LNG Research Study

Direct Vent Water Boiler

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Prepared By:

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Disclaimer

Table of Contents

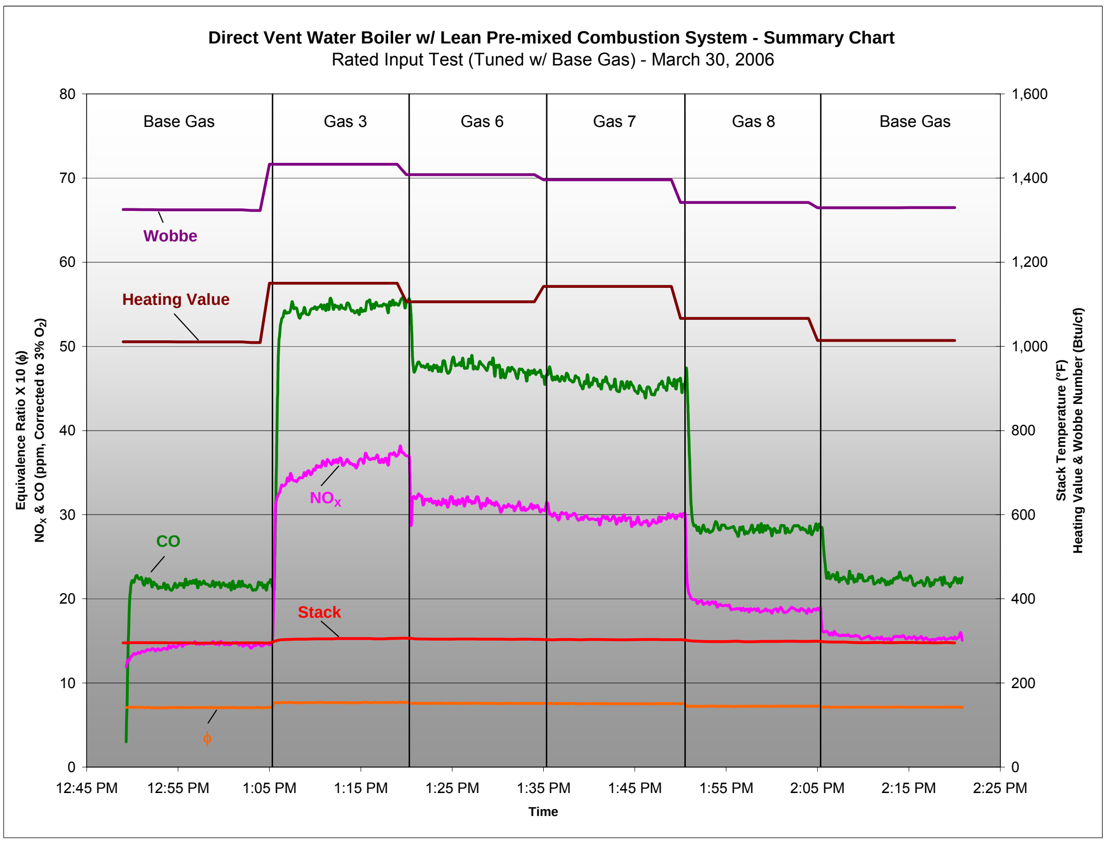
Results Summary

Results obtained from all tests conducted revealed: (a) There were no operational, ignition, safety, flame stability, flame lifting, flashback or yellow tipping problems; (b) CO emissions were highest with Gas 3; (c) NO_X and CO emissions followed the same pattern as the equivalence ratio and the Wobbe Number; and (d) none of the temperature measurements showed a significant increase.

The manufacturer's representative tuned this appliance with Base Gas to ~483,500 Btu/hr; which is ~3 % below the rated input.

Rated Input Test (Tuned w/ Base Gas)

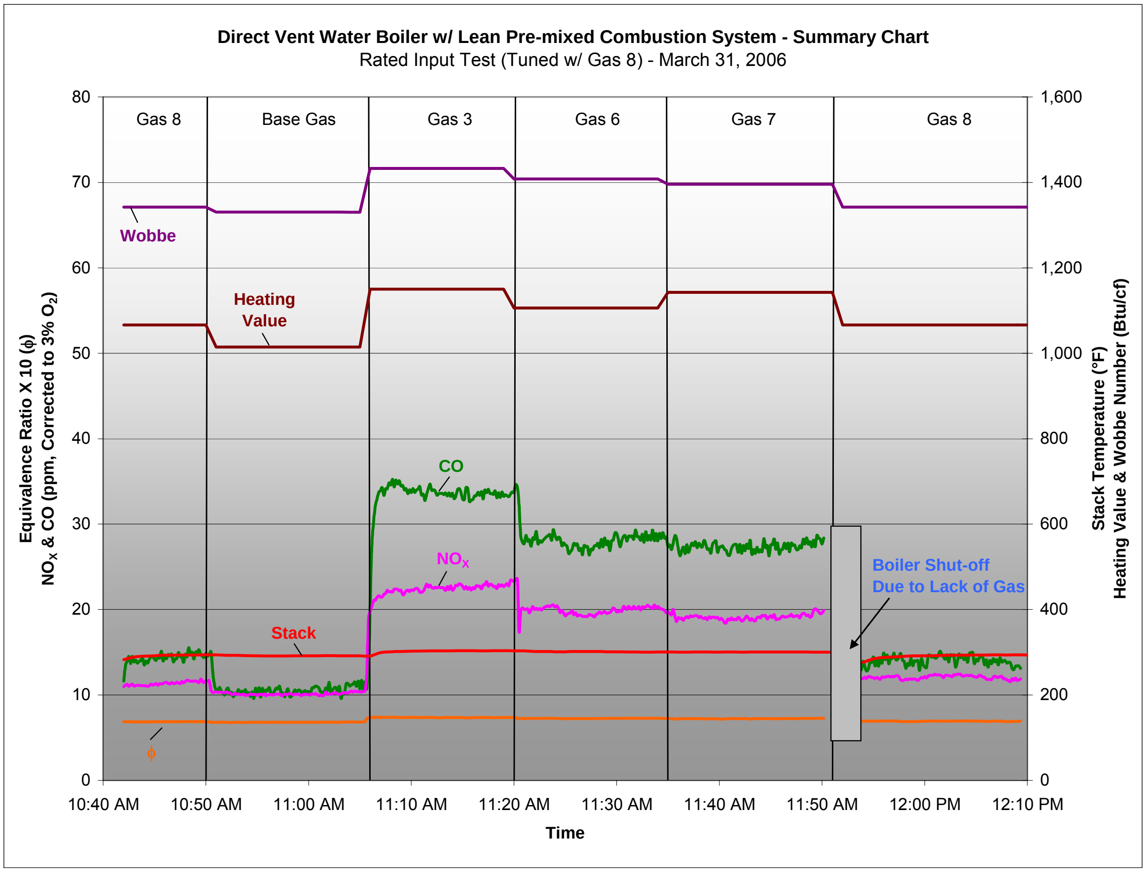
When tuned with Base Gas, NO_X emissions (corrected to 3% O_2) were highest with Gas 3 (35.6 ppm) and lowest with Base Gas (14.9 ppm). Similarly, CO emissions (corrected to 3% O_2) were highest with Gas 3 (53.7 ppm) and lowest with Base Gas (21.9 ppm). Changes in NO_X and CO emission correlated directly with changes in the equivalence ratio and Wobbe Number.



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

Rated Input Test (Tuned w/ Gas 8)

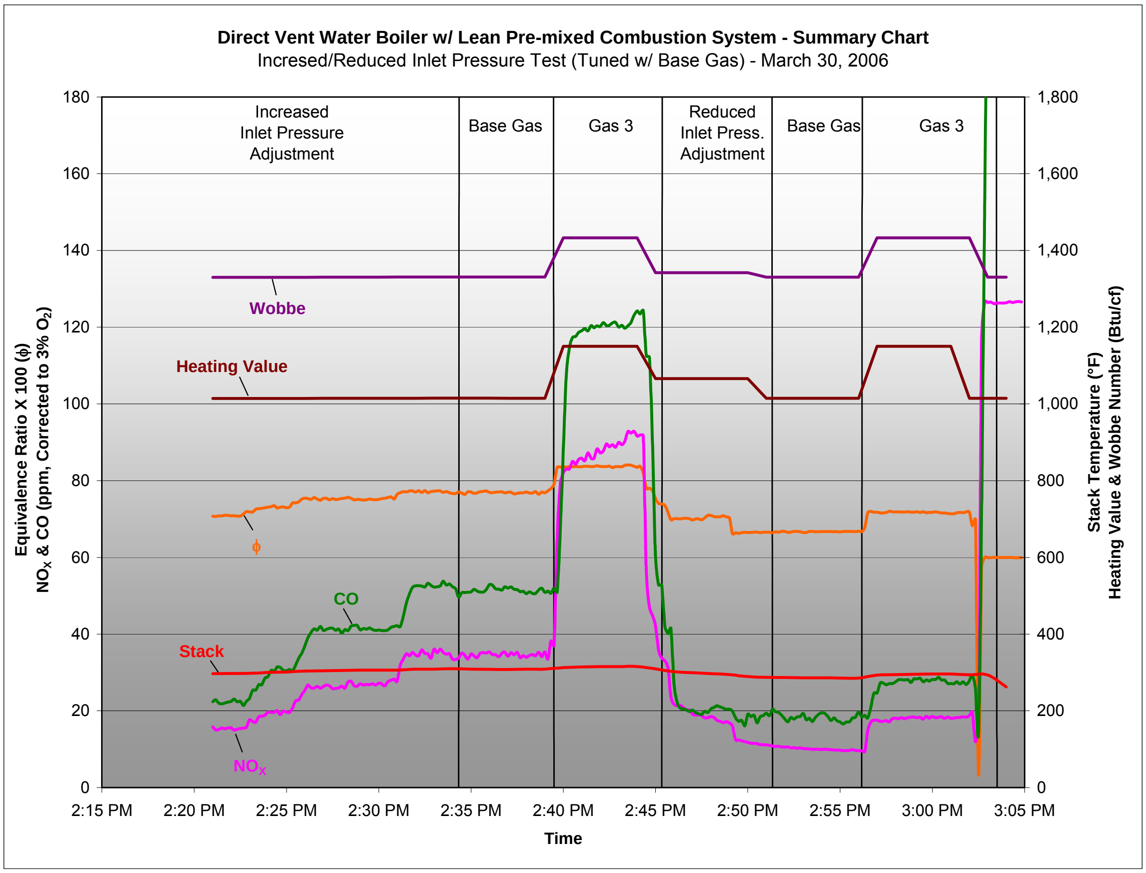
When tuned with Gas 8, NO_X emissions (corrected to 3% O_2) decreased for all test gases compared to values obtained when the appliance was tuned with Base Gas. NO_X emissions were 22.5 ppm for Gas 3 and 10.6 ppm for Base Gas. Changes in CO and NO_X emissions correlated directly with changes in the equivalence ratio and Wobbe Number.



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

Increased/Reduced Inlet Pressure Test (Tuned w/ Base Gas)

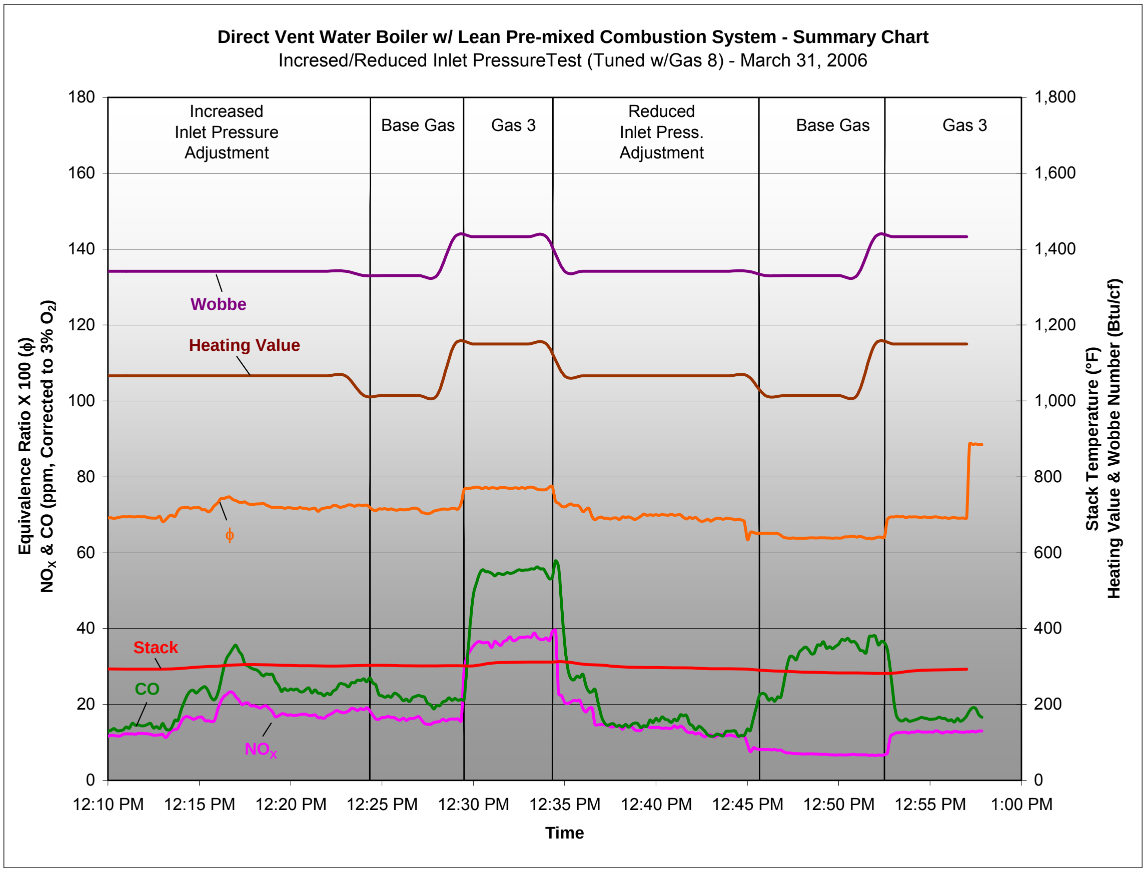
Testing at the reduced inlet pressure generated both lower NO_X and lower CO emissions compared to the increased inlet pressure setting. NO_X emissions dropped from 83 ppm to 18 ppm with Gas 3 and from 35 ppm to 10 ppm with Base Gas. CO emissions were reduced from 120 ppm (Gas 3) and 51 ppm (Base Gas) to 27 ppm and 18 ppm. Stack temperature also decreased with the reduced input rate.



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

Increased/Reduced Inlet Pressure Test (Tuned w/ Gas 8)

The increased/reduced inlet pressure test tuned with Gas 8 yielded lower emission values compared to the test tuned with Base Gas. With Gas 3, NO_X emissions averaged 37 ppm with the increased inlet test and 12 ppm with the reduced inlet test. Throughout the reduced inlet pressure test, CO emissions were higher with Base Gas than Gas 3, which is opposite the results of the icreased inlet pressure test.



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

Equipment Selection Criteria

This unit was tested to evaluate how it will react to the different test gases after tuning it with two different set up gases — Base Gas (low heating value and Wobbe Number) and Gas 8 (medium heating value and Wobbe Number).

In addition, this unit was selected because a) both the manufacturer and the combustion system are one of the most commonly used for water boilers in our service territory; b) it has been complex for boiler and burner manufacturers to meet SCAQMD emissions rules while adhering to the Gas-Fired Low Pressure Steam and 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 2 boilers (from 400,000 Btu/hr up to and including 2,000,000 Btu/hr). The ANSI Z21.13 and UL standards cover safety, construction and performance, with each having combustion tests that limit CO emissions.

Equipment Specification

Description	Direct Vent Water Boiler
Burner	Lean Premixed Power Combustion System w/ 8 Cylindrical Barb Burners
Maximum rated input	500,000 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 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 boiler was installed according to manufacturer specifications for outdoor installation. The boiler specifications called for a minimum inlet water temperature of 121°F and a water flow rate of 39 gpm. The outlet water was adjusted to maintain at least a 20°F differential from the inlet temperature. This allowed the boiler to operate at full input rate and prevent it from cycling “on” and “off” throughout the test runs.

Instrumentation was installed following the above test standards and input from the manufacturer and industry experts. Thermocouples were installed to measure make-up water, steam, flue gas, ambient, gas and other critical temperatures on the appliance. Pressure transducers were installed to measure gas manifold, gas delivery system, gas supply and steam pressures. A gas meter was installed to measure gas flow and an emissions probe was installed in the 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	1,323 (Low Wobbe)	1009 (Low heat content)
3	1,433 (Highest Wobbe)	1,150 (Highest 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 with input from the manufacturers and Industry experts that were directed to develop a sound test procedure.

This test was divided into 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 series of tests will determine how the boiler reacts to numerous test gases when tuned to each set-up gas.

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:

- Setup 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 between test gases.

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, the manifold pressure was adjusted to achieve a rated input of 500,000 ± 5% Btu/hr. Once readings were stable, data collection was started and the gases were run continuously in the following order.

- Base Gas for 15 minutes.
- Gas 3 for 15 minutes.
- Gas 6 for 15 minutes.
- Gas 7 for 15 minutes.
- Gas 8 for 15 minutes.
- Conclude testing with Base Gas for 15 minutes.

Increased/Reduced Inlet Pressure Test (Tuned w/ Base Gas)

Using Base Gas, both gas manifolds on the appliance were adjusted to 3.1 in. w.c. and the inlet pressure was increased to 9.5 in. w.c.. The input rate for Base Gas at increased inlet pressure was 538,853 Btu/hr. 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.

For the reduced inlet pressure test, the appliance was adjusted to operate at rated input, then the inlet pressure was decreased to 4 in. w.c. without changing the manifold pressures on either gas manifold. The input rate for Base Gas at reduced inlet pressure was 464,207 Btu/hr. Once readings were stable, data collection began and the test gases were ran in the following order:

- Base Gas for 5 minutes.
- Conclude testing with Gas 3 for 5 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 a similar input rate and performance (including emissions, temperatures, etc.) as with Base Gas. The input rate was 480,514 Btu/hr; which is 3.9% below rated input. Once readings were stable, data collection began and the test gases were ran in the following order:

- Gas 8 for 15 minutes.
- Base Gas for 15 minutes.
- Gas 3 for 15 minutes.
- Gas 6 for 15 minutes.
- Gas 7 for 15 minutes.
- Conclude testing with Gas 8 for 15 minutes.

Increased/Reduced Inlet Pressure Test (Tuned w/ Gas 8)

Using Gas 8, both gas manifolds on the appliance were adjusted to 2.8 in. w.c. and the inlet pressure was increased to 9.6 in. w.c. The input rate for Base Gas at increased inlet pressure was 496,023 Btu/hr. Once readings were stable, data collection began and the test gases were run in the following order:

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

For the reduced inlet pressure test the appliance was adjusted to operate at rated input, then the inlet pressure was decreased to 4 in. w.c. without changing the manifold pressures on either gas manifold. The input rate for Base Gas at reduced inlet pressure was 443,759 Btu/hr. Once readings were stable, data collection began and the test gases were run in the following order:

- Base Gas for 5 minutes.
- Conclude testing with Gas 3 for 5 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

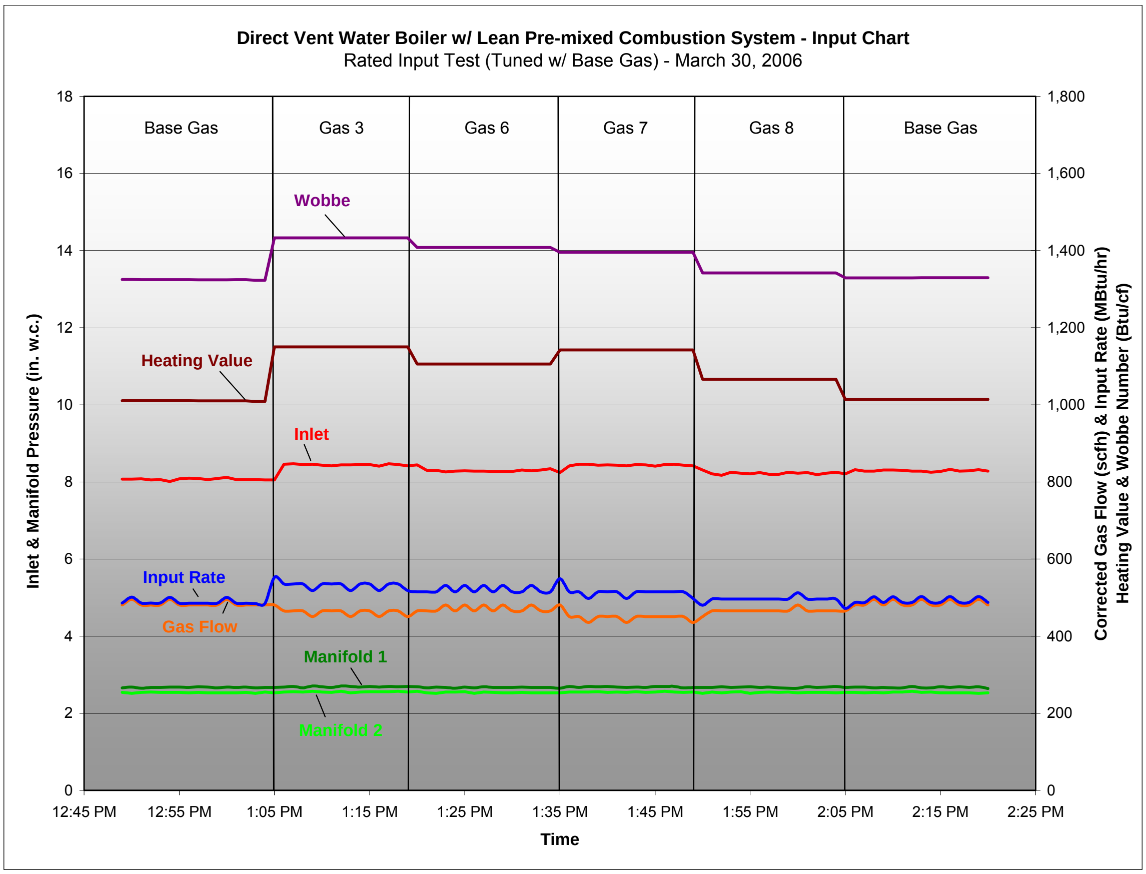
The unit was tuned with each setup gas. After steady-state operating conditions were achieved, three ignition tests were conducted following the protocol detailed in §7.3 & §7.4 of Appendix A.

Results[1,2,3]

Rated Input Test (Tuned w/ Base Gas)

Input

The highest input rate was observed with Gas 3 (532,014 Btu/hr) and the lowest with Base Gas (489,760 Btu/hr). Corrected gas flow rates ranged from 470.6 scfh (Gas 6) to 483.9 scfh (Base Gas). Manifold and inlet pressures remained stable and within tolerances specified in the test protocol.



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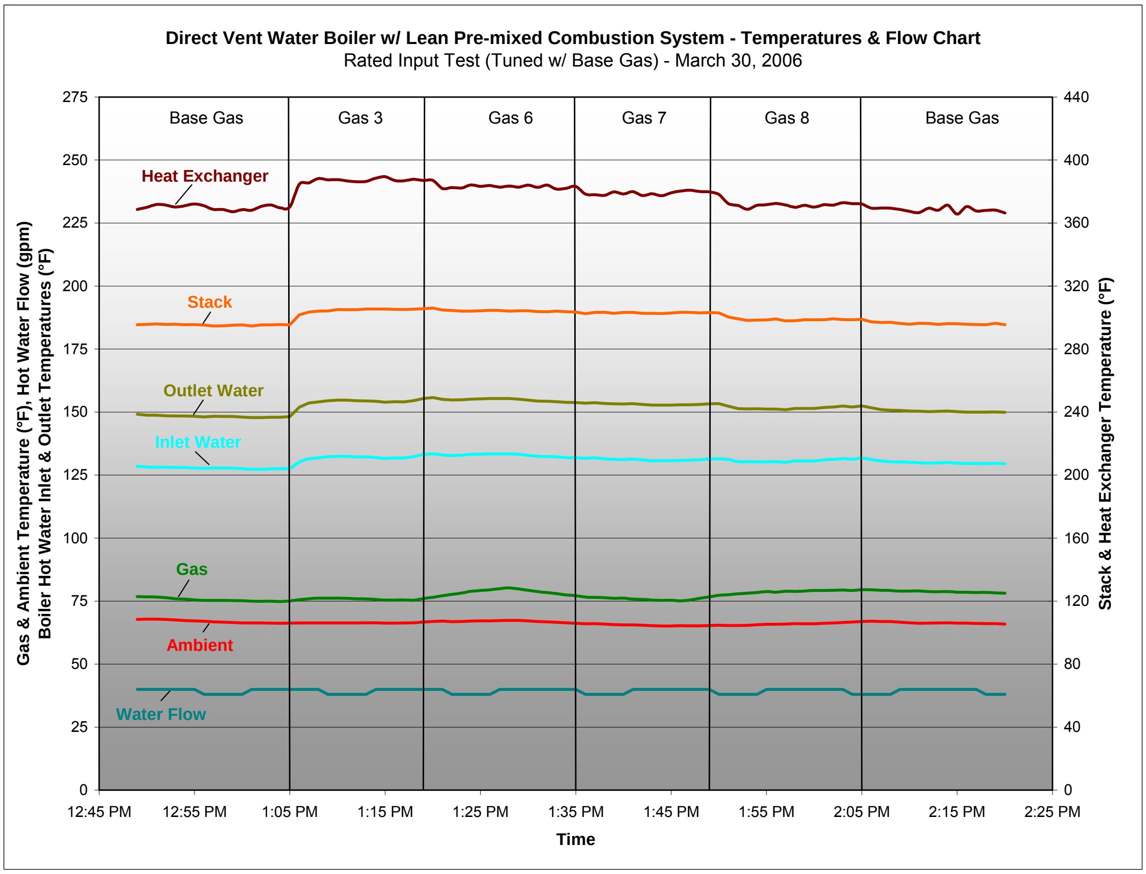
[1] All emissions, temperature and input values mentioned throughout the results section are average values.
[2] CO, HC & NO_X emissions values are corrected to 3% O_2.
[3] When either Base Gas or Gas 8 is used as the set-up gas, the values reported for the set-up gas are the average values of all runs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

Temperatures

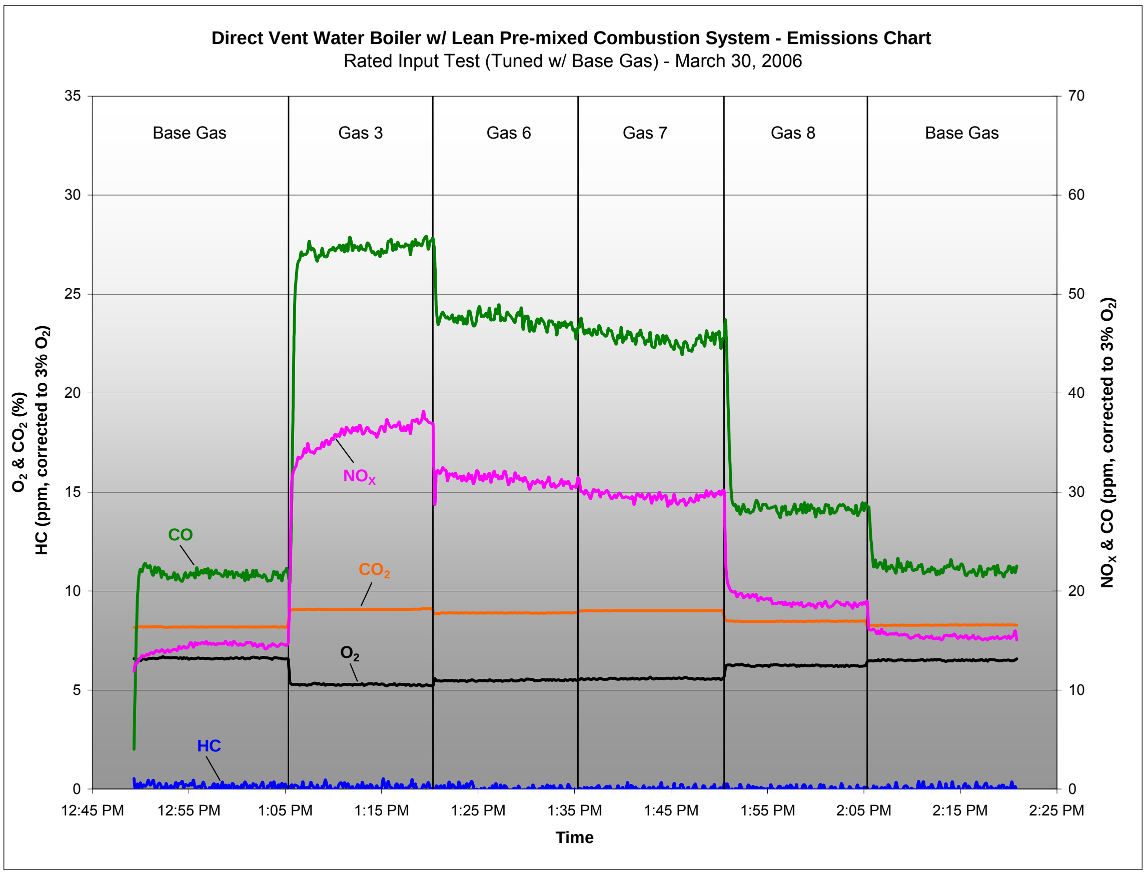
The highest heat exchanger temperature was observed with Gas 3 (386.0°F), whereas Base Gas (369.3°F) had the lowest temperature. Stack temperature was highest with Gas 6 (304.3°F) and lowest with Base Gas (295.8°F).

The inlet and outlet water temperature differential was maintained at 20°F. The hot water temperature ranged between 148 and 155°F. Ambient temperature remained steady throughout the test and water flow remained at 39.2 ± 0.2 gpm throughout the course of the test.



Emissions

When tunned with Base Gas, NO_X emissions were highest with Gas 3 (35.6 ppm) and lowest with Base Gas (14.9 ppm). NO_X and CO emissions followed the same pattern throughout the test; which was inversely proportional with the O_2 pattern. CO emissions were highest with Gas 3 (54 ppm) and lowest with Base Gas (21 ppm). HC emissions remained negligibly low throughout the course of the test.

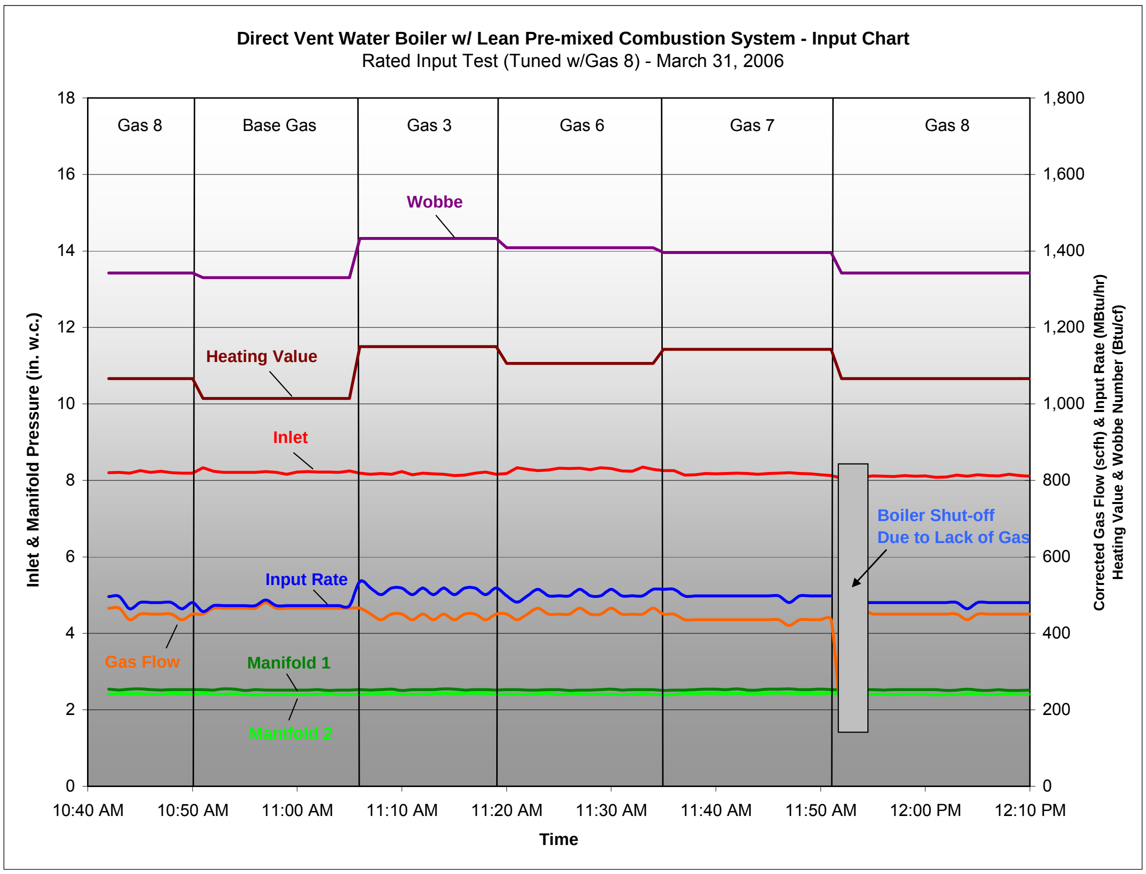


NOTE: Emission test results are for information purposes. They were not the result of certified tests.

Rated Input Test (Tuned w/ Gas 8)

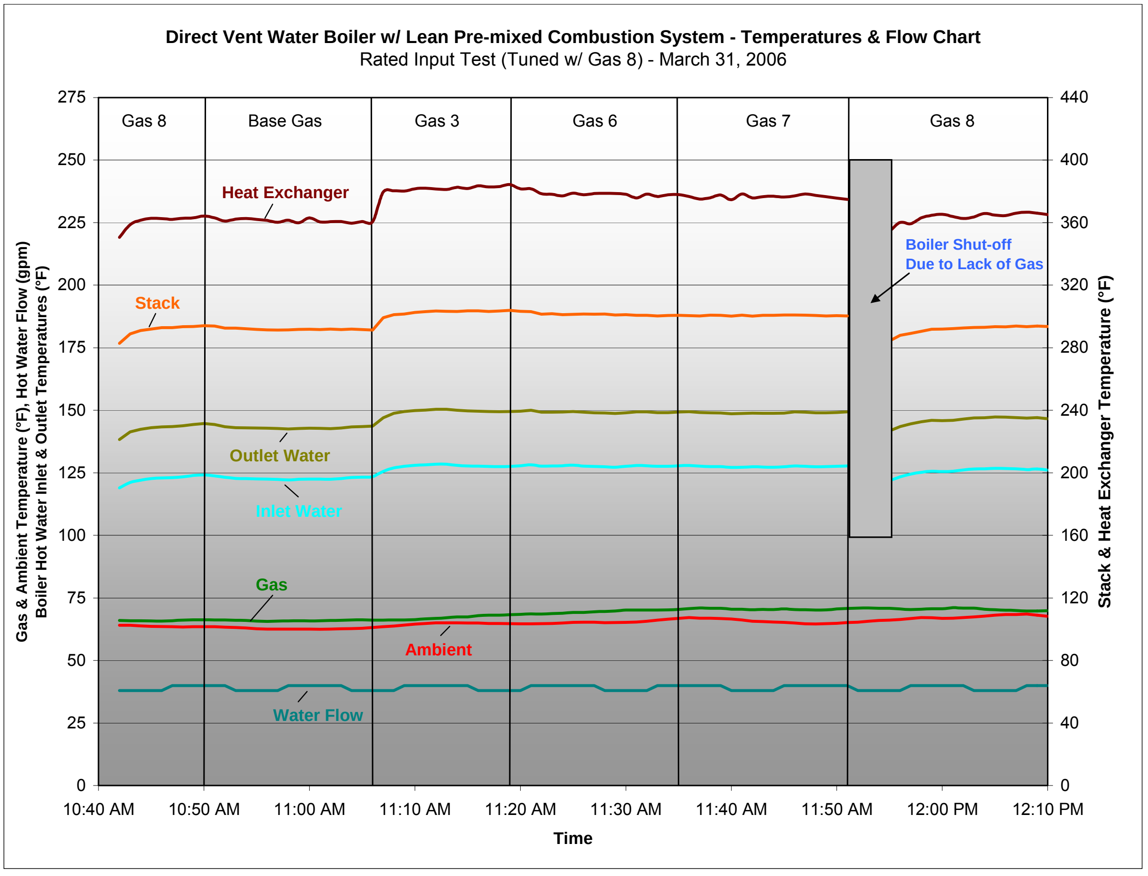
Input

When tunned with Base Gas, the highest input rate was observed with Gas 3 (513,317 Btu/hr) whereas the lowest was observed with Base Gas (472,377 Btu/hr). Corrected gas flow rates ranged from 436.5 scfh (Gas 7) to 465.6 scfh (Base Gas). Manifold and inlet pressures remained stable and within tolerances specified in the test protocol.



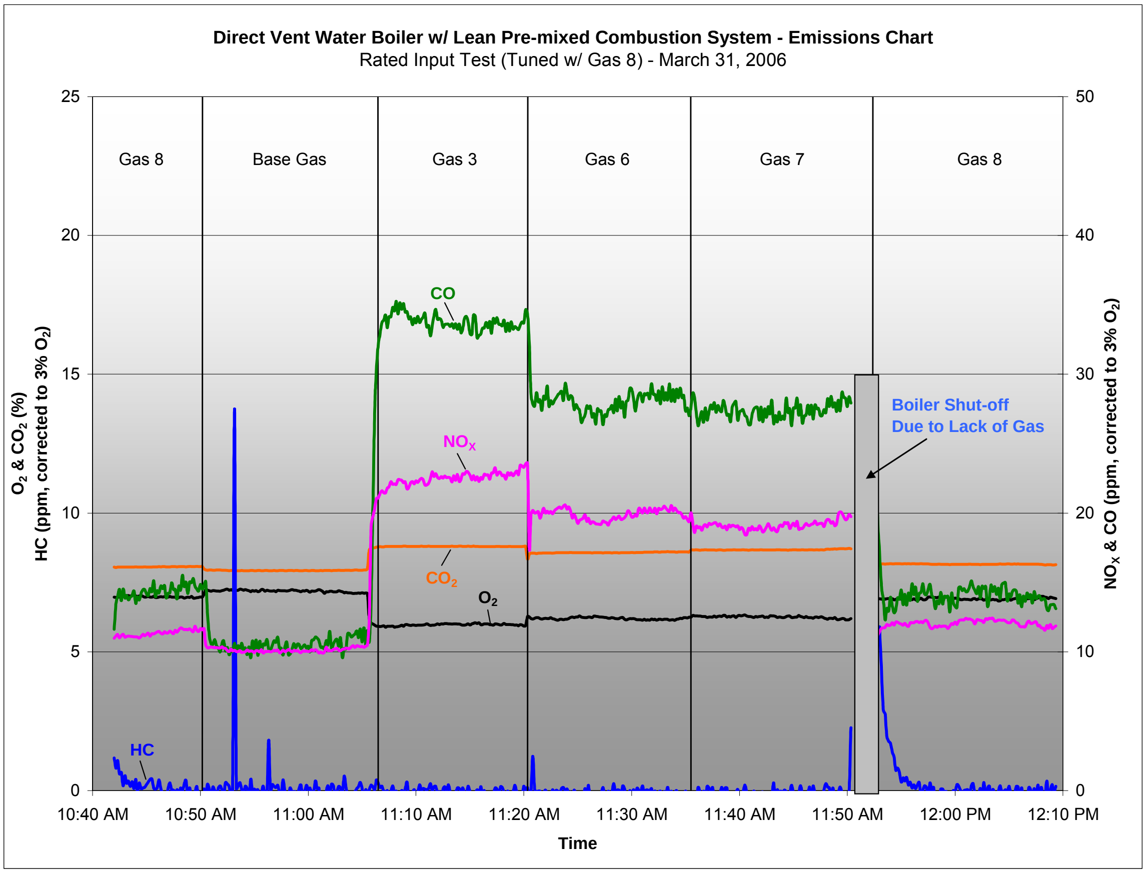
Temperatures

The heat exchanger exhibited temperatures as high as 380°F with Gas 3, and temperatures as low as 361°F with Base Gas. Similarly, stack and outlet water generated higher temperatures with Gas 3 (302°F, 149°F), and lower temperatures with Base Gas (291°F, 143°F). Ambient and gas temperatures started at 63°F and 66°F and raised ~5°F as the test progressed. The inlet water temperature ranged from 123°F to 128°F.



Emissions

When tuned with Gas 8, the boiler generated lower emission values than compared to when tuned with Base Gas. NO_X emissions reached a high of 23 ppm with Gas 3 and a low of 10 ppm with Base Gas. CO emissions ranged from 11 ppm (Base Gas) to 34 ppm (Gas 3). HC emissions remained negligibly low throughout the course of the test.

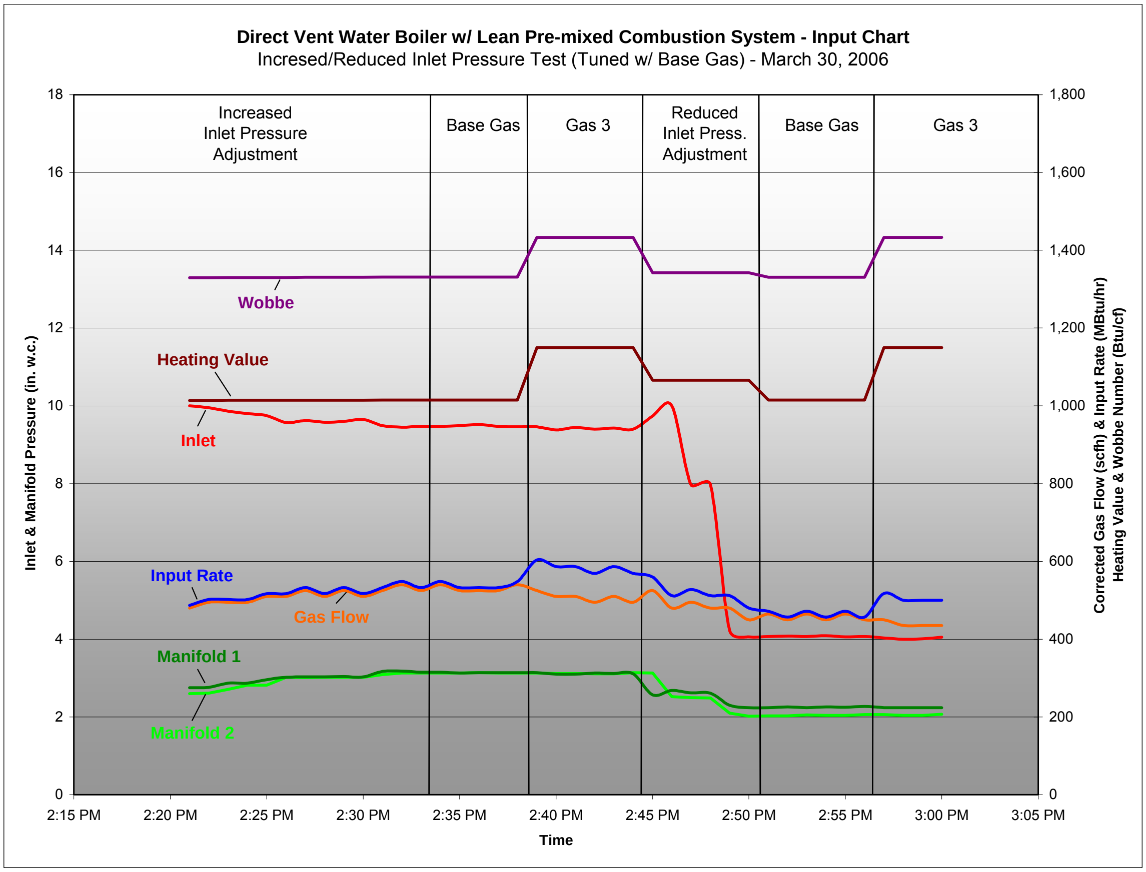


NOTE: Emission test results are for information purposes. They were not the result of certified tests.

Increased/Reduced Inlet Pressure Test (Tuned w/ Base Gas)

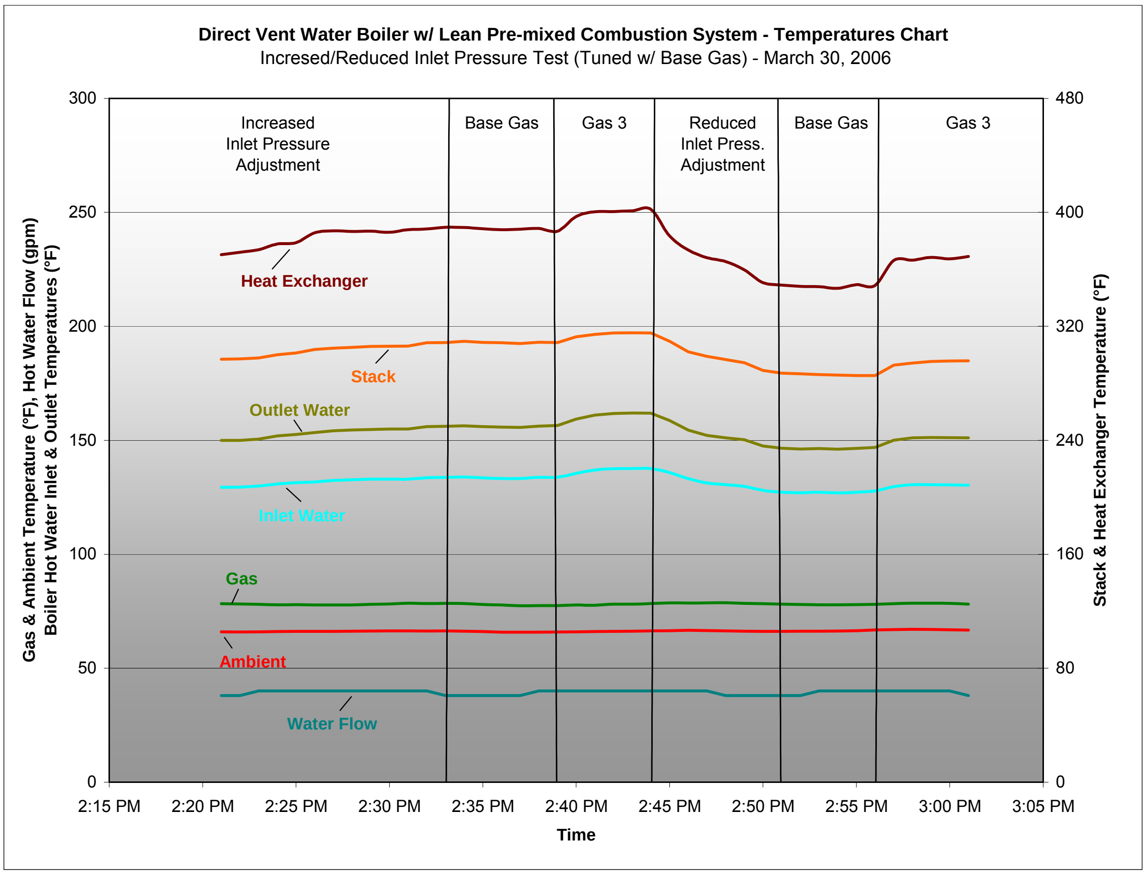
Input

The highest input rate occurred with Gas 3 (572,812 Btu/hr) at the increased inlet pressure and the lowest input rate occurred with Base Gas (449,700 Btu/hr) at the reduced inlet pressure. Corrected gas flow ranged from 425 scfh (Gas 3) to 521 scfh (Base Gas) for both inlet pressure settings. Both gas supply pressure and manifold pressures were stable at 9.5 in. w.c. and 3.1 in. w.c. for the increased inlet pressure test. For the reduced inlet pressure, the supply pressure was 4.1 in. w.c. and manifold pressures were 2.3 in. w.c. and 2.1 in. w.c.



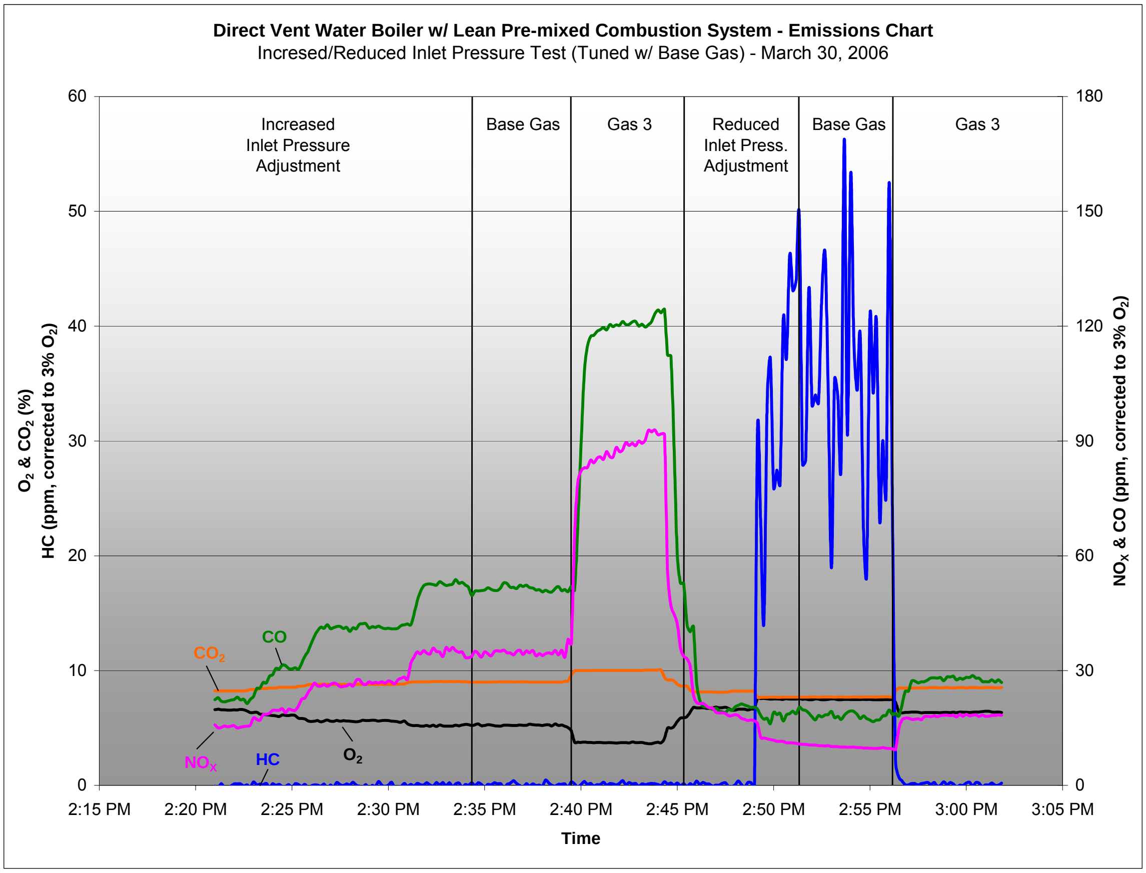
Temperatures

The stack temperature ranged from 286°F (Base Gas, reduced inlet) to 314°F (Gas 3, increased inlet). The highest inlet water, outlet water, and heat exchanger temperatures occurred with Gas 3 at the increased inlet pressure settings (137°F, 160°F, 398°F), whereas the lowest temperatures occurred with Base Gas at the reduced inlet pressure settings (127°F, 146°F, 348°F). Both ambient (67°F) and gas (78°F) temperatures remained stable throughout the test.



Emissions

When tunned with Base Gas, CO emissions were highest with Gas 3 (120 ppm) at the increased inlet pressure and lowest with Base Gas (18 ppm) at the reduced inlet pressure. NO_X and CO emissions followed the same pattern. The highest NO_X emissions occurred with Gas 3 (83 ppm) at the increased inlet pressure. HC emissions increased to 35 ppm with Base Gas when the appliance was adjusted to operate at the reduced inlet pressure.



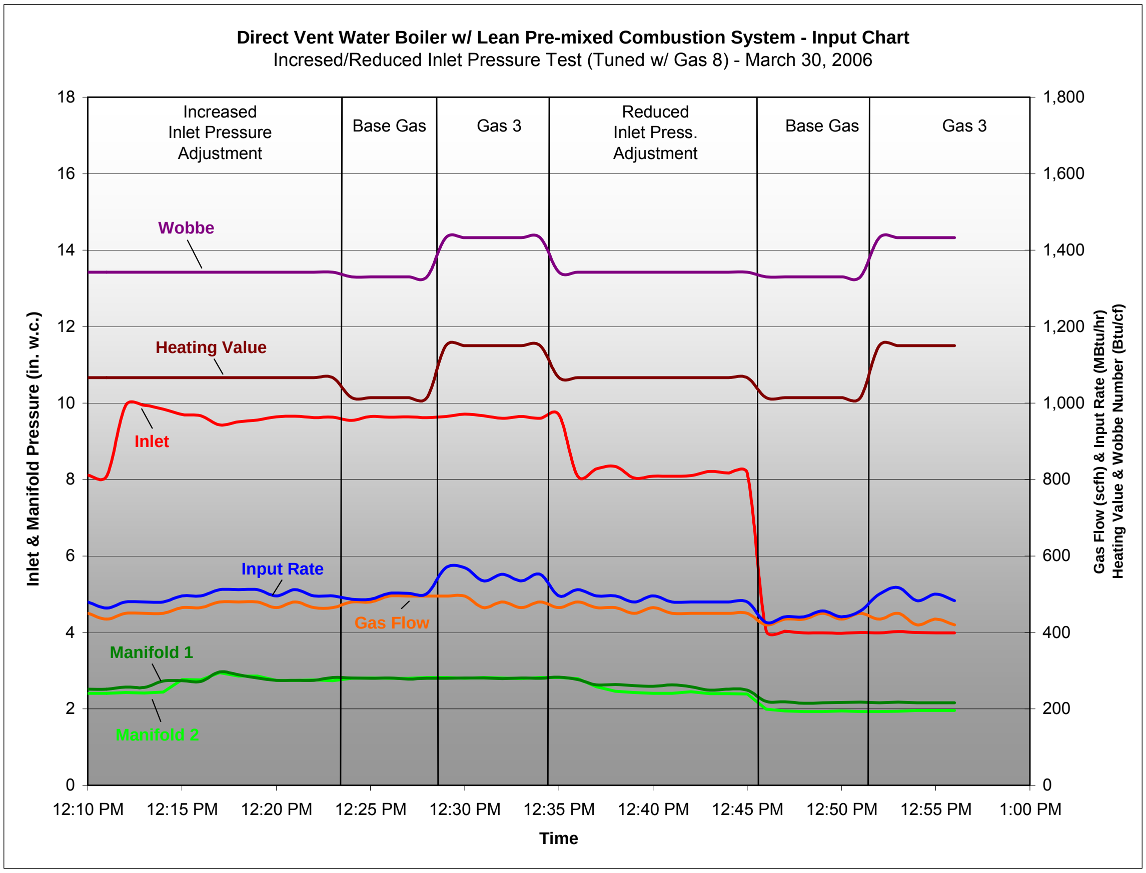
NOTE: Emission test results are for information purposes. They were not the result of certified tests.

Increased/Reduced Inlet Pressure Test (Tuned w/ Gas 8)

Input

The input rate was the highest with Gas 3 (552,000 Btu/hr at the increased inlet pressure) and lowest with Base Gas (443,759 Btu/hr at the reduced pressure test). Corrected gas flow ranged from 430.0 scfh (Gas 3 at reduced inlet pressure) to 489.0 scfh (Base Gas at increased inlet pressure).

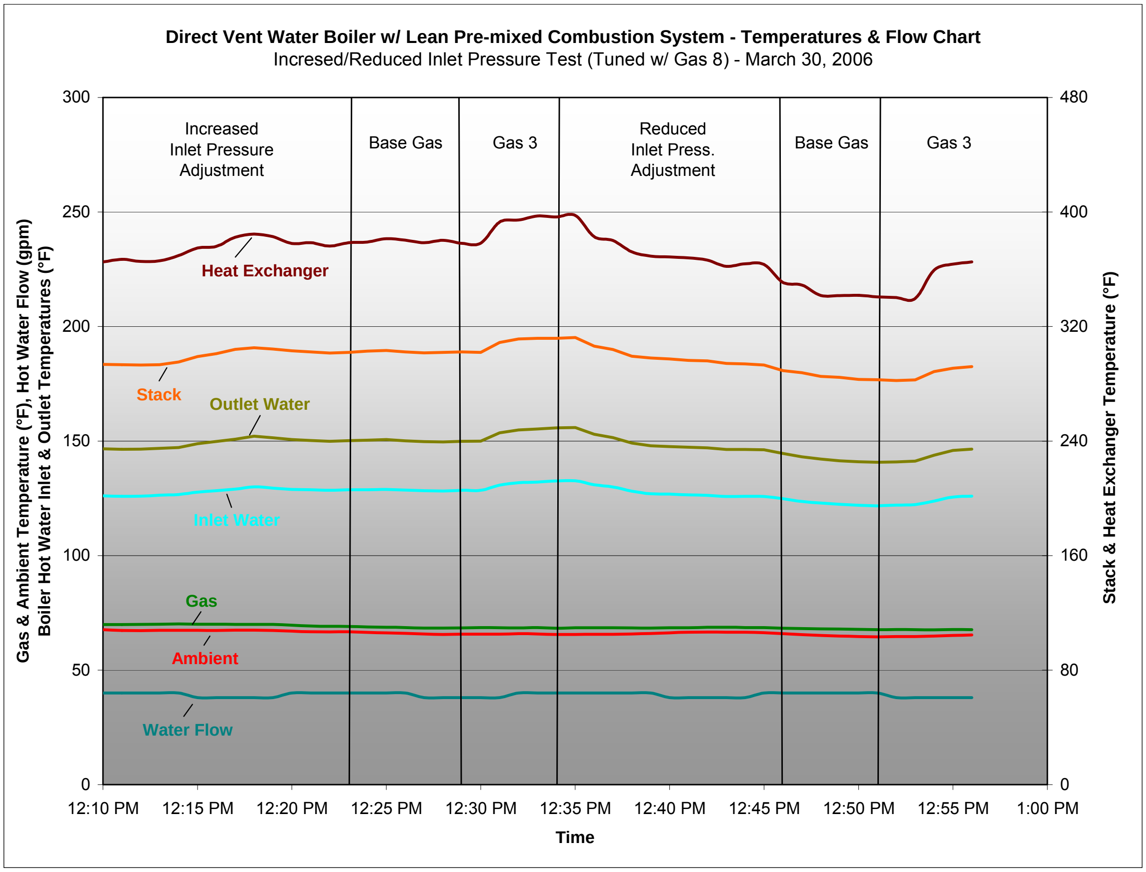
At increased inlet pressure, manifold pressure for both gas manifolds was 2.8 in. w.c and inlet pressure was 9.6 in. w.c.. At reduced inlet pressure, the manifold pressure for both gas manifolds was 2.1 ± 0.2 in. w.c. and and inlet pressure was 4.0 in. w.c.



Temperatures

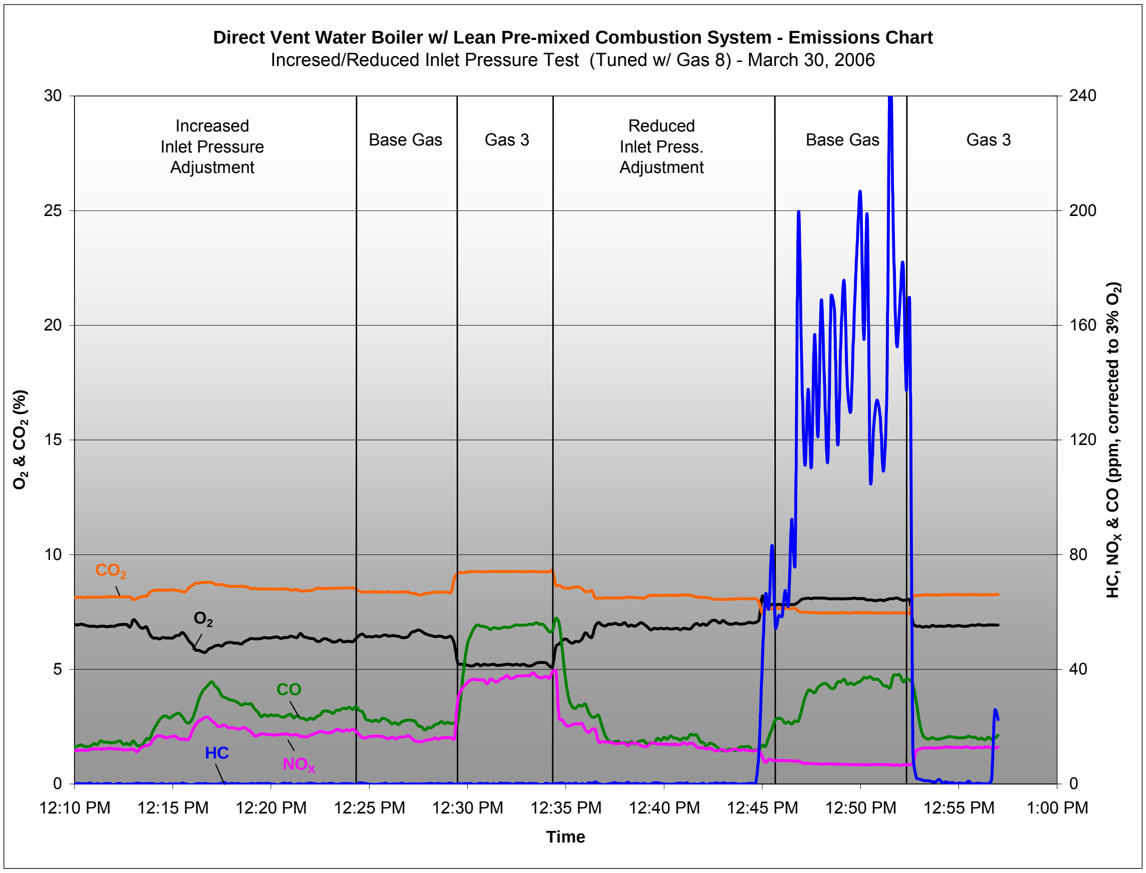
The highest inlet water, outlet water, heat exchanger and stack temperatures were observed at increased inlet pressure with Gas 3 (130.7°F, 153.2°F, 389.6°F and 308.0°F) whereas the lowest temperatures were observed at reduced inlet pressure with Base Gas (122.9°F, 142.2°F, 344.3°F and 285.4°F). Although the results were similar, the values obtained during this test were lower than those obtained when the appliance was tuned with Base Gas.

Both ambient (65 ± 1°F) and gas (68 ± 1°F) temperatures remained stable and water flow was 39 ± 1 gpm throughout the test.



Emissions

When tunned with Base Gas, NO_X emissions ranged from 7.1 ppm (Base Gas at reduced inlet pressure) to 36.5 ppm (Gas 3 at increased inlet pressure). CO emissions were highest at increased inlet pressure with Gas 3 (52.2 ppm) and HC emissions increased to 138.0 ppm with Base Gas 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 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
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

Hot Ignition Test

For each set-up gas (Base Gas and Gas 8), the boiler turned "on" without any problems during all ignition tests. After ignition, flames were stable 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
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

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 Water Boilers
SCAQMD Protocol	Nitrogen Oxides Compliance Testing for Natural Gas-Fired Water Heaters and Small Boilers (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	Direct Vent Hot Water Boiler
Burner	Lean Premixed Power Combustion System with 8 Cylindrical Barb Burners
Maximum rated input	~500,000 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. If necessary, provide a supply water pump and valves necessary to adjust water flow rate and temperatures. Maintain water level to assure proper boiler operation.

3.3. Vent Pipe

The vent pipe used must be similar to the 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	6 inches
Length	60 inches
Material	Sheet metal
Thermocouple Location	10 inches from the bottom
Emissions Sample Probe Location	54 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

In addition to data required for firing rate, provide thermocouples in inlet and outlet water piping as prescribed in Figure 8 of the SCAQMD protocol, as close to the boiler as possible. Also provide a thermocouple for measurement of the test ambient temperature – at mid-height of the boiler and shielded from abnormal radiation and convective effects.

Provide thermocouples in other locations as appropriate to record possible effects of gas blend changes. If possible, seek assistance from the manufacturer in selecting critical locations. The heat exchanger temperature was measured by a thermocouple in between the fins on the cold side of the heat exchanger

3.7. Instrumentation

All instrumentation is to be per the SCAQMD Protocol for Rule 1146.2.

3.8. Special Measures

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	1,323 (Low Wobbe)	1,009 (Low heat content)
3	1,433 (Highest Wobbe)	1,150 (Highest 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

Ambient conditions shall be measured as specified in §7.4.1.6 & §7.1.6 of the AQMD Protocol. Ambient temperature would not be controlled since the test will be performed outdoor.

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.

5.3. Basic Firing Setup

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 Base Gas or 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. Water Flow and Temperature

Provide instrumentation to measure the water temperature and flow in outlet water piping as illustrated in Figure #8 of the SCAQMD protocol. Adjust outlet temperature as close as possible to 145 ± 5°F and do not make any adjustments after starting the test. Adjust inlet water temperature and flow to obtain the required outlet temperature while following manufacturer's recommended installation procedures for a boiler utilized in domestic hot water heating. The inlet water shall be maintained at a minimum of 120°F.

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).

If the As Received input rate is within ± 5% of the boiler rated input, omit the As Received test and carry on the Rated Input test following the procedure listed in section §6.2, below. Otherwise, continue steady boiler operation with Base Gas for a specified duration and conduct a high-speed switch to Gas 3. 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 that boiler controls must not be allowed to adjust firing rate in response to a water temperature change).

When testing has been conducted with Gas 3, 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/ Base Gas)

Adjust boiler with Base Gas to operate at the face plate rating input, maintaining manifold pressure within ± 10% of that specified on the rating plate and changing gas orifices if necessary. Also, begin collecting temperature, pressure, input rate and combustion data, and verify that the firing rate is within ± 5% of the rated input.

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:** that the firing rate is not to be adjusted and that 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 next test gas and record observations and data per above. Reestablish steady state conditions with the Base Gas at the end of the 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.

6.3. Under-fire & Over-fire Testing

6.3.1. Under-fire Testing

Using Base Gas, adjust supply pressure to 4 in. w.c. and clock the boiler input rate. If the input rate dropped, continue the test by running Base Gas and the critical test gas for 5 minutes each. Record all operating data including firing rate, stack temperature, and other temperatures per §6.2. Also, record combustion data as required by the SCAQMD Protocol. Omit testing if no change in the boiler input rate is observed.

6.3.2. Over-fire Testing

Using Base Gas, adjust supply pressure to 10 in. w.c. If the boiler input rate remained below 106% of the rated input, adjust the manifold pressure to achieve the 106% input rate target. Run Base Gas and the critical test gas for 5 minutes each and record all operating data including firing rate, stack temperature, and other temperatures per §6.2. Also, record combustion data (NO_X, CO_2 & CO) as required by the SCAQMD Protocol.

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

6.4. 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 §6.2.

7. Ignition Tests

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

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)

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

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 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. 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 factory de-rate practices might affect conclusions.

11.3. Vent pipe choice:

ANSI Standard Z21.13 specifies that the vent pipe consist of an elbow at the vent collar, a short horizontal section, another elbow and a vertical section, the top of which is to be 5 ft. above the vent collar or draft relief opening, whichever is lower. The AQMD protocol requires a 5 ft. vertical vent pipe.

To minimize test time the vent pipe height is specified at 5 ft. for all testing and is allowed to be as short as 4 ft. if necessary for compatibility with laboratory ceiling height. The height compromise departs from standards, but is not considered to materially affect results, especially with respect to performance comparison when gas fuel blend is changed. With respect to Standard Z21.13, a shortened vertical stack is considered to have an effect on the order of, and probably less than, a stack with two elbows and a horizontal section.

11.4. Inlet Temperature

ANSI Standard Z21.13 specifies an inlet temperature at 80 ± 10°F and an outlet temperature of 180 ± 2°F, unless the manufacturer states a maximum permissible water temperature rise. In the latter case inlet water is tempered by mixing outlet and supply water to meet the manufacturer's specification.

The AQMD protocol specifies an inlet temperature of 70 ± 2°F and an outlet temperature of 180 ± 2°F, unless the manufacturer states a maximum permissible water temperature rise. In the latter case inlet water is tempered to meet the manufacturer's requirement.

In the belief that the differences in these specifications do not have significant effect on safety and emission performance and in the interest of testing economy water temperatures are specified at the same values for all testing. Inlet water temperature is to be a minimum of 120°F. Outlet water temperature is to be 145 ± 5°F.

Appendix B: Table of Averages

Rated Input Test (Tuned w/ Base Gas)

Table of Averages Direct Vent Water Boiler Rated Input Test (Tuned w/ Base Gas) March 30, 2005						
Gases	**Base**	**3**	**6**	**7**	**8**	**Base**
HHV (Btu/cf)	1,010	1,150	1,106	1,143	1,066	1,014
Wobbe (Btu/cf)	1,324	1,433	1,408	1,396	1,342	1,329
Input Rate (Btu/hr)	488,467	532,014	520,463	513,753	496,482	491,052
Corrected Gas Flow (scfh)	483.4	462.6	470.6	449.6	465.6	484.3
Emissions (not from certified tests)						
O_2 (%)	6.6	5.3	5.5	5.6	6.2	6.5
CO_2 (%)	8.2	9.1	8.9	9.0	8.5	8.3
CO (ppm @ 3% O_2)	21.4	53.7	47.6	45.5	29.0	22.4
HC (ppm @ 3% O_2)	0.1	0.1	0.0	0.0	0.0	0.0
NO_X (ppm @ 3% O_2)	14.3	35.6	31.3	29.6	19.1	15.4
Ultimate CO_2 (%)	12.0	12.1	12.1	12.3	12.1	12.0
Equivalence Ratio (Φ)	0.707	0.767	0.757	0.754	0.724	0.712
Temperatures (°F)						
Ambient	67.0	66.4	67.0	65.5	65.9	66.4
Gas	75.6	75.8	78.6	76.0	78.7	78.8
Inlet Water	127.8	131.7	132.9	131.2	130.8	130.1
Outlet Hot Water	148.3	153.8	154.9	153.2	151.7	150.5
Heat Exchanger	369.9	386.0	383.2	379.2	371.8	368.7
Stack	295.4	304.1	304.3	303.0	299.0	296.3
Pressures (in. w.c.)						
Gas Inlet	8.1	8.4	8.3	8.4	8.2	8.3
Manifold 1	2.7	2.7	2.7	2.7	2.7	2.7
Manifold 2	2.5	2.6	2.5	2.5	2.5	2.5
Flow (gpm)						
Water Flow	39.4	39.3	39.3	39.3	39.2	39.1

Rated Input Test (Tuned w/ Gas 8)

Table of Averages Direct Vent Water Boiler Rated Input Test (Tuned w/ Gas 8) March 31, 2005						
Gases	**8**	**Base**	**3**	**6**	**7**	**8**
HHV (Btu/cf)	1,066	1,015	1,150	1,106	1,143	1,066
Wobbe (Btu/cf)	1,342	1,330	1,433	1,408	1,396	1,342
Input Rate (Btu/hr)	480,514	472,377	513,317	501,695	498,788	479,517
Corrected Gas Flow (scfh)	450.6	465.6	446.4	453.6	436.5	449.7
Emissions (not from certified tests)						
O_2 (%)	7.0	7.1	6.0	6.2	6.3	6.9
CO_2 (%)	8.1	8.0	8.8	8.6	8.7	8.2
CO (ppm @ 3% O_2)	14.3	11.2	33.7	28.1	27.4	14.2
HC (ppm @ 3% O_2)	0.2	0.2	0.0	-0.1	-0.1	0.3
NO_X (ppm @ 3% O_2)	11.3	10.6	22.5	19.9	19.1	12.0
Ultimate CO_2 (%)	12.1	12.1	12.3	12.2	12.6	12.2
Equivalence Ratio (Φ)	0.69	0.68	0.74	0.73	0.67	0.69
Temperatures (°F)						
Ambient	63.7	62.8	64.5	65.2	65.8	67.4
Gas	66.0	66.0	67.1	69.4	70.5	70.4
Inlet Water	122.5	122.7	127.3	127.7	127.5	125.6
Outlet Hot Water	142.8	143.0	149.1	149.3	149.0	146.0
Heat Exchanger	360.9	361.3	380.4	378.4	376.6	363.5
Stack	291.3	291.9	301.9	301.4	300.6	291.8
Pressures (in. w.c.)						
Gas Inlet	8.2	8.2	8.2	8.3	8.2	8.1
Manifold 1	2.5	2.5	2.5	2.5	2.5	2.5
Manifold 2	2.4	2.4	2.4	2.4	2.4	2.4
Flow (gpm)						
Water Flow	38.9	39.1	39.0	39.2	39.4	39.1

Increased/Reduced Inlet Pressure Test (Tuned w/ Base Gas)

Table of Averages Direct Vent Water Boiler Increased/Reduced Inlet Pressure Test (Tuned w/ Base Gas) March 30, 2005				
Inlet Pressure Test	**Increased**		**Reduced**	
Gases	**Base**	**3**	**Base**	**3**
HHV (Btu/cf)	1,015	1,150	1,015	1,150
Wobbe (Btu/cf)	1,331	1,433	1,330	1,433
Input Rate (Btu/hr)	538,853	583,625	464,207	504,563
Corrected Gas Flow (scfh)	531.0	507.5	457.5	438.8
Emissions (not from certified tests)				
O_2 (%)	5.2	4.1	7.5	6.4
CO_2 (%)	9.0	9.8	7.7	8.5
CO (ppm @ 3% O_2)	51.4	120.0	18.3	26.8
HC (ppm @ 3% O_2)	0.1	0.1	35.1	0.2
NO_X (ppm @ 3% O_2)	34.7	83.1	10.1	17.7
Ultimate CO_2 (%)	12.0	12.2	12.0	12.2
Equivalence Ratio (Φ)	0.8	0.8	0.7	0.7
Temperatures (°F)				
Ambient	66.0	66.1	66.4	67.0
Gas	77.8	77.9	77.9	78.4
Inlet Water	133.5	136.5	127.2	130.3
Outlet Hot Water	156.0	160.4	146.4	150.9
Heat Exchanger	388.5	398.0	348.3	367.1
Stack	308.7	313.6	286.1	294.5
Pressures (in. w.c.)				
Gas Inlet	9.5	9.4	4.1	4.0
Manifold 1	3.1	3.1	2.3	2.2
Manifold 2	3.1	3.1	2.0	2.1
Flow (gpm)				
Water Flow	38.4	40.0	39.3	40.0

Increased/Reduced Inlet Pressure Test (Tuned w/ Gas 8)

Table of Averages Direct Vent Water Boiler Increased/Reduced Inlet Pressure Test (Tuned w/ Gas 8) March 31, 2005				
Inlet Pressure Test	**Increased**		**Reduced**	
Gases	**Base**	**3**	**Base**	**3**
HHV (Btu/cf)	1,014	1,150	1,014	1,150
Wobbe (Btu/cf)	1,330	1,433	1,330	1,433
Input Rate (Btu/hr)	496,023	552,000	443,759	494,500
Corrected Gas Flow (scfh)	489.0	480.0	437.5	430.0
Emissions (not from certified tests)				
O_2 (%)	6.5	5.2	8.0	6.9
CO_2 (%)	8.4	9.3	7.5	8.2
CO (ppm @ 3% O_2)	21.6	52.2	32.3	18.2
HC (ppm @ 3% O_2)	0.0	0.1	138.0	8.7
NO_X (ppm @ 3% O_2)	16.0	36.5	7.1	12.3
Ultimate CO_2 (%)	12.1	12.3	12.2	12.3
Equivalence Ratio (Φ)	0.7	0.8	0.6	0.7
Temperatures (°F)				
Ambient	66.1	65.7	65.1	65.0
Gas	68.6	68.5	68.0	67.7
Inlet Water	128.6	130.7	122.9	124.3
Outlet Hot Water	150.1	153.2	142.2	144.2
Heat Exchanger	379.9	389.6	344.3	355.4
Stack	302.4	308.0	285.4	288.2
Pressures (in. w.c.)				
Gas Inlet	9.6	9.6	4.0	4.0
Manifold 1	2.8	2.8	2.2	2.2
Manifold 2	2.8	2.8	1.9	2.0
Flow (gpm)				
Water Flow	39.2	39.0	40.0	38.3

<u>Appendix C:</u> Test Gases

Gas Sample Date	Baseline 8/1/2005	3 7/1/2005	6 7/1/2005	7 6/20/2005	8 8/5/2005
COMPONENTS	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**
C6 + 57/28/14	0.010	0.000	0.000	0.023	0.001
NITROGEN	0.378	0.128	0.274	3.025	3.839
METHANE	96.411	86.549	91.168	86.466	89.998
CARBON DIOXIDE	1.627	0.035	0.003	0.034	0.120
ETHANE	1.256	9.480	5.747	0.312	0.000
PROPANE	0.218	2.725	1.727	9.946	5.997
i-BUTANE	0.041	1.034	0.534	0.094	0.041
n-BUTANE	0.039	0.000	0.531	0.061	0.000
NEOPENTANE	0.000	0.000	0.000	0.000	0.000
i-PENTANE	0.013	0.000	0.000	0.019	0.001
n-PENTANE	0.008	0.000	0.000	0.016	0.001
OXYGEN	0.000	0.049	0.016	0.004	0.003
TOTAL	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**
Compressibility Factor	0.9978	0.9972	0.9975	0.9971	0.9976
HHV (Btu/real cubic foot)	**1009.92**	**1150.00**	**1106.00**	**1142.00**	**1066.30**
LHV (Btu/real cubic foot)	913.49	1039.90	998.90	1033.40	963.10
Specific Gravity	0.5825	0.6442	0.6167	0.6697	0.6312
WOBBE Index	**1323.27**	**1432.81**	**1408.37**	**1395.49**	**1342.13**

Appendix D: Zero, Span and Linearity Tables

Rated Input Test (Tuned w/ Base Gas)

Increased/Reduced Inlet Pressure Test (Tuned w/ Base Gas)

Zero, Span & Linearity Data
Direct Vent Water Boiler
Rated Input Test & Increased/Reduced Inlet Pressure Test (Tuned w/ Base Gas)
March 30, 2006

		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**
Zero	**Allowable Zero Drift (Less Than ± 3% of Range)**	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
Zero	Zero Calibration - 12:40:19 PM	0.00	0.00	0.30	-0.30	0.00
Zero	Zero Drift Check - 3:14:34 PM	0.00	0.00	-1.60	0.00	0.00
Zero	**Total Drift Over Test Period**	**0.00**	**0.00**	**1.90**	**0.30**	**0.00**
Zero	**Was the Zero Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Span	**Span Calibration Gas (High-Range Values)**	**8.97**	**12.20**	**181.00**	**432.00**	**84.50**
Span	**Allowable Span Drift (Less Than ± 3% of Range)**	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
Span	Span Calibration - 12:46:47 PM	8.90	12.20	180.80	432.40	84.70
Span	Span Drift Check - 3:07:24 PM	8.90	12.30	179.80	435.30	84.70
Span	**Total Drift Over Test Period**	**0.00**	**0.10**	**1.00**	**2.90**	**0.00**
Span	**Was the Span Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**8.97**	**12.20**	**82.00**	**432.00**	**44.70**
Linearity	**Allowable Linearity Drift (Less Than ±1% of Range)**	**0.25**	**0.20**	**2.00**	**10.00**	**1.00**
Linearity	Linearity Check - 11:24:25 AM	8.90	12.20	80.90	432.90	46.40
Linearity	**Difference From Mid-Range Values**	**0.07**	**0.00**	**1.10**	**0.90**	**1.70**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**No**
Linearity	Linearity Check - 03:11:59 PM	8.90	12.30	79.10	435.30	46.30
Linearity	**Difference From Mid-Range Values**	**0.07**	**0.10**	**2.90**	**3.30**	**1.60**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**Yes**	**No**	**Yes**	**No**

Rated Input Test (Tuned w/ Gas 8)

Increased/Reduced Inlet Pressure Test (Tuned w/ Gas 8)

	Zero, Span & Linearity Data Direct Vent Water Boiler Rated Input Test & Increased/Reduced Inlet Pressure Test (Tuned w/ Gas 8) March 31, 2006	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 - 9:01:59 AM	0.00	0.00	0.40	-0.50	0.00
	Zero Drift Check - 1:18:28 PM	0.00	0.10	4.40	-0.10	0.00
	Total Drift Over Test Period	**0.00**	**0.10**	**4.00**	**0.40**	**0.00**
	Was the Zero Drift Within Allowable Deviation?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Span	**Span Calibration Gas (High-Range Values)**	**8.97**	**12.20**	**181.00**	**432.00**	**84.50**
	Allowable Span Drift (Less Than ± 3% of Range)	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
	Span Calibration -9:08:35 AM	8.90	12.20	180.90	432.00	84.40
	Span Drift Check - 1:05:35 PM	8.90	12.30	175.30	433.50	84.70
	Total Drift Over Test Period	**0.00**	**0.10**	**5.60**	**1.50**	**0.30**
	Was the Span Drift Within Allowable Deviation?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**8.97**	**12.20**	**82.00**	**432.00**	**44.70**
	Allowable Linearity Drift (Less Than ±1% of Range)	**0.25**	**0.20**	**2.00**	**10.00**	**1.00**
	Linearity Check - 9:21:26 AM	8.90	12.20	80.00	431.80	46.20
	Difference From Mid-Range Values	**0.07**	**0.00**	**2.00**	**0.20**	**1.50**
	Was the Linearity Within Allowable Deviation?	**Yes**	**Yes**	**No**	**Yes**	**No**
	Linearity Check - 1:11:20 PM	8.97	12.10	76.60	431.80	46.10
	Difference From Mid-Range Values	**0.00**	**0.10**	**5.40**	**0.20**	**1.40**
	Was the Linearity Within Allowable Deviation?	**Yes**	**Yes**	**No**	**Yes**	**No**

<u>Appendix E:</u> 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)	$CH_4 + 2O_2 + 2(3.78)N_2 \Longrightarrow 1CO_2 + 2H_2O + 2(3.78)N_2$	9.56	8.56
Ethane (C_2H_6)	$C_2H_6 + 3.5O_2 + 3.5(3.78)N_2 \Longrightarrow 2CO_2 + 3H_2O + 3.5(3.78)N_2$	16.73	15.23
Propane (C_3H_8)	$C_3H_8 + 5O_2 + 5(3.78)N_2 \Longrightarrow 3CO_2 + 4H_2O + 5(3.78)N_2$	23.90	21.90
i-Butane (C_4H_{10})	$C_4H_{10} + 6.5O_2 + 6.5(3.78)N_2 \Longrightarrow 4CO_2 + 5H_2O + 6.5(3.78)N_2$	31.07	28.57
n-Butane (C_4H_{10})	$C_4H_{10} + 6.5O_2 + 6.5(3.78)N_2 \Longrightarrow 4CO_2 + 5H_2O + 6.5(3.78)N_2$	31.07	28.57
i-Pentane (C_5H_{12})	$C_5H_{12} + 8O_2 + 8(3.78)N_2 \Longrightarrow 5CO_2 + 6H_2O + 8(3.78)N_2$	38.24	35.24
n-Pentane (C_5H_{12})	$C_5H_{12} + 8O_2 + 8(3.78)N_2 \Longrightarrow 5CO_2 + 6H_2O + 8(3.78)N_2$	38.24	35.24
Hexanes (C_6H_{14})	$C_6H_{14} + 9.5O_2 + 9.5(3.78)N_2 \Longrightarrow 6CO_2 + 7H_2O + 9.5(3.78)N_2$	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					
Model Number: 8C15			**Meter Number:** 12171480		
Date: February 28, 2006					
Test Point	**Prover Flow** cfh	**Rated Capacity**	**Meter Accuracy**	**Meter Error**	**Meter Flow** cfh
1	797.10	99.6%	100.09%	**0.09%**	**797.82**
2	199.70	25.0%	99.69%	**-0.31%**	**199.08**
3	80.00	10.0%	99.34%	**-0.66%**	**79.47**

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 535.0 actual cubic feet per hour (acfh), the gas meter flow rate range would be 199.08 to 797.82 acfh and the meter error range (divided by 100) would be -0.0031 to 0.0009. Using this information, the meter error (y) is:

$$y = \frac{0.0009 + 0.0031}{797.82\text{ acfh} - 199.08\text{ acfh}}(535.0\text{ acfh} - 199.08\text{ acfh}) - 0.0031 = -0.000856$$

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

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

$$F_{meter} = \frac{535.0\text{ acfh}}{(1 - 0.000856)} = 535.458\text{ acfh}$$

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.

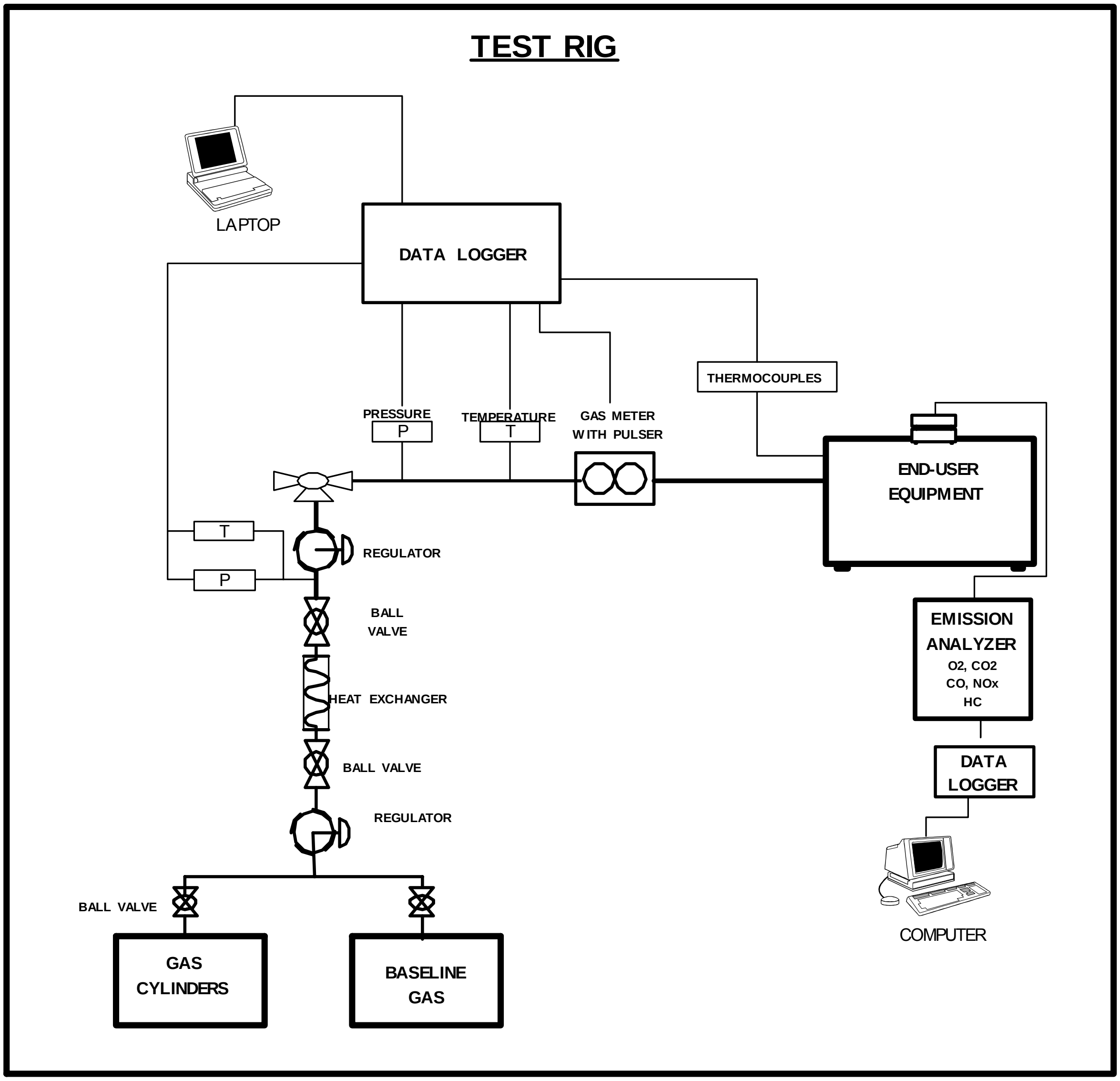
Emissions Analyzer				
Analyzer	**Manufacturer**	**Model**	**Type**	**Accuracy**
NO/NO_X	California Analytical Instruments, Inc.	650	Chemiluminescent	± 1% of full scale
CO	Thermo Environmental Instruments Inc.	48	Nondispersive infrared (NDIR) gas analyzer	± 1% of full scale
CO_2	Fuji	ZRH	Nondispersive 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	± 2%
NO/NO_X	Matheson Tri Gas	Certified Master Class	± 2%
CO	Matheson Tri Gas	Certified Master Class	± 2%
CO_2	Matheson Tri Gas	Certified Master Class	± 2%
HC	Scott Specialty Gases	Certified Master Class	± 2%
O_2	Scott Specialty Gases	Certified Master Class	± 2%

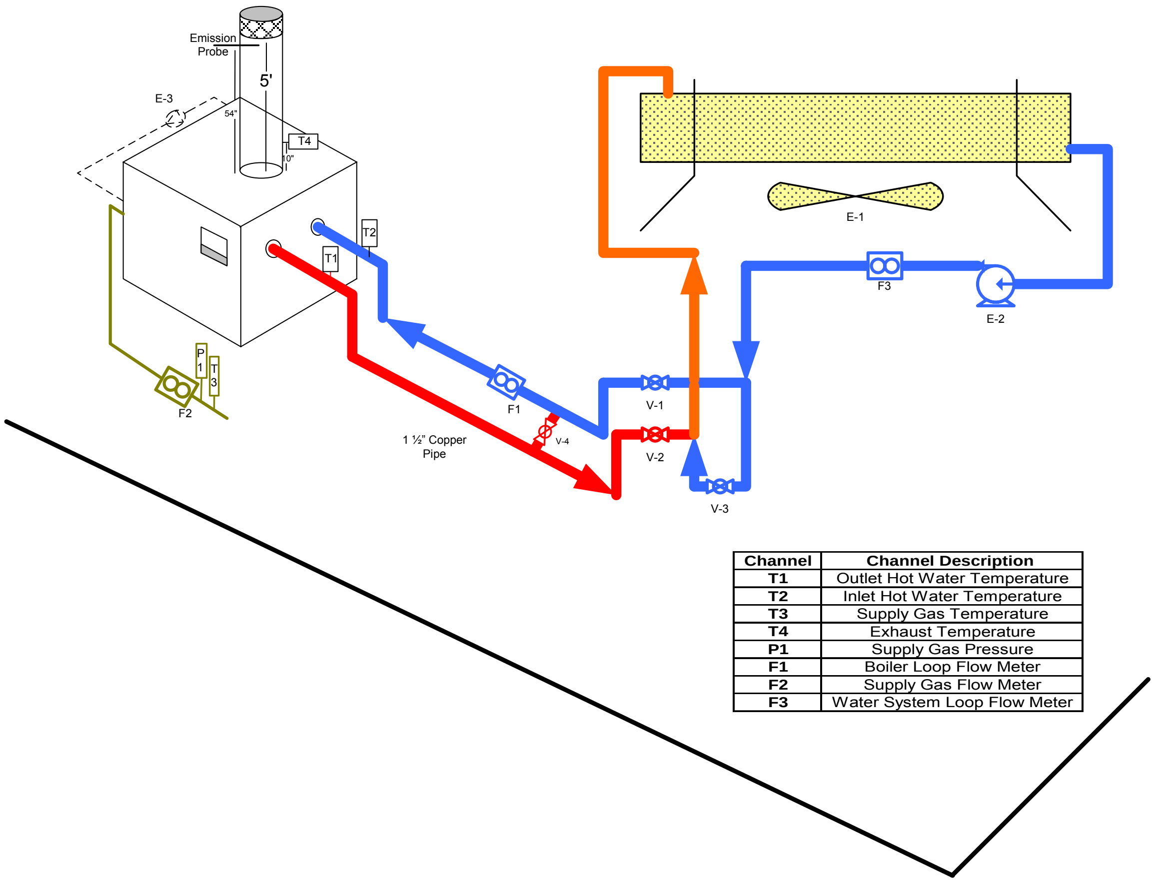
Test Equipment			
Equipment	**Manufacturer**	**Model**	**Accuracy**
Datalogger	Delphin	D51515	n/a
Gas Chromatograph	Agilent	6890	± 0.5 BTU/scf
K Thermocouple	Omega Engineering Co.	KMQSS	2.2^{o}C or 0.75%
J Thermocouple	Omega Engineering Co.	JMQSS	2.2^{o}C or 0.75%
R Thermocouple	Omega Engineering Co.	RMQSS	2.2^{o}C or 0.75%
T Thermocouple	Omega Engineering Co.	TMQSS	2.2^{o}C or 0.75%
Drytest Gas Meter 800 cf/h max	Roots Meter	8C175	n/a
Gas Meter Pulser 1 pulse per 1/4 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
Water Temperature Mixing Valve	Powers	434	n/a

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.



Appendix H: Schematic



Channel	Channel Description
T1	Outlet Hot Water Temperature
T2	Inlet Hot Water Temperature
T3	Supply Gas Temperature
T4	Exhaust Temperature
P1	Supply Gas Pressure
F1	Boiler Loop Flow Meter
F2	Supply Gas Flow Meter
F3	Water System Loop Flow Meter