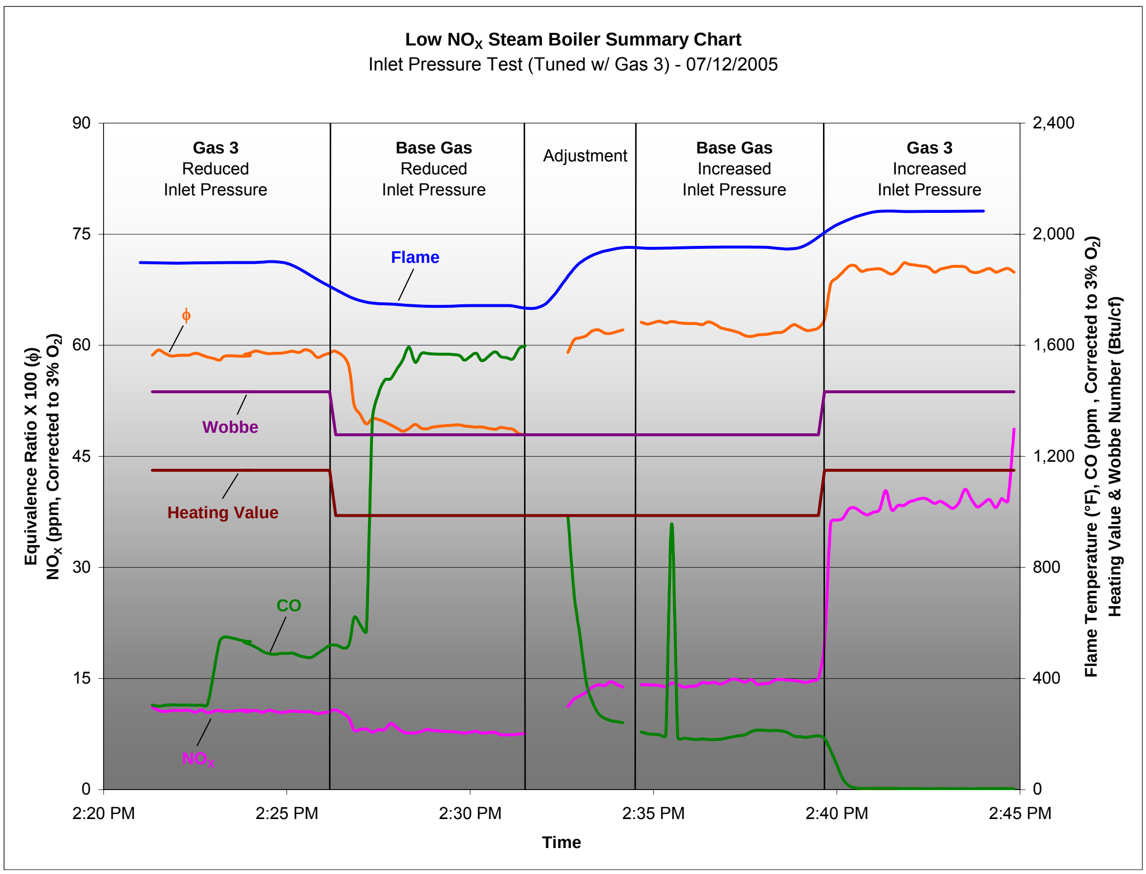


NOTE: Emission test results are for information purposes. They were not the result of certified tests.

Reduced & Increased Inlet Pressure Test (Tuned w/ Gas 3)

For the Reduced Inlet Pressure Test, NO_X emissions (corrected to 3% O_2) were 10.6 ppm (Gas 3) and 7.9 ppm (Base Gas). CO emissions (corrected to 3% O_2) were 435.7 ppm (Gas 3) and 1,563 ppm (Base Gas). The flame temperatures were 1,897°F (Gas 3) and 1,763°F (Base Gas). The equivalence ratio was to 0.59 with Gas 3 and 0.49 with Base Gas.

For the Increased Inlet Pressure Test, NO_X emissions (corrected to 3% O_2) increased to 38.7 ppm (Gas 3) and 14.4 ppm (Base Gas). CO emissions (corrected to 3% O_2) decreased to 3.6 ppm (Gas 3) and 195.1 ppm (Base Gas). The flame temperatures increased to 2,072°F (Gas 3) and 1,952°F (Base Gas). The equivalence ratio increased to 0.62 with Base Gas and 0.70 with Gas 3.



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

Equipment Selection Criteria

This type of boiler (with a premix power surface burner operating in blue flame mode) was selected for a second test to verify the results obtained during the first phase of testing (September 2004) and to evaluate how the appliance would react to the test gases after tuning it with two different setup gases — Base Gas (lowest heating value and Wobbe Number) and Gas 3 (highest heating value and Wobbe Number). This boiler does not have the same input rate as the one tested last year but uses the same burner type, controls and heat exchanger technology as the boiler tested last year.

Originally, this type of appliance was selected because it has been difficult for boiler and burner manufacturers to meet SCAQMD requirements while adhering to the Gas-Fired Low Pressure Steam and Hot Water Boilers Standard (ANSI Z21.13) and/or UL–795 from the Underwriters Laboratory. SCAQMD requirements limit the NO_X and CO emissions for boilers. Both ANSI Z21.13 and UL-795 cover safety, construction, performance, and each have combustion tests that limit CO emissions. This unit was also selected because both the boiler manufacturer and the burner system are widely used in our service territory.

Equipment Specifications

Description	15 Boiler HP Low NO_X Steam Boiler
Burner	Premix power surface burner operating on blue flame mode
Maximum rated input	645,000 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. The test protocol was developed 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 approximately 60 psig inside the boiler, allowing the boiler to run without opening the pressure relief valve.

Instrumentation was installed following the above test standards and input from the manufacturer and consultants. Thermocouples were installed to monitor flame, inlet water, steam, flue gas, ambient and gas temperatures. Pressure transducers were installed to measure manifold pressure, inlet pressure and steam pressures inside the boiler. A gas meter was installed to measure the gas flow and an emissions probe was installed in the flue vent of the boiler.

Once all testing instrumentation was installed, the boiler was operated on the facility's pipeline gas to verify that the boiler and all instrumentation operated properly.

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. 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)
3	1,433 (Highest Wobbe)	1,150 (Highest heat content)
4A	1,362 (Medium Wobbe)	1,135 (High heat content)
6	1,408 (High Wobbe)	1,106 (High heat content)
7	1,395 (High Wobbe)	1,142 (Highest 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 limitations, the test procedures were simplified with input from the manufacturers and consultants directed to develop a sound test procedure.

The appliance was tuned with Base Gas (lowest heating value and Wobbe Number) and Gas 3 (highest heating value and Wobbe Number) to determine how it would react to various test gases of different heating values and Wobbe Numbers.

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, pressure and temperature data was observed before, during and after changeover.

After every test, the following steps were performed:

- Test data was downloaded.
- Linearity and drift inspections were performed on all emissions analyzers.

Rated Input Test (Tuned w/ Base Gas)

Using Base Gas, the manifold pressure was adjusted by the manufacturer's representative to operate at 587,225 Btu/hr; which is 8.96% below rated input. Once readings were stable, data collection began and the test gases were ran in the following order:

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

Increased Inlet Pressure Test (Tuned w/ Base Gas)

Using Base Gas, both manifold and inlet pressures were increased to 4 in. w.c. and 9 in. w.c., respectively. Once readings were stable, data collection began and the test gases were ran in the following order:

- Base Gas for 5 minutes.
- Gas 3 for 5 minutes.

Rated Input Test (Tuned w/ Gas 3)

Using Gas 3 as the setup gas, the manifold pressure was adjusted by the manufacturer's representative to achieve a similar input rate and performance (including emissions, temperatures, etc.) as with Base Gas. The input rate was 594,977 Btu/hr; which is 7.76% below rated input. Once readings were stable, data collection began and the test gases were ran in the following order:

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

Reduced & Increased Inlet Pressure Test (Tuned w/ Gas 3)

For the Reduced Inlet Pressure Test, both manifold and inlet pressures were decreased to 2.2 in. w.c. and 3.5 in. w.c., respectively. Once readings were stable, data collection began and the test gases were run in the following order:

- Base Gas for 5 minutes at reduced inlet pressure.
- Gas 3 for 5 minutes at reduced inlet pressure.

For the Increased Inlet Pressure Test, both manifold and inlet pressure were increased to 4.3 in. w.c. and 10.8 in. w.c., respectively. Once readings were stable, the test continued in the following order:

- Base Gas for 5 minutes at increased inlet pressure.
- Gas 3 for 5 minutes at increased inlet pressure.

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 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 of Appendix A.

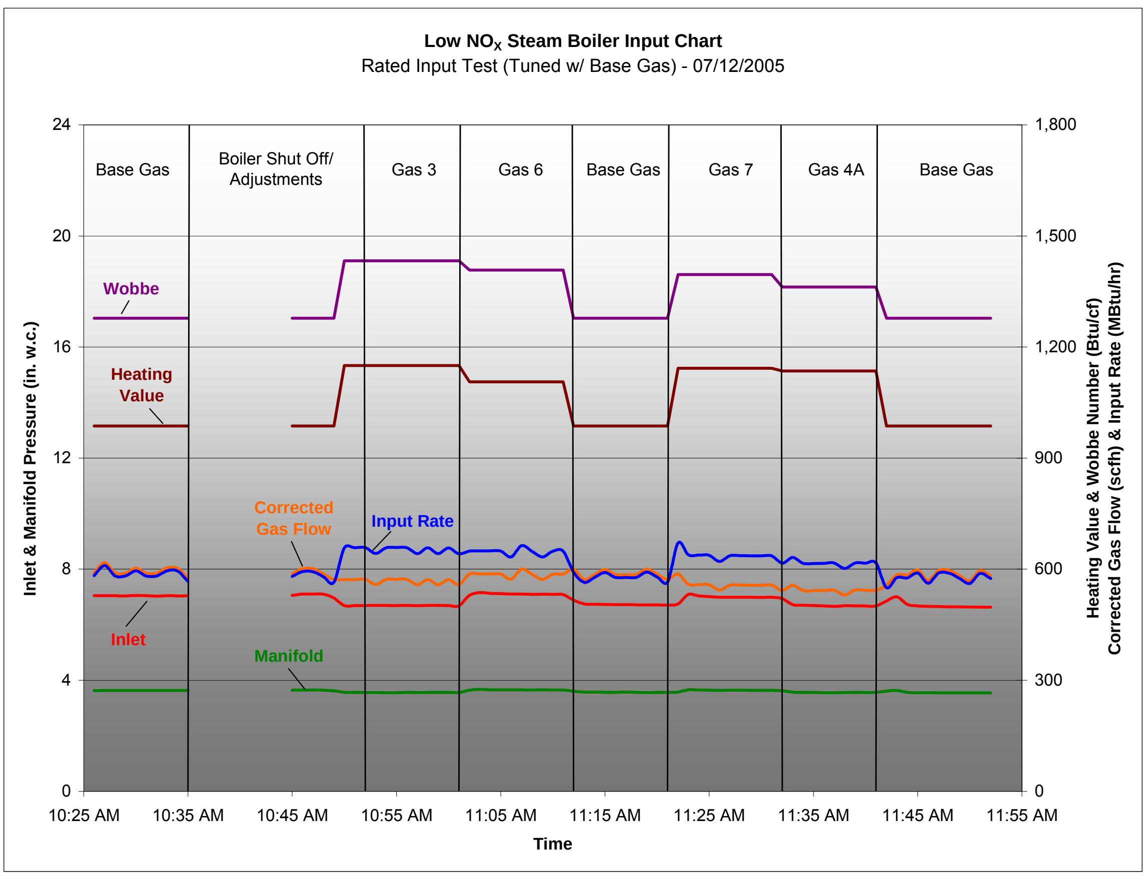
Results[1,2,3]

Rated Input Test (Tuned w/ Base Gas)

Input

Prior to testing, the manufacturer's representative tuned this appliance with Base Gas to an input rate of 587,225 Btu/hr; which is 8.96% below rated input. The appliance input rate ranged from 580,858 Btu/hr (lowest - Base Gas) to 651,550 Btu/hr (highest - Gas 3). The corrected gas flow ranged from 542.9 scfh (lowest - Gas 4A) to 588.5 scfh (highest - Base Gas). Inlet pressure ranged between 6.7 in. w.c. to 7.1 in. w.c. and manifold pressure was 3.6 ± 1 in. w.c..

The input rate followed Wobbe Number patterns, with lower values when the appliance operated on low Wobbe Number gases and higher values when testing on high Wobbe Number gases.



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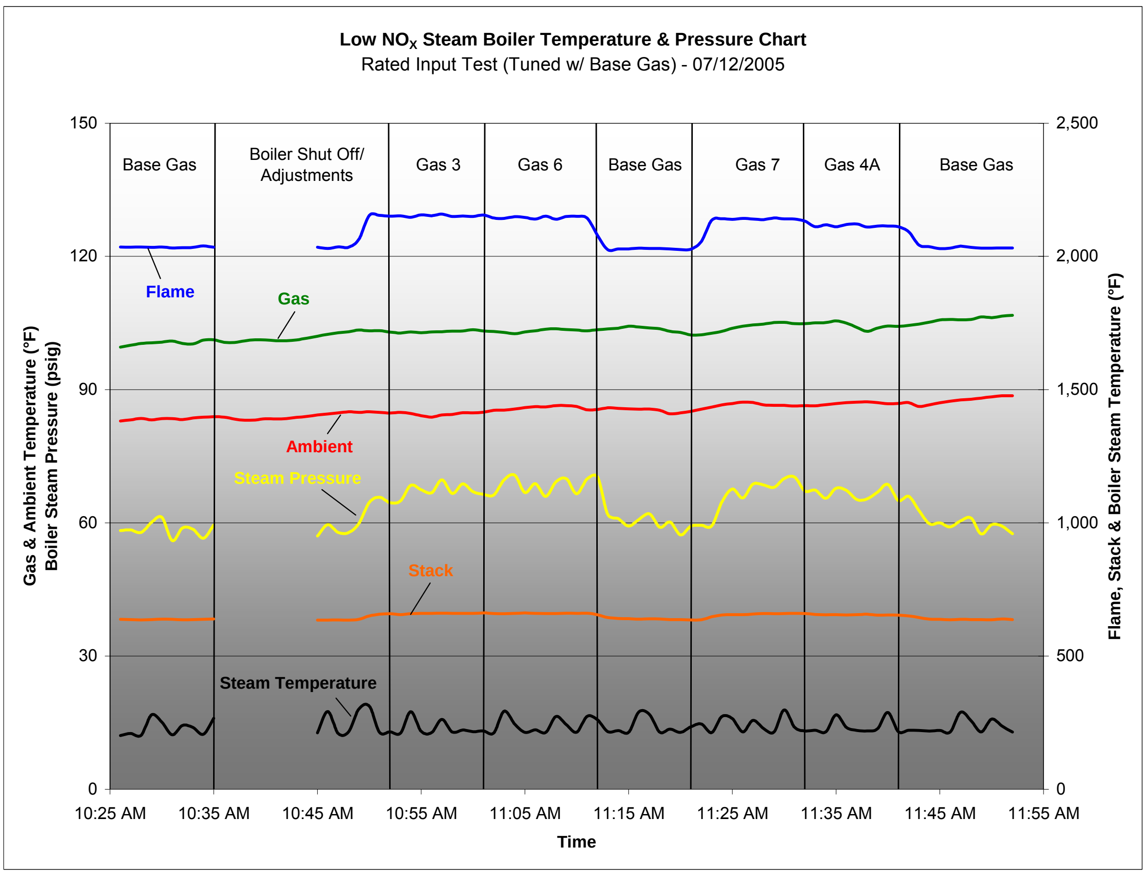
[1] All emissions, temperature and input values mentioned throughout the results section are average values.
[2] CO, HC & NO_X emissions values are corrected to 3% O_2.
[3] When either Base Gas or Gas 3 is used as the set-up gas, the values reported for the set-up gas are the average values of all runs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

Temperature and Pressure Chart

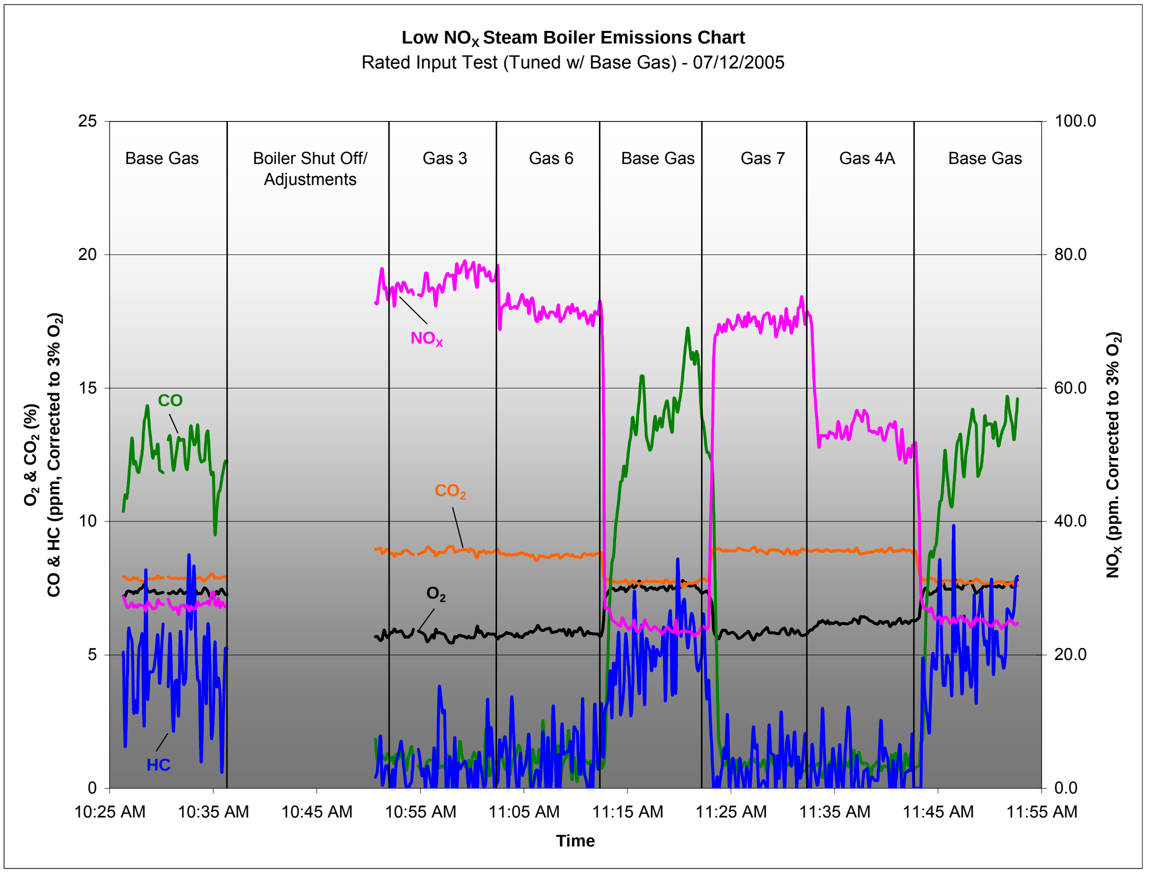
The highest flame temperatures were observed with Gas 3 (2,153°F), Gas 6 (2,146°F), and Gas 7 (2,132°F). Base Gas (2,036°F) had the lowest flame temperature of all gases tested. Stack temperatures fluctuated from 639°F to 660°F and steam temperature ranged from 228°F to 244°F.

The lowest steam pressure was observed with Base Gas (60.0 psig) and was highest with Gas 3 (67.1 psig) and Gas 6 (68.4 psig). Gas temperatures ranged between 101°F and 106°F and ambient temperatures ranged between 83°F and 88°F. Both gas and ambient temperatures increased as the test progressed.



Emissions

NO_X emissions were highest with Gas 3 (76.0 ppm) and lowest with Base Gas (25.6 ppm). CO and HC emissions remained at or below 1.1 ppm for all gases with the exception of Base Gas. CO and HC emissions for Base Gas were 13.1 ppm and 5.0 ppm, respectively. O_2 percentage for gases 3, 4A, 6, and 7 ranged from 5.7% to 6.2% whereas Base Gas had the highest percentage (7.5%).

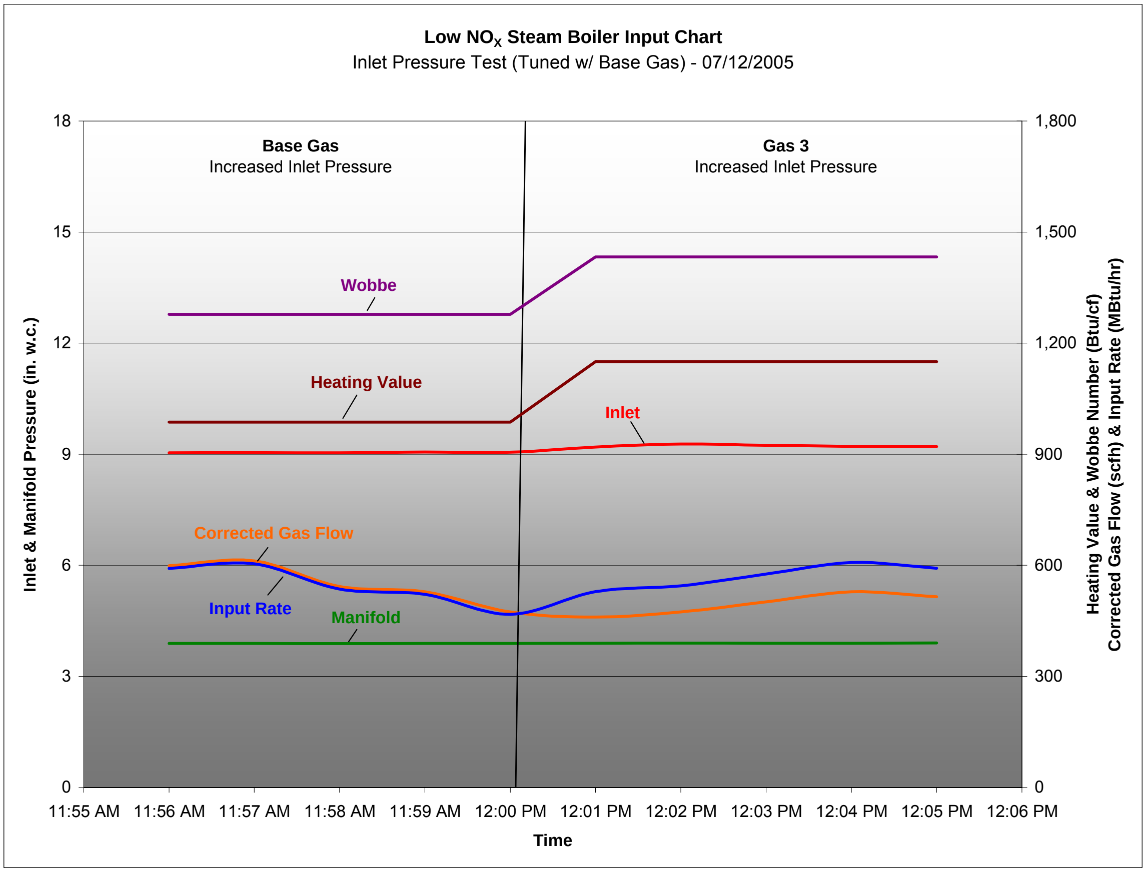


NOTE: Emission test results are for information purposes. They were not the result of certified tests.

Increased Inlet Pressure Test (Tuned w/ Base Gas)

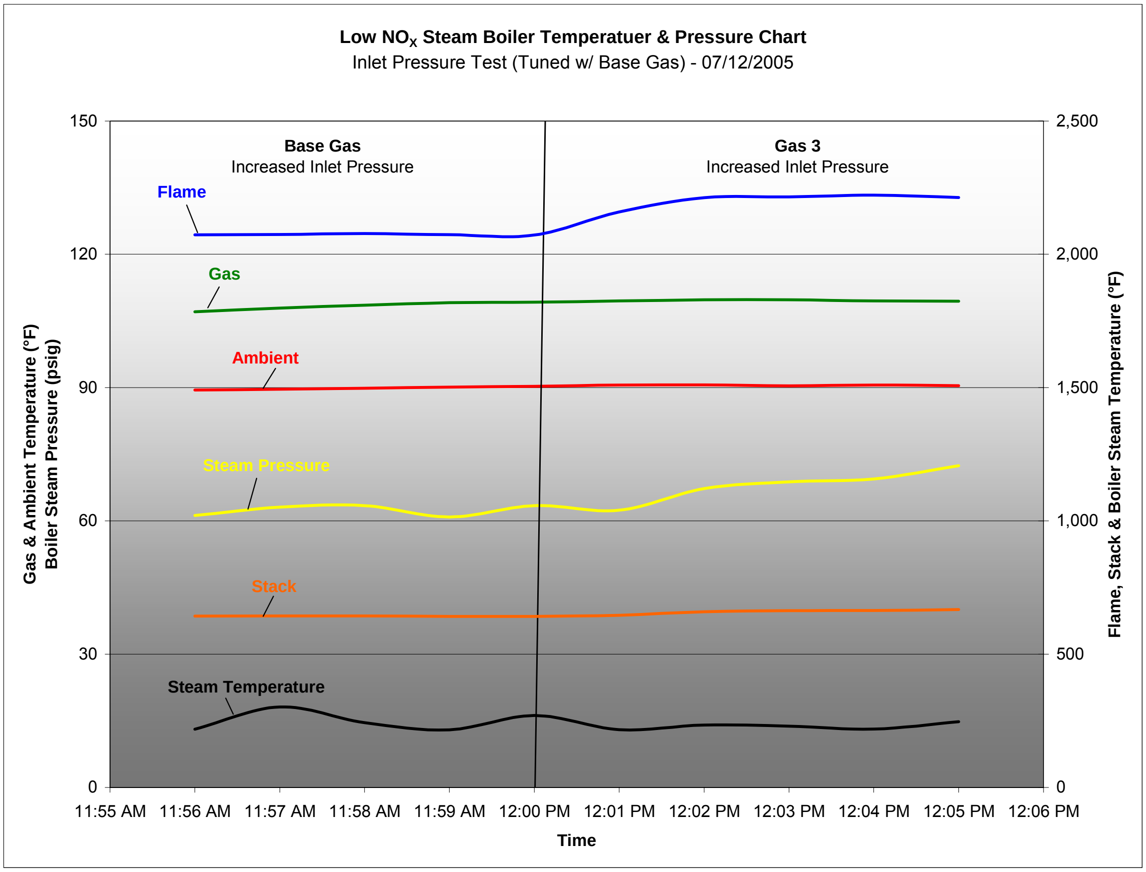
Input

The input rate increased from 544,120 Btu/hr with Base Gas to 569,880 Btu/hr with Gas 3. Corrected gas flow decreased from 551.2 scfh (Base Gas) to 495.6 scfh (Gas 3). Throughout the Base Gas and Gas 3 runs, the input rate and corrected gas flow did not stablize. The reasons for this phenomena are unknown considering inlet pressure (9.1 ± 0.1 in w.c.) and manifold pressure (3.9 in. w.c.) remained stable throughout the test and within tolerances specified in the test protocol.



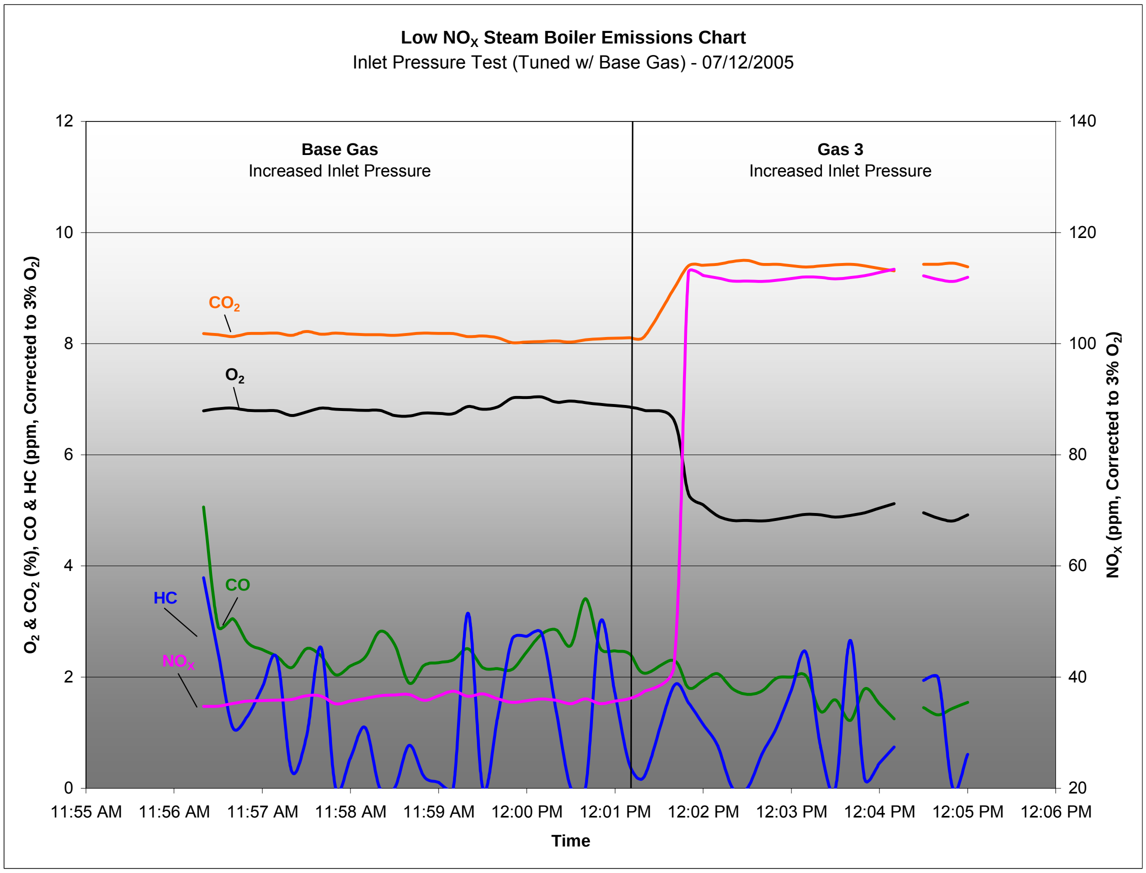
Temperature & Pressure

Flame temperature (2,074°F to 2,204°F), stack temperature (642.6°F to 659.9°F) and boiler steam pressure (62.4 psig to 68.1 psig) increased when the appliance transitioned from operation with Base Gas to operation with Gas 3. Both gas temperature (109 ± 0.6°F) and ambient temperature (90.2 ± 0.3°F) remained stable and within tolerances specified in the test protocol.



Emissions

When transitioning from Base Gas to Gas 3, NO_X emission increased from 36.1 ppm (Base Gas) to 112.2 ppm (Gas 3), O_2 percentage decreased from 6.8% (Base Gas) to 5.0% (Gas 3) and CO emissions decreased from 2.5 ppm (Base Gas) to 1.7 ppm (Gas 3). Despite fluctuations throughout the test, HC emissions remained within 1.1 ± 0.1 ppm for both gases.



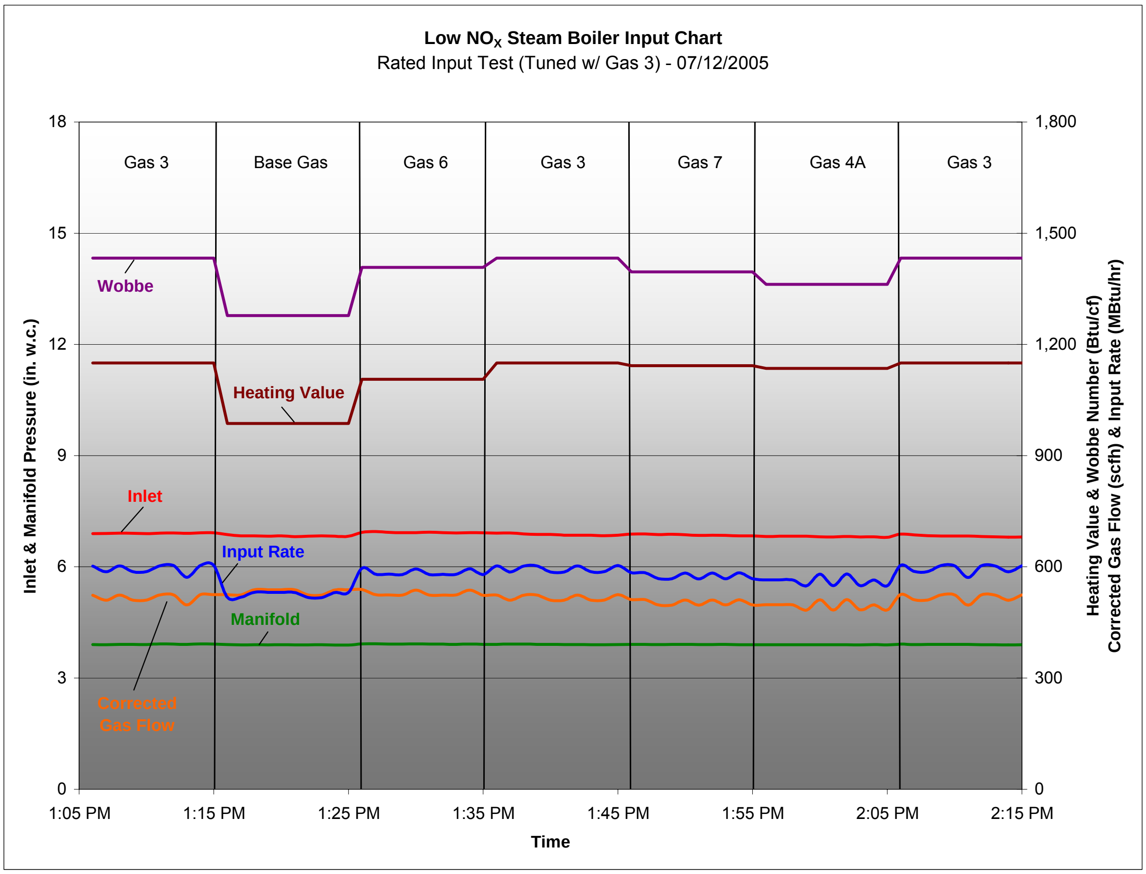
NOTE: Emission test results are for information purposes. They were not the result of certified tests.

Rated Input Test (Tuned w/ Gas 3)

Input

Prior to testing, the manufacturer's representative tuned this appliance with Gas 3 to an input rate of 594,977 Btu/hr; which is 7.76% below rated input. The appliance input rate ranged from 525,746 Btu/hr (lowest - Base Gas) to 594,887 Btu/hr (highest - Gas 3). The corrected gas flow ranged from 494.7 scfh (lowest - Gas 4A) to 532.6 scfh (highest - Base Gas). Inlet pressure (6.8 ± 0.1 in. w.c.) and manifold pressure (3.9 in. w.c.) remained stable and within tolerances specified in the test protocol.

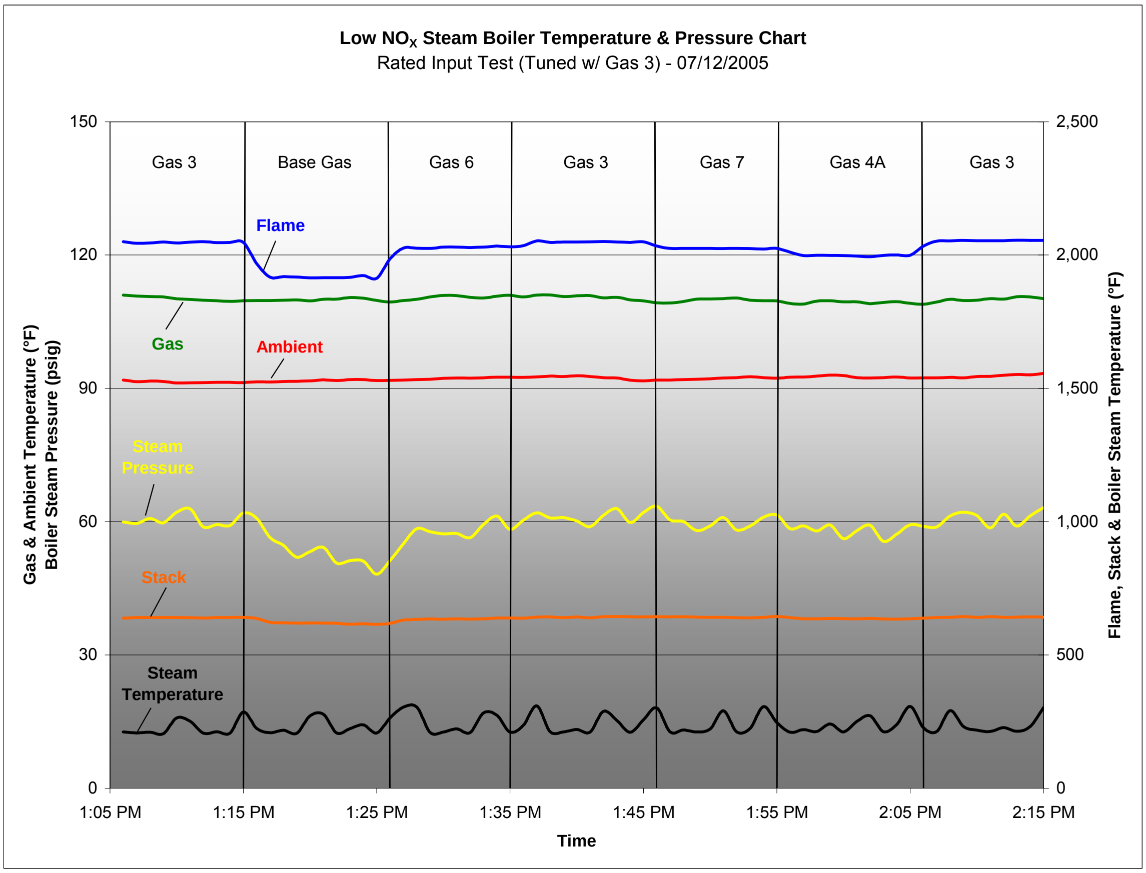
The input rate followed Wobbe Number patterns, with lower values when the appliance operated on low Wobbe Number gases and higher values when testing on high Wobbe Number gases. However, the gas flow and input rate values were much lower than values observed for the test tuned with Base Gas.



Temperature & Pressure

The highest flame temperature occurred with Gas 3 (2,049°F) while the lowest was with Base Gas (1,922°F). Stack temperatures fluctuated from 620.4°F (Base Gas) to 641.6°F (Gas 7) and inlet water temperature ranged from 228.0°F (Base Gas) to 248.9°F (Gas 6). Flame and stack temperatures for all gases were lower compared to values obtained when the appliance was tuned with Base Gas.

The lowest steam pressure value was observed with Base Gas (53.3 psig) but highest with Gas 3 (60.7 psig). Gas temperature (110.9 ± 5°F) and ambient temperature (92.0 ± 0.7°F) remained stable and within tolerances specified in the test protocol.

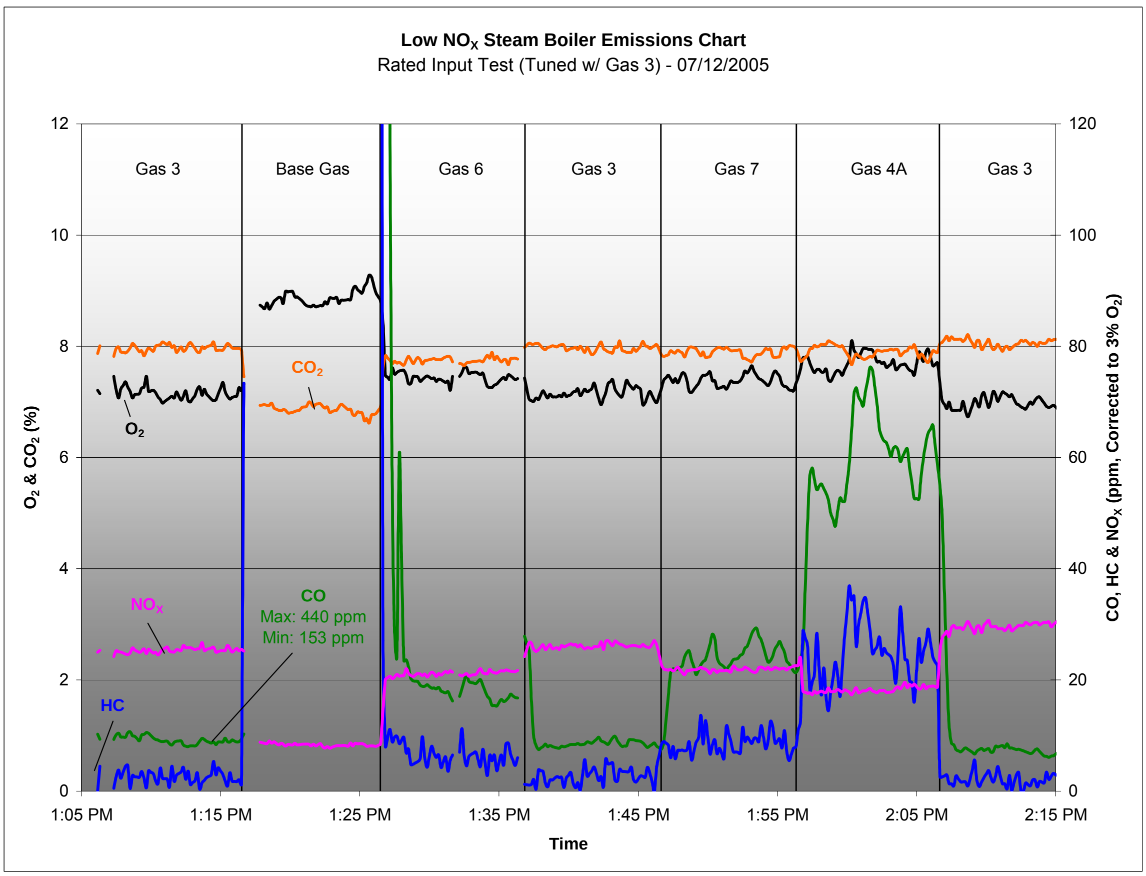


Emissions

Results show NO_X emissions were lower and CO emissions were higher when the appliance was tuned with Gas 3. The highest NO_X emissions were obtained with Gas 3 (27.0 ppm) and the lowest with Base Gas (8.3 ppm). When the appliance was tuned with Base Gas, NO_X emission values for Gas 3 and Base Gas were 76.0 ppm and 25.6 ppm, respectively.

CO emissions were highest with Base Gas (325.4 ppm) and the remaining gases ranged from 8.3 ppm (Gas 3) to 60.6 ppm (Gas 4A). With the appliance tuned to Base Gas, CO emissions for Base Gas were 13.1 ppm and 1.0 ppm or less for the remaining gases.

HC emissions were highest with Gas 4A (25.0 ppm) and Base Gas (281.4 ppm), while all other gases were below 9 ppm. The highest O_2 percentage was observed with Base Gas (8.9%) whereas the remaining gases ranged from 7.0% to 7.7%. O_2 percentage followed an opposite trend to NO_X emissions; increasing when NO_X emissions decreased and vice versa.



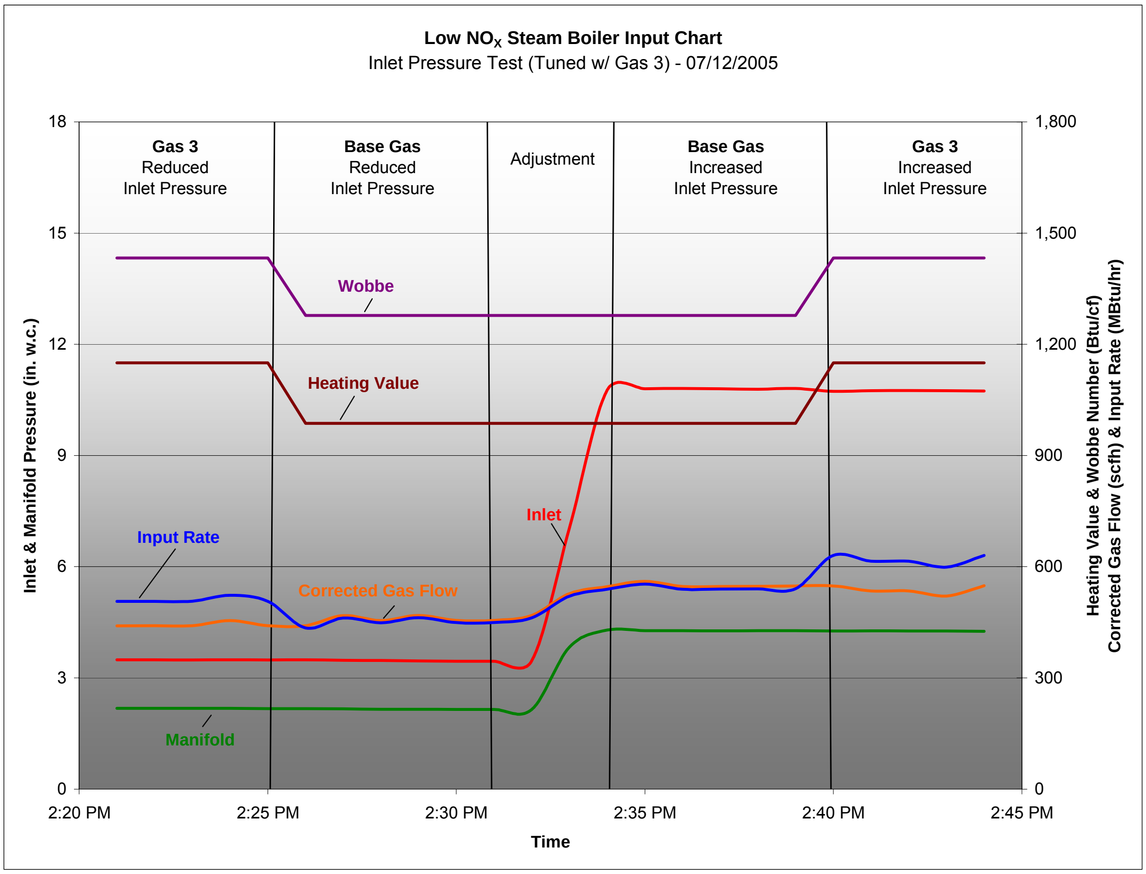
NOTE: Emission test results are for information purposes. They were not the result of certified tests.

Reduced and Increased Inlet Pressure Test (Tuned w/ Gas 3)

Input

The highest input rate occurred with Gas 3 (617,973 Btu/hr) at increased inlet pressure and the lowest occurred with Base Gas (451,476 Btu/hr) at reduced inlet pressure. Corrected gas flow ranged from 443.4 scfh (Gas 3 at reuced inlet pressure) to 549.8 scfh (Base Gas at increased inlet pressure).

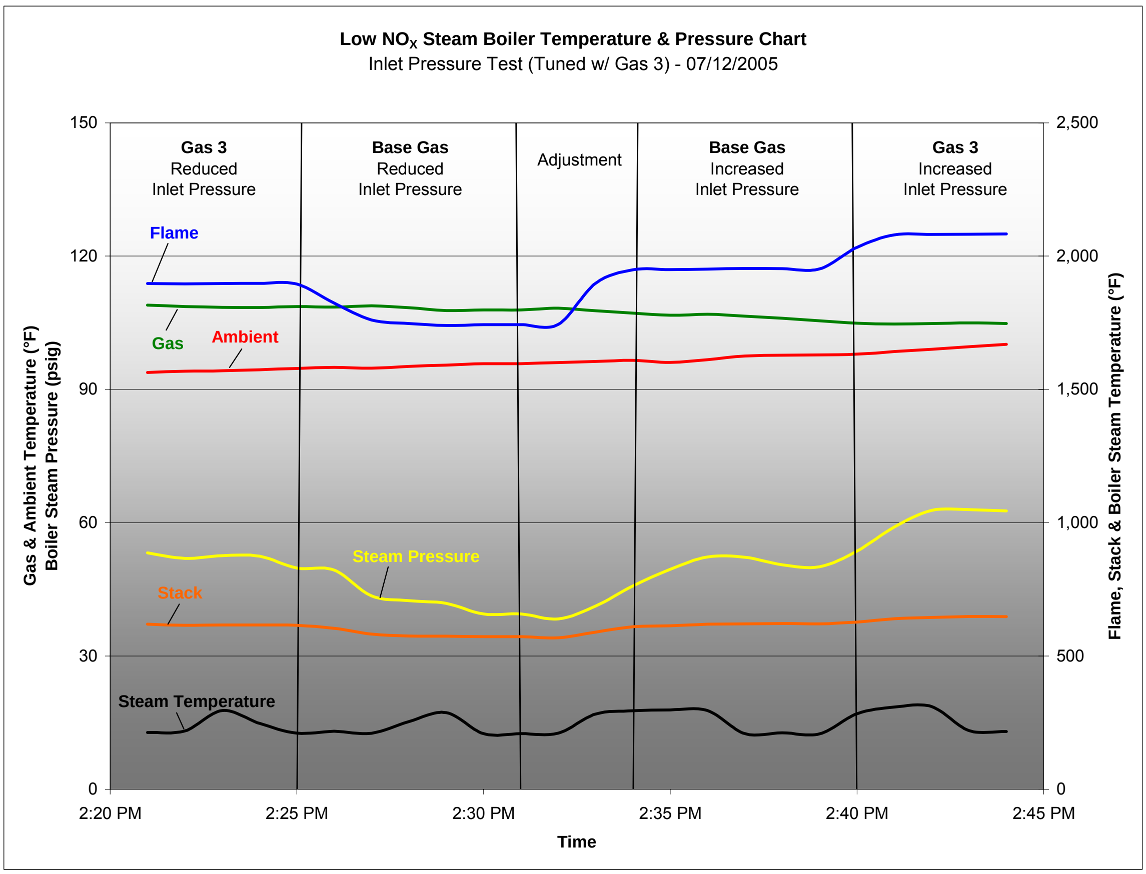
For the Increased Inlet Pressure Test, inlet pressure was 10.8 in. w.c. and manifold pressure was 4.3 in. w.c.. For the Reduced Inlet Pressure Test, inlet pressure was 3.5 in. w.c. and manifold pressure was 2.2 in. w.c..



Temperature & Pressure

Flame and stack temperatures were lower when the appliance was at reduced inlet pressure compared to increased inlet pressure. The lowest flame and stack temperatures occurred at reduced inlet pressure with Base Gas (1,763°F and 581.7°F) and the highest flame and stack temperatures occurred at increased inlet pressure with Gas 3 (2,072°F and 641.4°F).

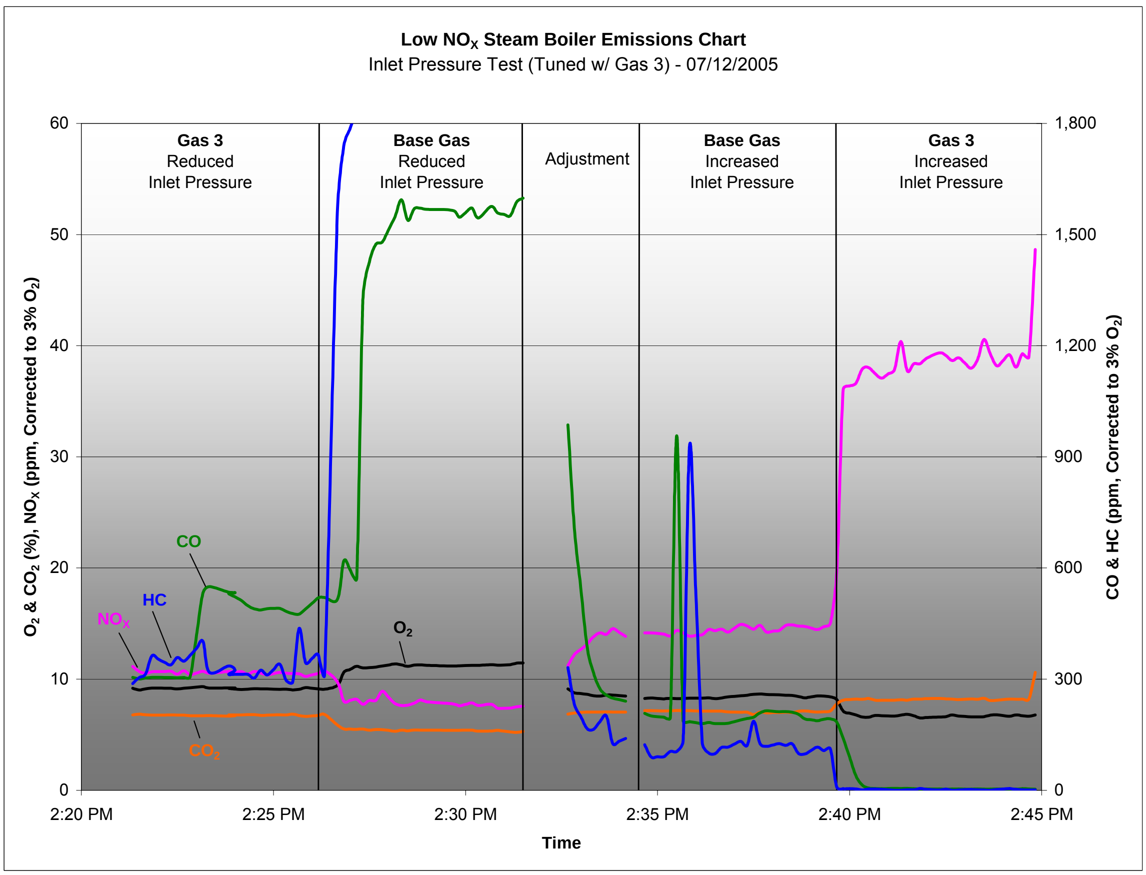
There was a slight increase in ambient temperatures as testing progressed, with temperatures rising from 94.3°F to 99.1°F. In contrast, there was a slight decrease in gas temperature as testing progressed, with the temperature dropping from 108.6°F to 104.8°F. The highest steam pressure value occurred at increased inlet pressure with Gas 3 (97.2 psig) and the lowest at reduced inlet pressure with Base Gas (43.3 psig). Also, steam temperature ranged from 236.8°F to 268.0°F.



Emissions

NO_X emissions were highest at increased inlet pressure and CO emissions were highest at reduced inlet pressure. NO_X emissions for Gas 3 increased from 10.6 ppm at reduced inlet pressure to 38.7 ppm and Base Gas increased from 7.9 ppm to 14.4 ppm. CO emissions for Base Gas decreased from 1,563 ppm at reduced inlet pressure to 195.1 ppm and Gas 3 decreased from 435.7 ppm to 3.6 ppm.

HC emissions and O_2 percentage decreased at increased inlet pressure compared to the values observed at reduced inlet pressure.



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

Cold Ignition Test

For each setup gas (Base Gas and Gas 3), the boiler turned "on" without any problems during each one of the ignition tests.

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 3)		
Gas	Start-Up #	Comment & Observation
3	1	Normal and without delays
	2	Normal and without delays
	3	Normal and without delays
Base	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 3), the boiler turned "on" without any problems during each one of the ignition tests.

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 3)		
Gas	Start-Up #	Comment & Observation
3	1	Normal and without delays
	2	Normal and without delays
	3	Normal and without delays
Base	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	15 (Boiler) HP Low NO_X Steam Boiler
Burner	Premix power surface burner operating on a blue flame mode
Maximum rated input	~645,000 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 paved and level surface. Fuel gas, electrical power, and water are to be provided at rates and conditions according to manufacturer specifications. Combustion products are to be sampled in a vent stack constructed according to required standards.

3.2. Water Flow and Piping
Provide water at the flow rate and temperature as close as possible to those required by the test standards and manufacturer specifications. If necessary, provide a supply water pump and valves necessary to adjust water flow rate and temperatures. Maintain water pressure at a level sufficient to ensure proper boiler operation.

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	12 inches
Length	35 inches
Material	Sheet metal
Thermocouple Location	18 inches from the bottom
Emissions Sample Probe Location	18 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, exhaust/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 in selecting locations.

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.

3.7. Special Measures – Windows & camera access

If there are noticeable changes in flame stability, the color or shape of the flame, windows or openings for viewing the flame are to be provided to the extent that they will provide useful information and not affect boiler operation.

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)
3	1,433 (Highest Wobbe)	1,150 (Highest heat content)
4A	1,362 (Medium Wobbe)	1,135 (High heat content)
6	1,408 (High Wobbe)	1,106 (High heat content)
7	1,395 (High Wobbe)	1,142 (High heat content)

5. Basic Operating Condition

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

5.1. Ambient Temperature

This appliance will be tested outside, thus, ambient temperature cannot be controlled as specified in test standards. 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. Manifold and Inlet 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. As Received Test

Operate the boiler with Base Gas as received or provided 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 suspected 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/ Base Gas)

Tune the appliance with Base Gas to achieve the maximum input rate allowed by manufacturer. Follow the same procedures as specified in §6.1. If it is discovered during the As Received Test that the appliance is operating at rated input, then the As Received Test becomes the Rated Input Test.

6.3. Rated Input Test (Tuned w/ Gas 3)

Tune the appliance with Gas 3 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.

6.4. Reduced and Increased Inlet Pressure Test

Based on the information from manufacturers, consultants and the requirements of the test standards adjust the appliance to operate under and over the rated input by changing the inlet pressures to ~ 3.5 and ~9 in. w.c.., respectively. Due to time limitations only the most critical test will be performed.

From a cold start, record input and combustion data (O_2, NO_X, CO, CO_2 and HC) and verify that the firing rates are under and over the rated input after 15 minutes. If the burner modulates, automatically continue the test at operating input.

During testing, observe flames and note yellow tipping and flame lifting or flashback phenomena or lack of the same. Record these observations. If significant yellow tipping was observed, inspect flue collector and 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.

7. Ignition Test

7.1. Cold Ignition (Tuned w/ Base Gas)

With the appliance 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 ambient 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 ambient temperature then repeat this procedure 2 more times.

7.2. Cold Ignition Test (Tuned w/ Gas 3)

Follow the same procedure as Cold Ignition Test (Tuned w/ Base Gas) but substitute Base Gas with Gas 3.

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 cool 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 3)

Follow the same procedure as Cold Ignition Test (Tuned w/ Base Gas)

8. Special Tests

Special tests may be conducted to investigate phenomena of concern to the boiler manufacturer. The decision of whether or not 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, per the Phase II protocol, when test results or observations indicate it is necessary. If additional testing is outside of the project scope, include appropriate comment in the test report.

10. Calculation

CO, HC & 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

11.1. 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 the 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.

11.2. 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 Low NO_X Steam Boiler Rated Input Test (Tuned w/ Base Gas) July 12, 2005							
Gases	**Base**	**3**	**6**	**Base**	**7**	**4A**	**Base**
HHV (Btu/cf)	987	1,150	1,106	987	1,143	1,135	987
Wobbe (Btu/cf)	1,278	1,433	1,408	1,278	1,396	1,362	1,278
Input Rate (Btu/hr)	587,225	651,550	647,145	579,524	638,737	616,348	575,824
Corrected Gas Flow (scfh)	594.9	566.6	585.2	587.1	559.0	542.9	583.4
Emissions (not from certified tests)							
O_2 (%)	7.4	5.7	5.8	7.5	5.8	6.2	7.6
CO_2 (%)	7.9	8.9	8.7	7.7	8.9	8.9	7.7
CO (ppm @ 3% O_2)	12.4	1.0	1.0	14.1	0.9	0.9	12.9
HC (ppm @ 3% O_2)	4.5	0.9	1.1	5.0	0.9	0.8	5.4
NO_X (ppm @ 3% O_2)	27.5	76.0	71.7	24.0	69.8	53.3	25.2
Ultimate CO_2 (%)	12.1	12.2	12.1	12.1	12.3	12.7	12.1
Equivalence Ratio (Φ)	0.67	0.75	0.74	0.70	0.74	0.72	0.66
Temperatures (°F)							
Ambient	83.4	84.5	85.9	85.4	86.5	86.9	87.6
Gas	100.5	103.1	103.2	103.5	104.1	104.5	105.8
Steam	229.4	228.2	240.3	236.9	244.3	234.0	234.1
Stack	637.5	659.7	660.2	640.8	654.5	655.3	639.3
Flame	2,035	2,153	2,146	2,033	2,132	2,117	2,039
Pressures							
Gas Inlet (in. w.c.)	7.0	6.7	7.1	6.7	7.0	6.7	6.7
Manifold (in. w.c.)	3.6	3.6	3.7	3.6	3.6	3.6	3.6
Steam (psig)	58.5	67.1	68.4	61.1	66.2	66.6	60.3

Increased Inlet Pressure Test (Tuned w/ Base Gas)

Table of Averages Low NO_X Steam Boiler Inlet Pressure Tests (Tuned w/ Base Gas) July 12, 2005		
Pressure Test	**Increased (9.0 in. w.c.)**	
Gases	**Base**	**3**
HHV (Btu/cf)	987	1,150
Wobbe (Btu/cf)	1,278	1,433
Input Rate (Btu/hr)	544,120	569,880
Corrected Gas Flow (scfh)	551.2	495.6
Emissions (not from certified tests)		
O_2 (%)	6.8	5.0
CO_2 (%)	8.1	9.4
CO (ppm @ 3% O_2)	2.5	1.7
HC (ppm @ 3% O_2)	1.2	1.0
NO_X (ppm @ 3% O_2)	36.1	112.2
Ultimate CO_2 (%)	12.1	12.3
Equivalence Ratio (Φ)	0.70	0.78
Temperatures (°F)		
Ambient	89.9	90.5
Gas	108.4	109.6
Steam	249.9	229.3
Stack	642.6	659.9
Flame	2,074	2,204
Pressures		
Gas Inlet (in. w.c.)	9.0	9.2
Manifold (in. w.c.)	3.9	3.9
Steam (psig)	62.4	68.1

Rated Input Test (Tuned w/ Gas 3)

Table of Averages Low NO_X Steam Boiler Rated Input Test (Tuned w/ Gas 3) July 12, 2005							
Gases	**3**	**Base**	**6**	**3**	**7**	**4A**	**3**
HHV (Btu/cf)	1,150	987	1,106	1,150	1,143	1,135	1,150
Wobbe (Btu/cf)	1,433	1,278	1,408	1,433	1,396	1,362	1,433
Input Rate (Btu/hr)	594,977	525,746	584,169	594,570	575,839	561,636	595,113
Corrected Gas Flow (scfh)	517.4	532.6	528.2	517.0	504.0	494.7	517.5
Emissions (not from certified tests)							
O_2 (%)	7.2	8.9	7.4	7.2	7.4	7.7	7.0
CO_2 (%)	8.0	6.9	7.8	8.0	7.9	7.9	8.1
CO (ppm @ 3% O_2)	9.2	325.4	18.6	8.5	24.3	60.6	7.2
HC (ppm @ 3% O_2)	2.5	281.4	6.5	2.6	8.5	25.0	2.0
NO_X (ppm @ 3% O_2)	25.3	8.3	21.2	26.1	21.9	18.2	29.7
Ultimate CO_2 (%)	12.1	11.9	12.0	12.1	12.2	12.5	12.1
Equivalence Ratio (Φ)	0.68	0.60	0.67	0.68	0.67	0.66	0.69
Temperatures (°F)							
Ambient	91.4	91.7	92.2	92.4	92.2	92.6	92.7
Gas	110.2	110.0	110.4	110.6	109.8	109.3	110.0
Steam	225.8	228.0	248.9	241.0	244.4	237.4	236.7
Stack	639.9	620.4	633.2	641.7	641.6	636.1	641.5
Flame	2,048	1,922	2,025	2,048	2,025	1,999	2,052
Pressures							
Gas Inlet (in. w.c.)	6.9	6.8	6.9	6.9	6.9	6.8	6.8
Manifold (in. w.c.)	3.9	3.9	3.9	3.9	3.9	3.9	3.9
Steam (psig)	60.4	53.3	57.2	60.9	60.2	58.0	60.6

Reduced and Increased Inlet Pressure Test (Tuned w/ Gas 3)

Table of Averages Low NO_X Steam Boiler Inlet Pressure Tests (Tuned w/ Gas 3) July 12, 2005				
Pressure Test	**Reduced (3.5 in. w.c.)**		**Increased (10.8 in. w.c.)**	
Gases	**3**	**Base**	**Base**	**3**
HHV (Btu/cf)	1,150	987	987	1,150
Wobbe (Btu/cf)	1,433	1,278	1,278	1,433
Input Rate (Btu/hr)	509,898	451,476	542,669	617,973
Corrected Gas Flow (scfh)	443.4	457.4	549.8	537.4
Emissions (not from certified tests)				
O_2 (%)	9.2	11.3	8.4	6.7
CO_2 (%)	6.8	5.4	7.1	8.2
CO (ppm @ 3% O_2)	435.7	1,563	195.1	3.6
HC (ppm @ 3% O_2)	336.2	6,469	115.7	1.6
NO_X (ppm @ 3% O_2)	10.6	7.9	14.4	38.7
Ultimate CO_2 (%)	12.0	11.6	11.8	12.0
Equivalence Ratio (Φ)	0.59	0.49	0.62	0.70
Temperatures (°F)				
Ambient	94.3	95.2	97.2	99.1
Gas	108.6	108.3	106.3	104.8
Steam	236.8	235.6	244.4	268.0
Stack	616.3	581.7	619.2	641.4
Flame	1,897	1,763	1,952	2,072
Pressures				
Gas Inlet (in. w.c.)	3.5	3.5	10.8	10.7
Manifold (in. w.c.)	2.2	2.2	4.3	4.3
Steam (psig)	52.0	43.3	97.2	60.2

Appendix C: Test Gases

Gas Sample Date	**Base** 7/8/05	**3** 7/1/05	**4A** 7/15/05	**6** 7/1/05	**7** 6/20/05
COMPONENTS	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**
METHANE	93.2990	86.5492	85.1030	91.1679	86.4659
ETHANE	1.4743	9.4799	0.0000	5.7474	0.3119
PROPANE	0.2919	2.7246	10.5884	1.7268	9.9457
i-BUTANE	0.0544	1.0339	0.0442	0.5340	0.0940
n-BUTANE	0.0497	0.0000	0.0247	0.5312	0.0614
i-PENTANE	0.0164	0.0000	0.0044	0.0000	0.0192
n-PENTANE	0.0107	0.0003	0.0040	0.0000	0.0156
NEOPENTANE	0.0000	0.0000	0.0000	0.0000	0.0000
C6 + 57/28/14	0.0491	0.0002	0.0142	0.0001	0.0232
OXYGEN	0.0000	0.0494	0.0205	0.0156	0.0038
NITROGEN	3.1952	0.1280	1.1174	0.2737	3.0250
CARBON DIOXIDE	1.5593	0.0345	3.0792	0.0032	0.0344
TOTAL	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**
Compressibility Factor	0.9981	0.9972	0.9970	0.9975	0.9971
HHV (Btu/real cubic foot)	**987.00**	**1150.00**	**1135.30**	**1106.00**	**1142.00**
LHV (Btu/real cubic foot)	889.20	1039.90	1027.50	998.90	1033.40
Specific Gravity	0.5967	0.6442	0.6946	0.6167	0.6697
WOBBE Index	**1277.73**	**1432.81**	**1362.21**	**1408.37**	**1395.49**

Appendix D: Zero, Span and Linearity Tables

Rated Input Test (Tuned w/ Base Gas)
Increased Pressure Test (Tuned w/ Base Gas)

	Zero, Span & Linearity Data Low NO_X Steam Boiler Rated Input Test & Inlet Pressure Test (Tuned w/ Base Gas) July 12, 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 - 8:54:35 AM	0.19	0.04	0.78	0.00	0.27
	Zero Drift Check - 12:28:50 PM	0.19	0.09	0.00	0.00	0.61
	Total Drift Over Test Period	**0.00**	**0.05**	**0.78**	**0.00**	**0.34**
	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 - 9:49:58 AM	20.09	12.23	181.61	433.19	85.40
	Span Drift Check - 12:22:49 PM	20.29	12.28	182.56	436.79	85.80
	Total Drift Over Test Period	**0.20**	**0.05**	**0.95**	**3.60**	**0.40**
	Was the Span Drift Within Allowable Deviation?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**8.97**	**8.00**	**78.20**	**443.00**	**18.30**
	Allowable Linearity Drift (Less Than ±1% of Range)	**0.25**	**0.20**	**2.00**	**10.00**	**1.00**
	Linearity Check - 9:54:57 AM	9.12	8.01	76.08	434.56	18.60
	Difference From Mid-Range Values	**0.15**	**0.01**	**2.12**	**8.44**	**0.30**
	Was the Linearity Within Allowable Deviation?	**Yes**	**Yes**	**No**	**Yes**	**Yes**
	Linearity Check - 12:25:35 PM	9.24	7.98	75.16	436.54	18.62
	Difference From Mid-Range Values	**0.27**	**0.02**	**3.04**	**6.46**	**0.32**
	Was the Linearity Within Allowable Deviation?	**No**	**Yes**	**No**	**Yes**	**Yes**

Rated Input Test (Tuned w/ Gas 3)
Reduced and Increased Pressure Test (Tuned w/ Gas 3)

	Zero, Span & Linearity Data Low NO_X Steam Boiler Rated Input Test & Inlet Pressure Test (Tuned w/ Gas 3) July 12, 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 - 12:58:12 PM	0.21	0.03	0.00	0.00	0.04
	Zero Drift Check - 2:55:12 PM	0.18	0.00	0.00	0.00	2.55
	Total Drift Over Test Period	**0.03**	**0.03**	**0.00**	**0.00**	**2.51**
	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 - 12:55:10 PM	20.10	12.19	182.25	433.66	85.35
	Span Drift Check - 2:47:21 PM	20.19	12.02	180.93	430.34	89.20
	Total Drift Over Test Period	**0.09**	**0.17**	**1.32**	**3.32**	**3.85**
	Was the Span Drift Within Allowable Deviation?	**Yes**	**Yes**	**Yes**	**Yes**	**No**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**8.97**	**8.00**	**78.20**	**443.00**	**18.30**
	Allowable Linearity Drift (Less Than ±1% of Range)	**0.25**	**0.20**	**2.00**	**10.00**	**1.00**
	Linearity Check - 12:25:35 PM	9.24	7.98	75.16	436.54	18.62
	Difference From Mid-Range Values	**0.27**	**0.02**	**3.04**	**6.46**	**0.32**
	Was the Linearity Within Allowable Deviation?	**No**	**Yes**	**No**	**Yes**	**Yes**
	Linearity Check - 2:50:00 PM	9.17	7.79	74.70	431.22	20.74
	Difference From Mid-Range Values	**0.20**	**0.21**	**3.50**	**11.78**	**2.44**
	Was the Linearity Within Allowable Deviation?	**Yes**	**No**	**No**	**No**	**No**

Appendix E: Calculations

Emission Concentrations

Corrected to O_2 Standard (3% O_2)

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

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 (%)

Raw 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)	$CH_4 + 2O_2 + 2(3.78)N_2$ ==> $1CO_2 + 2H_2O + 2(3.78)N_2$	9.56	8.56
Ethane (C_2H_6)	$C_2H_6 + 3.5O_2 + 3.5(3.78)N_2$ ==> $2CO_2 + 3H_2O + 3.5(3.78)N_2$	16.73	15.23
Propane (C_3H_8)	$C_3H_8 + 5O_2 + 5(3.78)N_2$ ==> $3CO_2 + 4H_2O + 5(3.78)N_2$	23.90	21.90
i-Butane (C_4H_{10})	$C_4H_{10} + 6.5O_2 + 6.5(3.78)N_2$ ==> $4CO_2 + 5H_2O + 6.5(3.78)N_2$	31.07	28.57
n-Butane (C_4H_{10})	$C_4H_{10} + 6.5O_2 + 6.5(3.78)N_2$ ==> $4CO_2 + 5H_2O + 6.5(3.78)N_2$	31.07	28.57
i-Pentane (C_5H_{12})	$C_5H_{12} + 8O_2 + 8(3.78)N_2$ ==> $5CO_2 + 6H_2O + 8(3.78)N_2$	38.24	35.24
n-Pentane (C_5H_{12})	$C_5H_{12} + 8O_2 + 8(3.78)N_2$ ==> $5CO_2 + 6H_2O + 8(3.78)N_2$	38.24	35.24
Hexanes (C_6H_{14})	$C_6H_{14} + 9.5O_2 + 9.5(3.78)N_2$ ==> $6CO_2 + 7H_2O + 9.5(3.78)N_2$	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:

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

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:

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

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

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

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

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	Logic Beach	Hyperlogger	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

<u>Appendix G:</u> 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.