LNG Research Study

Half Size Gravity Vented Wall Furnace

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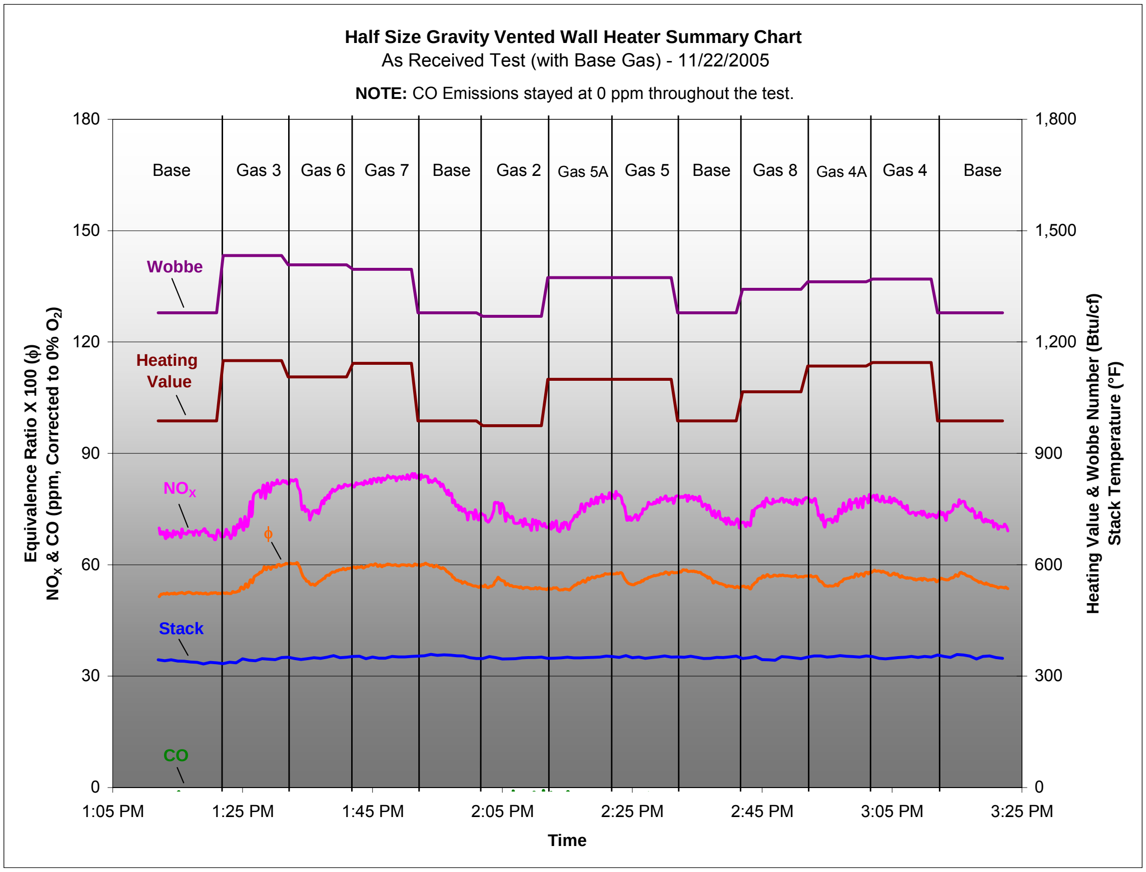
Results Summary

Results obtained from all tests conducted reveal (a) there were no operational, ignition, flame stability, flame lifting, flashback, yellow tipping or safety problems with the different gases or during transitioning; (b) none of the temperatures monitored experienced critical changes; (c) the flame temperature and NO_X emissions followed the same pattern as the equivalence ratio throughout each test; (d) after tuning the appliance with Gas 8 (Medium heating content and Wobbe Number) NO_X emissions were very stable and (e) CO emissions were negligible throughout all tests.

As Received Test

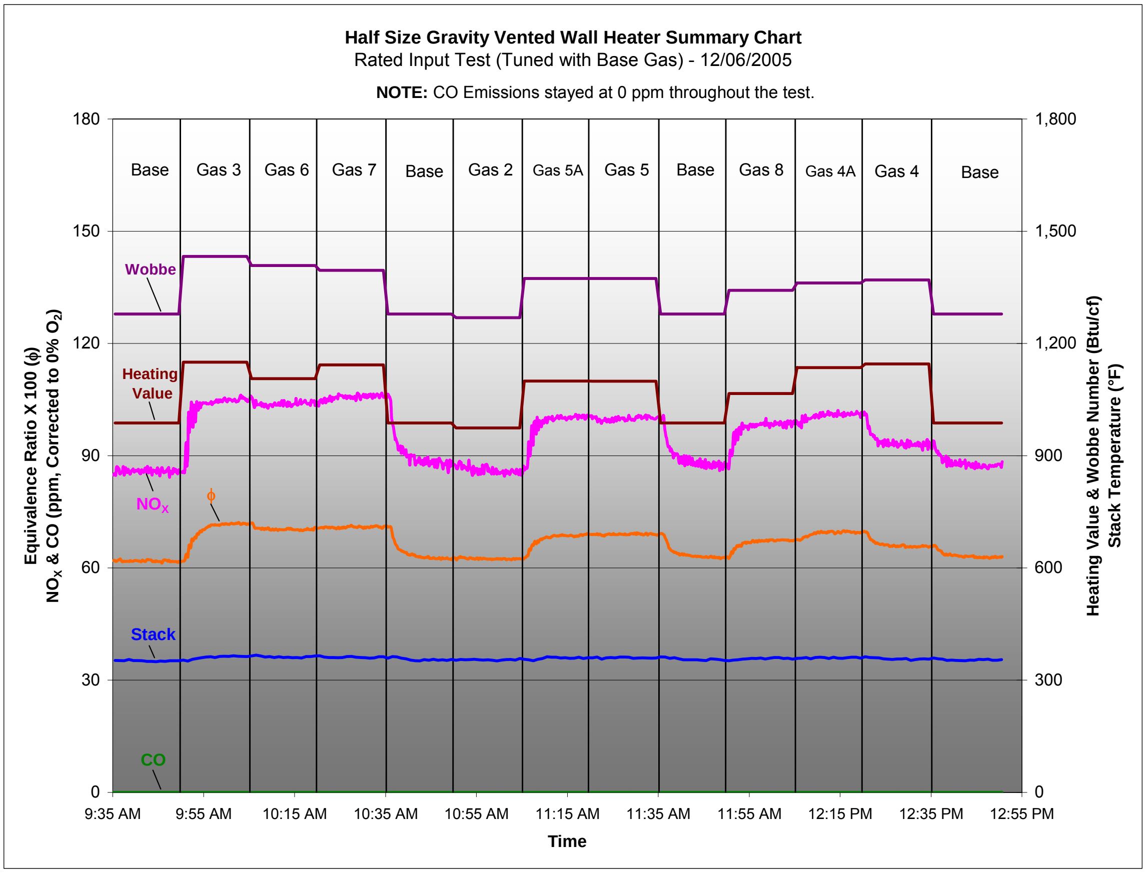
NO_X emissions (corrected to 0% O_2) did not exceed 83 ppm for all test gases. Base Gas NO_X emissions were 73.8 ppm. Changes in NO_X emissions correlated directly with changes in the equivalence ratio. CO emissions were negligible throughout the course of the test.



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

Rated Input Test (Tuned with Base Gas)

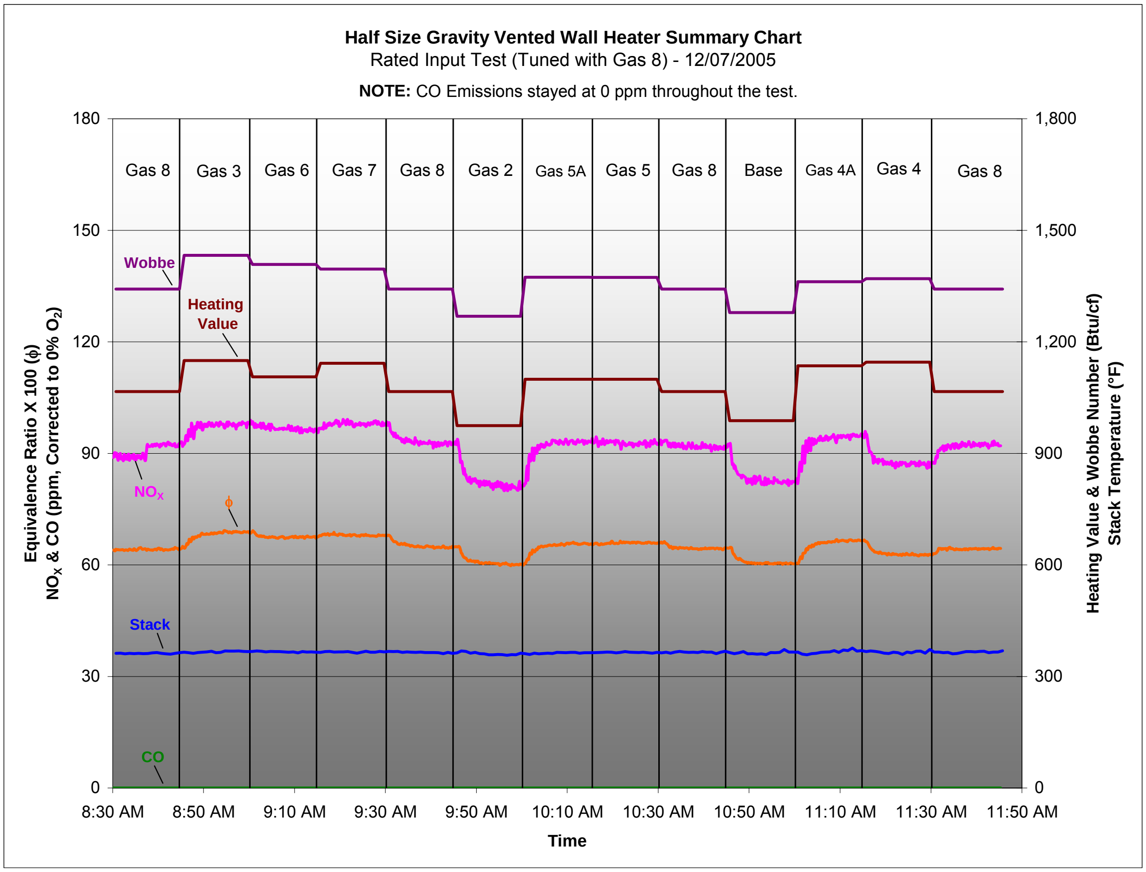
When tuned with Base Gas, NO_X emissions (corrected to 0% O_2) were highest with Gas 7 (106 ppm) and Base Gas NO_X emissions were 89 ppm. Changes in NO_X emissions correlated directly with changes in the equivalence ratio. CO emissions values were negligible throughout the test.



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

Rated Input Test (Tuned with Gas 8)

When tuned with Gas 8, NO_X emissions (corrected to 0% O_2) decreased for all test gases compared to values obtained when the appliance was tuned with Base Gas. NO_X emissions for Gas 7 were 97.9 ppm and 83.7 ppm for Base Gas; decreasing 7.7 ppm and 5.1 ppm from values obtained when the appliance was tuned with Base Gas. Changes in NO_X emissions correlated directly with changes in the equivalence ratio. CO emissions values were negligible throughout the test.



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

Equipment Selection Criteria

The legacy half size direct vented wall furnace consists of a sealed combustion system that draws outdoor air into the combustion chamber and discharges combustion air through tubes mounted on the rear end of the furnace. The Direct Vent Wall Heater was selected because of its unique air intake design, long life expectancy due to mild winters in Southern California and the potential for cracking to occur in the heat exchangers if overfired.

Equipment Specification

Description	Half size direct vented wall furnace with a steel heat exchanger
Burner	Cast iron atmospheric burner firing vertically into the heat exchanger
Maximum rated input	14,000 Btu/hr
Type of fuel	Natural Gas
Required Inlet pressure	4.5 – 10.5 in. w.c.

Standards

The test protocol was developed based on the following test standards.

ANSI Z21.86 - 2004	Vented Gas - Fired Space Heating Appliances
SCAQMD Method 100.1	Instrument Analyzer Procedures for Continuous Gaseous Emission Sampling

Installation

The half size direct vented wall furnace was installed into a test structure derived from ANSI Z21.86 - 2004 and according to the manufacturer's installation specifications. Testing instrumentation was installed following the cited test standards.

Thermocouples were installed to measure combustion area, stack, back wall, side wall, upper wall, discharge air, ambient and gas temperatures. Pressure transducers were installed to measure manifold and inlet gas pressures, a gas meter (with a pulser) was used to measure gas usage and a probe was built and placed in the flue vent of the furnace to measure emissions.

Test Gases

The following gases have been specifically formulated to cover the range, 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)
2	1,269 (Lowest Wobbe)	974 (Lowest heat content)
3	1,433 (Highest Wobbe)	1,150 (Highest heat content)
4	1,370 (Medium Wobbe)	1,145 (High heat content)
4A	1,362 (Medium Wobbe)	1,135 (High heat content)
5	1,374 (Medium Wobbe)	1,100 (High heat content)
5A	1,362 (Medium Wobbe)	1,100 (High heat content)
6	1,408 (High Wobbe)	1,106 (High heat content)
7	1,395 (High Wobbe)	1,142 (High heat content)
8	1,342 (Medium Wobbe)	1,066 (Medium heat content)

Test Procedure

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

Before every test, the following steps were performed:

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

During every test, the following steps were performed:

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

After every test, the following steps were performed:

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

As Received Test (with Base Gas)

Using Base Gas, the wall furnace was lit to allow the appliance to warm-up, the manifold pressure was examined and the input rate was found to be 9,373 Btu/hr, which is 33.1% below rated input. Once readings were stable, data collection was started and the gases were run in the following order:

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

Rated Input Test (Tuned with Base Gas)

Using Base Gas, the manifold and inlet pressures were adjusted and an input rate of 11,017 Btu/hr was achieved; which is 21.3% below rated input. Once readings were stable, data collection was started and the gases were run in the following order:

- Base Gas for 15 minutes.
- Gas 3 for 15 minutes.
- Gas 6 for 15 minutes.
- Gas 7 for 15 minutes.
- Reestablish Base Gas for 15 minutes.
- Gas 2 for 15 minutes.
- Gas 5A for 15 minutes.
- Gas 5 for 15 minutes.
- Reestablish Base Gas for 10 minutes.
- Gas 8 for 15 minutes.
- Gas 4A for 15 minutes.
- Gas 4 for 15 minutes.
- Conclude testing with Base Gas for 15 minutes.

Rated Input Test (Tuned with Gas 8)

Using Gas 8, the manifold was adjusted to achieve a similar input rate and performance (including emissions, temperatures, etc.) as with Base Gas. Once readings were stable, data collection was started and the gases were run in the following order:

- Gas 8 for 15 minutes.
- Gas 3 for 15 minutes.
- Gas 6 for 15 minutes.
- Gas 7 for 15 minutes.
- Reestablish Gas 8 for 15 minutes.
- Gas 2 for 15 minutes.
- Gas 5A for 15 minutes.
- Gas 5 for 15 minutes.
- Reestablish Gas 8 for 15 minutes.
- Base Gas for 15 minutes.
- Gas 4A for 15 minutes.
- Gas 4 for 15 minutes.
- Conclude testing with Gas 8 for 15 minutes.

Cold Ignition Test

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

Hot Ignition Test

The unit was tuned with each test 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.

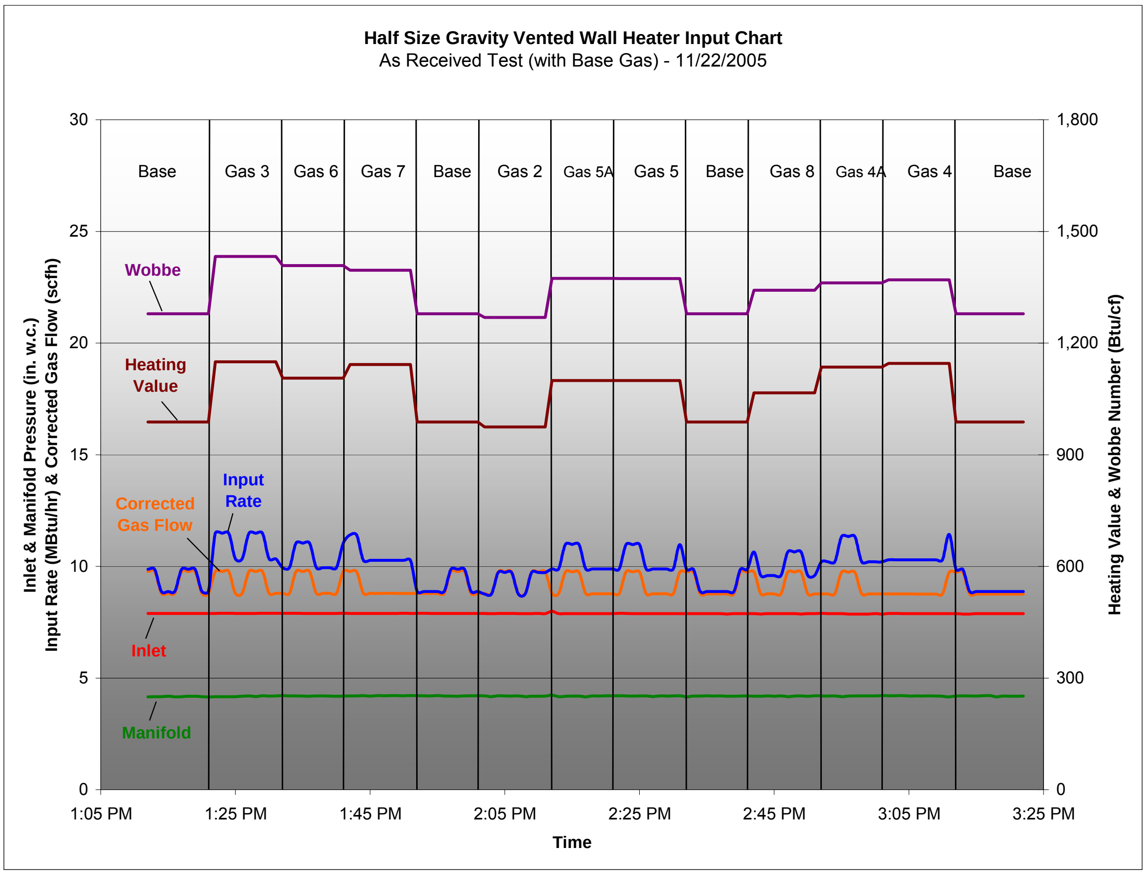
Results[1,2,3]

As Received Test (with Base Gas)

Input

The input rate corresponds with changes in Wobbe Number, with the minimum and maximum input rates being 9,225 Btu/hr (Base Gas) and 11,026 Btu/hr (Gas 3). The corrected gas flow ranged from 8.9 scfh to 9.4 scfh. Inlet and manifold pressures remained stable during the course of the test.

There were not drops in inlet pressure at the beginning of each gas run because we didn't to purge the gas supply hose before the gas meter.



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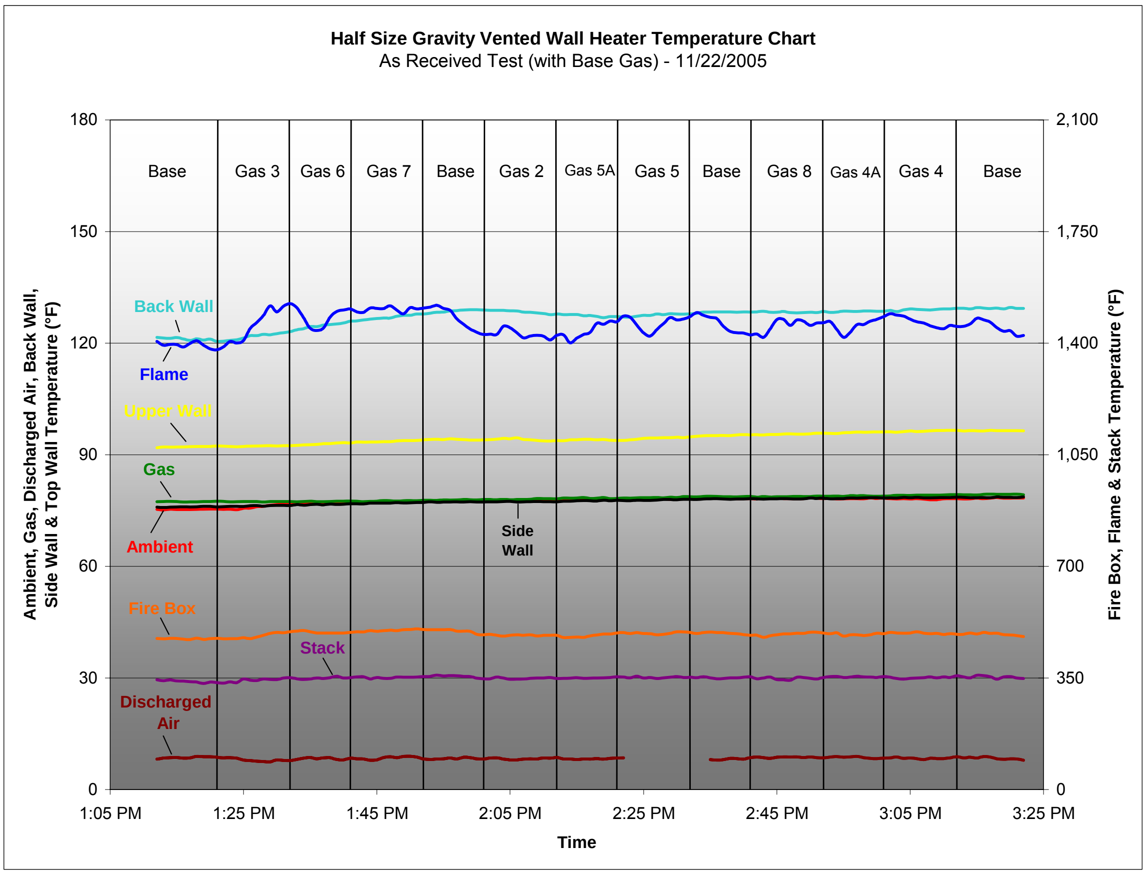
[1] All emissions, temperature and input values mentioned throughout the results section are average values.
[2] Emissions values are corrected to 0% O_2.
[3] When either Base Gas or Gas 8 is used as the set-up gas, the values reported for the set-up gas are the average values of all runs for that gas during each test.

Temperatures

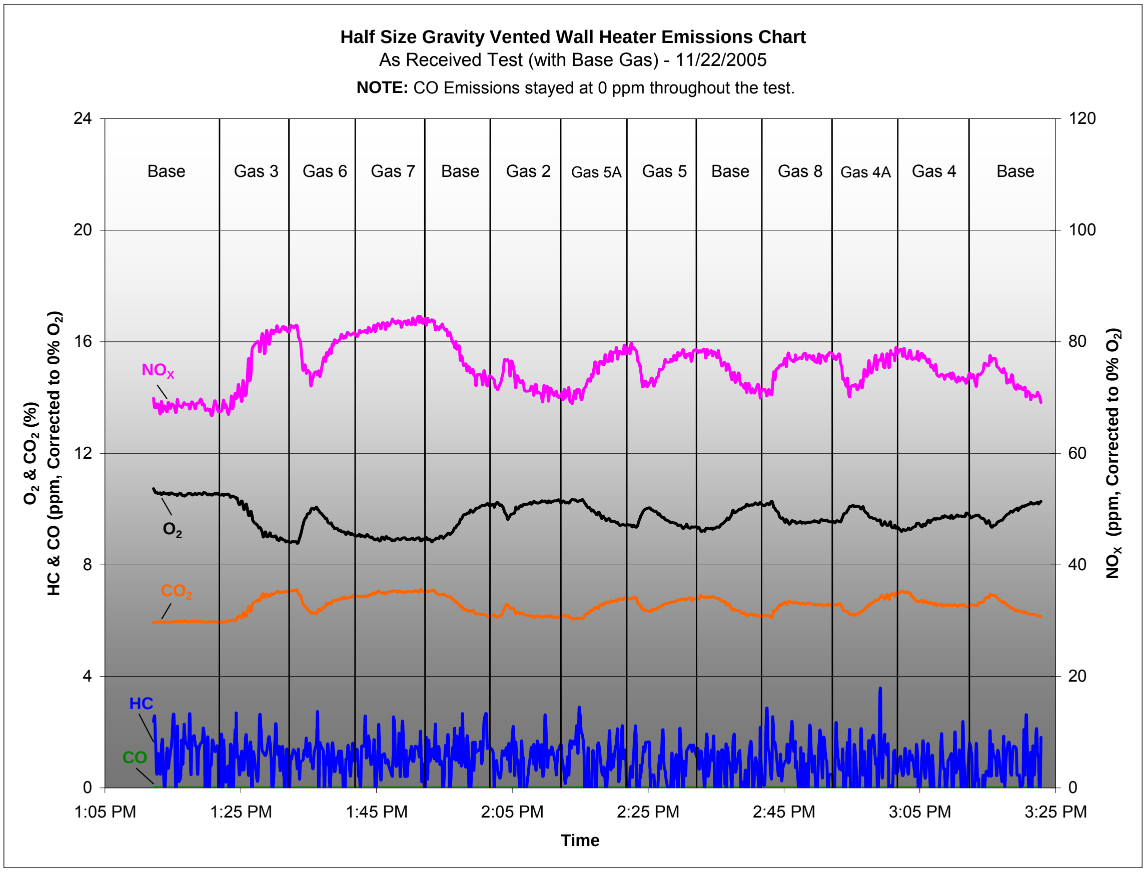
The highest flame temperature was observed with Gas 7 at 1,505°F then remained below 1,485°F for the rest of the gases tested. The back wall temperatures ranged between 121°F and 130°F, fire box temperature ranged between 480°F and 499°F and discharge air temperature remained below 101°F. Stack temperatures remained stable throughout the test and reached a high of 353.2°F with Gas 4A. Ambient and gas temperatures were stable at 77.0 ± 3.0°F.

The interruptions in discharge air temperature during Gas 5 and part of the Base Gas run was caused by a loose thermocouple wire connection.



Emissions

NO_X emissions ranged from 72.4 ppm (Gas 2) to 83.0 ppm (Gas 7). Base Gas NO_X emissions were 73.8 ppm. CO_2 percentage and NO_X emissions curves followed the same pattern throughout the test; which was inversely proportional to the O_2 percentage curve. CO emissions remained at 0 ppm and HC emissions stayed below 1.3 ppm throughout the course of the test.



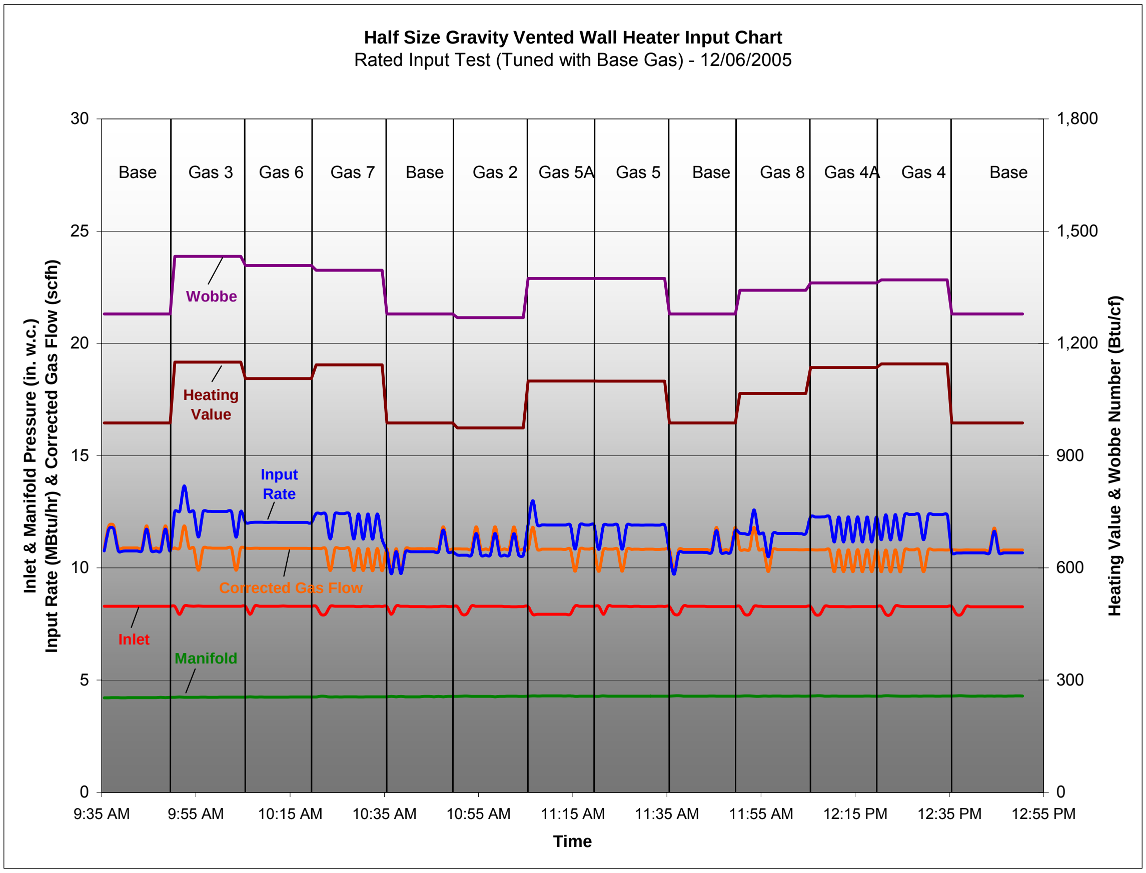
NOTE: Emission test results are for information purposes, they were not the result of certified tests.

Rated Input Test (Tuned with Base Gas)

Input

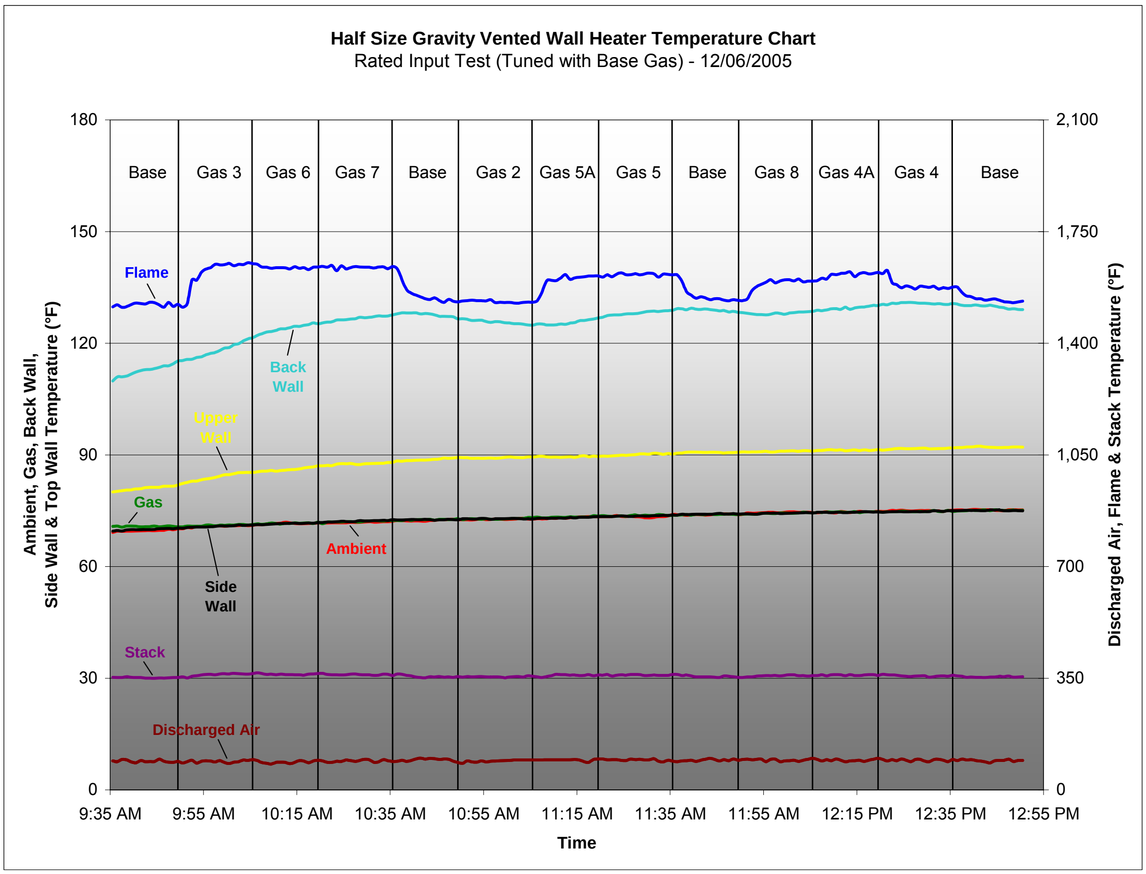
The highest input rate was observed with Gas 3 (12,440 Btu/hr) and the lowest with Gas 2 (10,760 Btu/hr). Corrected gas flow rates ranged from 10.5 scfh (Gas 4A) to 11.0 scfh (Gas 2). Manifold and inlet pressures were within tolerances specified in the test protocol.

The drops in inlet pressure at the beginning of each gas run were the result of purging the gas supply hose before the gas meter.



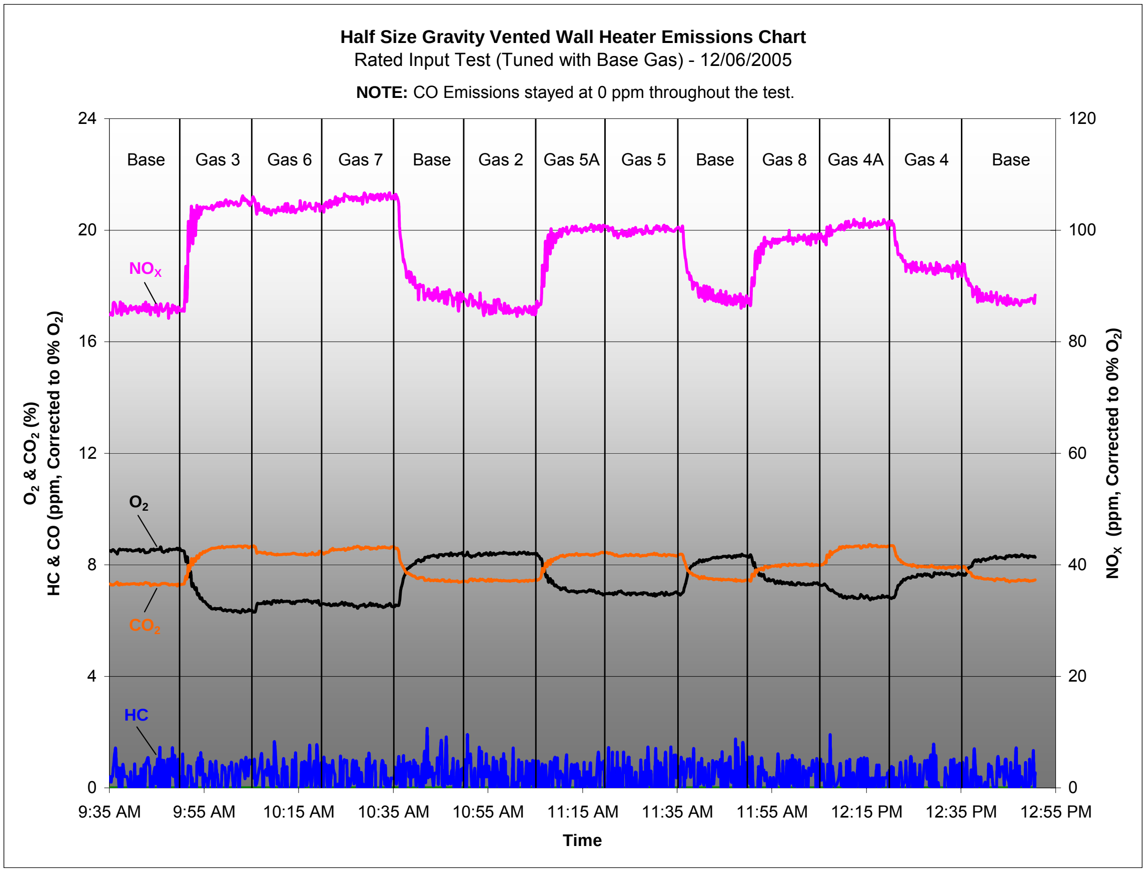
Temperatures

The highest flame temperature was observed with Gas 6 (1,638°F), whereas Gas 2 (1,531°F) had the lowest flame temperature. Stack temperature was highest with Gas 6 (362.5°F) while the lowest was observed with Gas 2 (354.5°F). Back wall temperature ranged from 117.9°F to 130.7°F and discharged air temperature ranged from 87.6°F to 93.9°F. Ambient, gas and side wall temperatures were steady throughout of the course of the test.



Emissions

NO_X emissions were highest with Gas 7 (105.6 ppm) and lowest with and Gas 2 (86.2 ppm). Base Gas NO_X emissions were at 88.8 ppm. CO_2 percentage and NO_X emissions followed the same pattern throughout the test; which was inversely proportional to the O_2 percentage. The HC emission remained below 1 ppm and CO emissions were negligible throughout the course of the test.



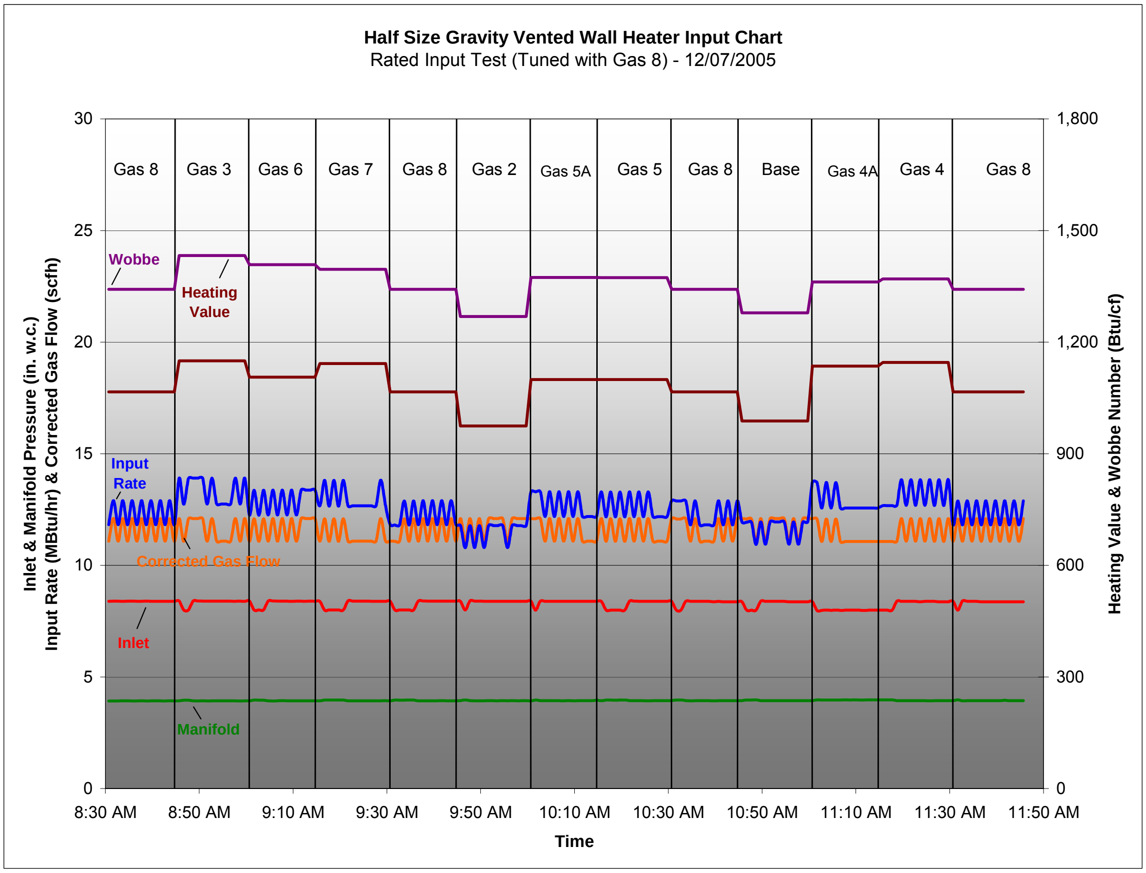
NOTE: Emission test results are for information purposes, they were not the result of certified tests.

Rated Input Test (Tuned with Gas 8)

Input

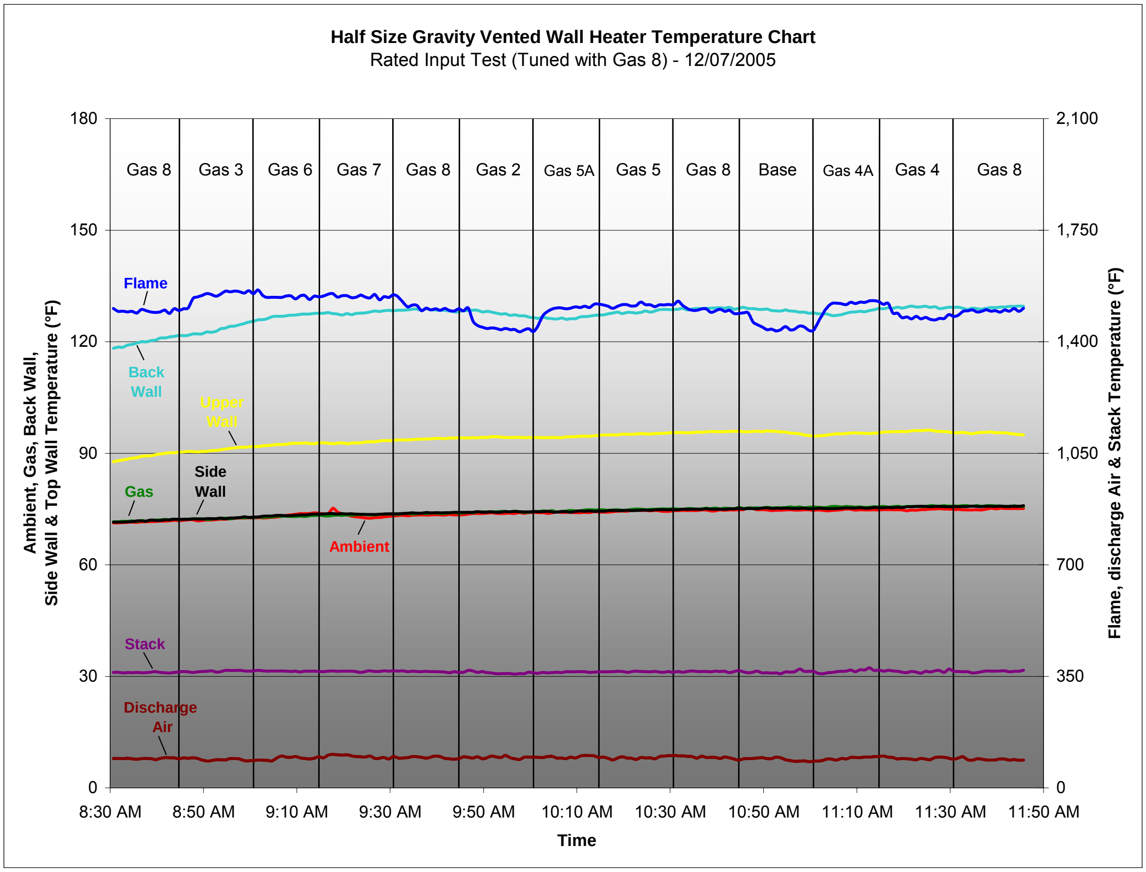
The highest input rate was observed with Gas 3 (13,365 Btu/hr) and the lowest with Gas 2 (11,519 Btu/hr). Corrected gas flow rates had little variance, ranging from 11.3 scfh (Gas 4A) to 11.8 scfh (Gas 2 and Base Gas). The manifold and inlet pressure remained stable throughout the course of the test.

The drops in inlet pressure at the beginning of each gas run were the result of purging the gas supply hose before the gas meter.



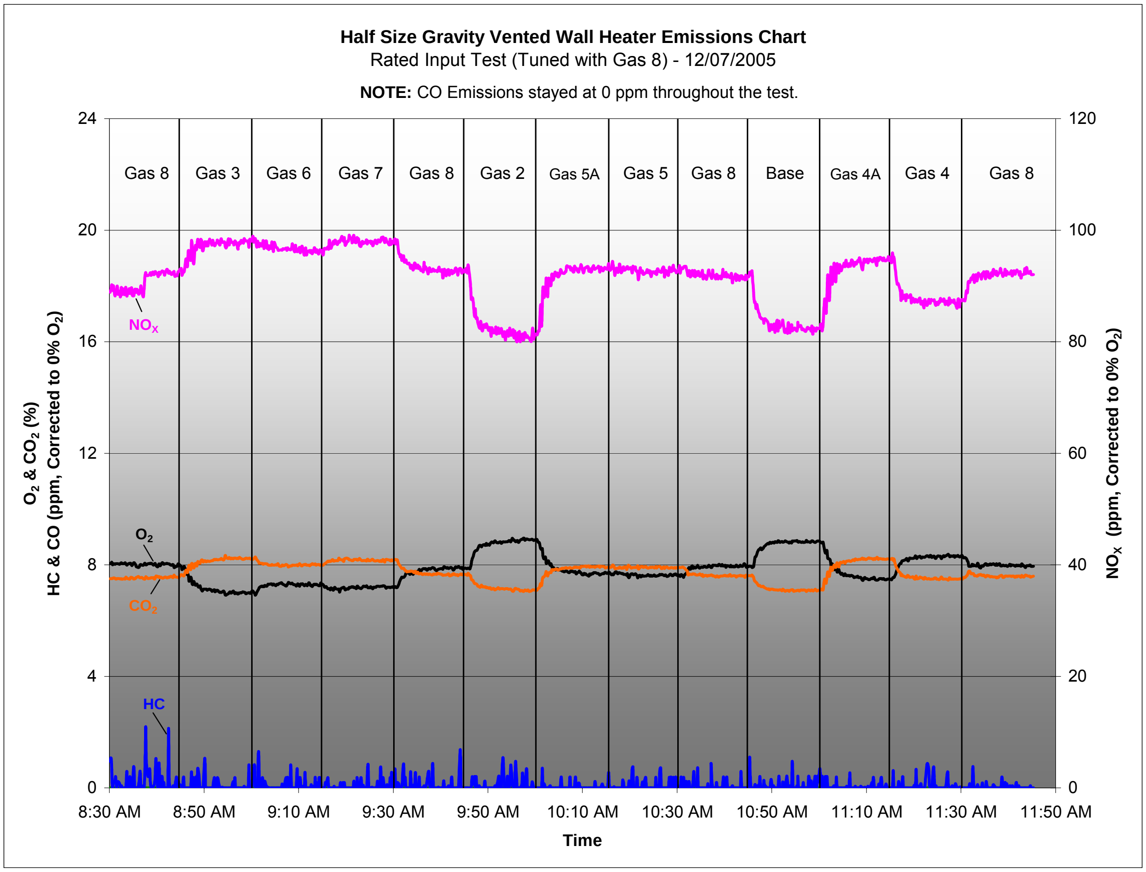
Temperatures

The flame temperature was highest with Gas 3 (1,545°F) and lowest with Base Gas and Gas 2 (1,450°F and 1,451°F, respectively). The back wall temperatures were 127.0 ± 4.0°F, stack temperatures were 364.0 ± 3.0°F and discharge air remained stable at 94.0 ± 5.0°F. Ambient and gas temperatures increased slightly as the test progressed but were stable at 74.0 ± 2.0°F.



Emissions

The NO_X emissions were highest with Gas 7 (97.9 ppm) and lowest with Gas 2 (83.1 ppm). Base Gas NO_X emissions were 83.7 ppm. CO_2 percentage and NO_X emissions curves followed the same pattern throughout the test; which was inversely proportional to the O_2 percentage curve. Both CO and HC emissions remained negligible throughout the course of the test.



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

Cold Ignition Test

For each set-up gas (Base Gas and Gas 8), the appliance 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 with 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 with 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 appliance 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 with 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 with 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:

ANSI Z21.86 - 2004	Vented Gas - Fired Space Heating Appliances
SCAQMD Method 100.1	Instrument Analyzer Procedures for Continuous Gaseous Emission Sampling

2. Equipment Description

Description	Half Size Direct Vented Wall Furnace with a steel heat exchanger
Burner	Cast iron atmospheric burner firing vertically into the heat exchanger
Maximum rated input	14,000 Btu/hr
Type of fuel	Natural Gas
Required inlet pressure	4.5 – 10.5 in. w.c.

3. Test Arrangement

3.1. Basic Setup

A test wall should be built as specified on Figure 6 of ANSI Z21.86 - 2004. The wall furnace shall be installed on the test wall as per the manufacturer's installation manual with minimum clearances of 5 inches to the adjacent side wall, 11 inches to the ceiling, and 1 ¾ inches to the floor.

3.2. Vent Pipe

The wall furnace vent pipe provided with the unit by the manufacturer is to be used. The emissions sample probe and three-point thermocouple grid (wired as a thermopile) must be constructed per SCAQMD Protocol.

3.3. Testing Instrumentation

Instrumentation must adhere as close as possible to the SCAQMD Method 100.1.

3.4. Temperatures and Pressures

Provide instrumentation to measure ambient, fuel (natural gas), wall, stack and discharge air temperatures. In addition, also provide instrumentation to measure inlet and manifold 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 additional thermocouple locations.

3.5. Special Measures - Windows & camera access
Cover pilot opening with a clear high temperature plastic material and utilize as a window to view the flame. Additional window or camera access will not be made because the gasket for the combustion area contains Asbestos.

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. Composition details are specified in Appendix C.

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

5. Basic Operating Condition

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

5.1. Room temperature

Room temperature shall be maintained between 65 - 85°F. The temperature shall be determined by means of 4 J-Type thermocouples, the junctions of which are shielded from radiation. These thermocouple junctions shall be located so room air temperature can be measured at points approximately 24 inches away from the approximate midpoints of each of the 4 sides of the appliance or test enclosure. The thermocouple leads shall be connected to a data logger, and room temperature shall be the average of the four individual temperature readings.

5.2. Test Pressures and Burner Adjustments

Unless otherwise stated, all tests will be conducted at normal inlet test pressure and normal input rate. Burner adjustments shall only be made after the appliance has been operated for 15 minutes from a cold start (i.e. all parts of the appliance are at room temperature) to verify the input rating. The burner input must be within ± 2% of the appliance's rated input. Primary air shall be set to give a good flame at this adjustment and neither burner ratings nor primary air adjustments shall be changed during a series of tests with any one test gas. Any adjustments resulting in an appreciable deposit of carbon during any of the tests specified shall not be acceptable.

5.3. Burner Operating Characteristics

Main burners and ignition devices shall be effectively ignited without delayed ignition or flashback when turned on and off at received and/or maximum allowable input rate and inlet test pressure, either manually or by a thermostatically actuated control device. When ignition is made, the flames shall not flash outside the appliance. The burners should ignite, operate and extinguish without any undue noise.

5.4. Pilot Burners and Safety Shutoff Devices

The pilot shall not deposit appreciable carbon during any test specified when adjusted according to the manufacturer's instructions. The pilot shall effect ignition of gas at the main burner port(s) (except for designed turn-off of intermittent or interrupted pilots) and shall not become extinguished and remain extinguished when the gas to the main burner(s) is turned off and on in a normal manner. The test shall be conducted for each type of gas using the following method of test:

Gas shall be admitted to the main burner(s) by turning on fully in a continuous movement any manual means provided for controlling main burner gas flow. At least 3 successive ignition tests shall be conducted with the main burner gas flow maintained for 30 seconds and interrupted for 30 seconds for each cycle.

Failure to affect ignition immediately after gas reaches the main burner port(s) in any one instance, or continued extinction of the pilot, shall be considered as noncompliance with this provision (Note: Test the unit with Gases 2 and 3 first. If it failed, retest with Gases 4A and 6). Any type of pilot equipped with an automatic igniter shall not cause excessive flame flash out or damage to the appliance.

5.5. Wall, Floor and Ceiling Temperatures

The temperatures on the surface of any exterior portion of the test walls and ceiling structures in contact with the wall furnace shall not be more than 117°F in excess of room temperature when the appliance is operated as required in the following test method. The temperatures of the back wall of the appliance, the test vent, on the floor under the appliance and for a distance of 18 inches in front of and to the sides of the appliance shall not be more than 90°F in excess of room temperature when the appliance is operated as required in the following method of test.

5.6. Flue Gas temperature

Under normal operating conditions, the average flue gas temperature of the wall furnace shall not exceed 380°F above room temperature. The flue gas temperature shall be determined by a grid of parallel-connected No. 24 AWG thermocouples, located at the flue outlet and connected to a data logger.

5.7. Temperature at Discharge Air Opening and Surface Temperature

Testing shall be conducted as specified in §8.7.1 of ANSI Z21.86 - 2004.

5.8. 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 wall furnace with Base Gas as received (i.e. with furnace gas regulator and manifold pressure as set by manufacturer/vender). Also, begin collecting temperature, pressure and emissions data while verifying proper operation of all equipment and instrumentation.

Continue steady furnace 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 furnace firing rate is <u>not</u> to be adjusted).

With the furnace 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 as indicated 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 the furnace 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 deposited soot in the appliance.

6.2. Rated Input (Tuned with Base Gas)

Tune the appliance with Base Gas to the maximum achievable input rate. Follow the same procedures as specified in the As Received Test above. 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 (Tuned with Gas 8)

Tune the appliance with Gas 8 to achieve the same input rate and similar performance as with Base Gas. Follow the same procedures as specified in the As Received Test.

7. Ignition Tests

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

7.1. Cold Ignition Test (Tuned with Base Gas)

With the appliance at room temperature and at the maximum achievable input rate observed 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 with Gas 8)

Follow the same procedure as Cold Ignition Test (Tuned w/ Base Gas) but substitute Base Gas with Gas 8.

7.3. Hot Ignition Test (Tuned with Base Gas)

With the appliance at steady state temperatures and at the maximum achievable input rate observed 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 with Gas 8)

Follow the same procedure as Cold Ignition Test (Tuned w/ Base Gas) but substitute Base Gas with Gas 8.

8. Special tests

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

9. Additional Testing

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

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

Appendix B: Tables of Averages

As Received Test (with Base Gas)

Table of Averages
Half Size Gravity Vented Wall Furnace
As Received Test (with Base Gas)
November 22, 2005

Gases	**Base**	**3**	**6**	**7**	**Base**	**2**	**5A**	**5**	**Base**	**8**	**4A**	**4**	**Base**
HHV (Btu/cf)	988	1,150	1,106	1,143	988	974	1,100	1,099	988	1,066	1,135	1,145	988
Wobbe (Btu/cf)	1,279	1,433	1,408	1,396	1,279	1,269	1,374	1,373	1,279	1,342	1,362	1,370	1,279
Input Rate (Btu/hr)	9,373	11,026	10,384	10,500	9,176	9,343	10,217	10,322	9,274	10,012	10,546	10,409	9,077
Corrected Gas Flow (scfh)	9.3	9.4	9.2	9.0	9.1	9.4	9.1	9.2	9.2	9.2	9.1	8.9	9.0
Emissions (not from certified tests)													
O_2 (%)	10.5	9.7	9.4	8.9	9.5	10.1	9.9	9.6	9.7	9.7	9.7	9.6	9.8
CO_2 (%)	6.0	6.5	6.7	7.0	6.6	6.2	6.4	6.6	6.5	6.5	6.6	6.7	6.5
CO (ppm @ 0% O_2)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HC (ppm @ 0% O_2)	1.2	1.0	1.0	1.1	1.2	1.0	1.0	0.7	0.7	1.0	0.8	0.7	0.8
NO_X (ppm @ 0% O_2)	68.4	75.9	78.6	83.0	78.6	72.4	74.2	76.0	74.9	75.9	75.1	75.6	73.2
Ultimate CO_2 (%)	12.0	12.1	12.1	12.2	12.1	12.1	12.2	12.2	12.2	12.2	12.3	12.3	12.3
Equivalence Ratio (Φ)	0.52	0.56	0.58	0.60	0.57	0.54	0.55	0.57	0.56	0.56	0.56	0.57	0.56
Temperatures (°F)													
Ambient	75.3	75.9	76.9	77.2	77.6	77.7	77.9	78.0	78.3	78.3	78.2	78.1	78.3
Gas	77.4	77.4	77.4	77.6	77.9	78.0	78.3	78.5	78.7	78.7	78.9	79.1	79.3
Stack	339.1	342.4	349.5	351.1	354.4	348.9	350.0	351.4	350.9	348.1	353.2	350.4	353.2
Flame	1,394	1,453	1,484	1,505	1,480	1,429	1,439	1,461	1,460	1,456	1,457	1,467	1,453
Back Wall	121.1	121.8	124.6	126.9	128.6	128.4	127.4	127.5	128.3	128.3	128.5	129.0	129.4
Side Wall	76.0	76.2	76.6	77.0	77.3	77.4	77.6	77.8	78.1	78.2	78.3	78.5	78.5
Upper Wall	92.1	92.3	92.9	93.6	94.1	94.1	94.0	94.4	95.2	95.5	96.0	96.3	96.5
Discharge Air	100.3	92.8	96.3	99.0	97.1	96.4	96.7	99.5	95.7	100.9	100.4	98.0	99.0
Fire Box	472.9	480.5	493.3	498.7	497.0	483.7	482.6	490.3	489.9	487.2	487.0	490.4	487.9
Pressures (in. w.c.)													
Inlet	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9
Manifold	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2

Rated Input Test (Tuned with Base Gas)

Table of Averages
Half Size Gravity Vented Wall Furnace
Rated Input Test (Tuned with Base Gas)
December 6, 2005

Gases	**Base**	**3**	**6**	**7**	**Base**	**2**	**5A**	**5**	**Base**	**8**	**4A**	**4**	**Base**
HHV (Btu/cf)	988	1,150	1,106	1,143	988	974	1,100	1,099	988	1,066	1,135	1,145	988
Wobbe (Btu/cf)	1,279	1,433	1,408	1,396	1,279	1,269	1,374	1,373	1,279	1,342	1,362	1,370	1,279
Input Rate (Btu/hr)	11,017	12,440	12,024	12,035	10,654	10,760	11,914	11,761	10,755	11,533	11,900	12,074	10,668
Corrected Flow (scfh)	11.2	10.8	10.9	10.5	10.8	11.0	10.8	10.7	10.9	10.8	10.5	10.5	10.8
Emissions (not from certified tests)													
O_2 (%)	8.5	6.8	6.6	6.6	8.0	8.4	7.3	7.0	8.0	7.5	6.9	7.5	8.2
CO_2 (%)	7.3	8.4	8.4	8.6	7.6	7.4	8.2	8.4	7.6	7.9	8.6	8.0	7.5
CO (ppm @ 0% O_2)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HC (ppm @ 0% O_2)	0.4	0.4	0.4	0.3	0.5	0.4	0.4	0.3	0.5	0.3	0.3	0.3	0.3
NO_X (ppm @ 0% O_2)	85.8	102.2	104.0	105.6	91.0	86.2	98.1	99.9	89.8	97.2	100.6	94.1	88.3
Ultimate CO_2 (%)	12.3	12.4	12.3	12.5	12.4	12.4	12.6	12.5	12.4	12.3	12.8	12.4	12.4
Equivalence Ratio (Φ)	0.62	0.70	0.70	0.71	0.64	0.62	0.68	0.69	0.64	0.67	0.69	0.65	0.63
Temperatures (°F)													
Ambient	69.7	70.8	71.5	71.9	72.4	72.7	73.1	73.4	74.0	74.5	74.7	75.0	75.2
Gas	70.8	71.0	71.6	72.1	72.6	72.8	73.3	73.7	74.0	74.3	74.6	74.8	75.0
Stack	351.7	360.7	362.5	361.4	355.8	354.5	358.4	359.7	356.1	357.2	359.6	357.4	354.9
Flame	1,521	1,620	1,638	1,638	1,558	1,531	1,592	1,615	1,555	1,584	1,613	1,583	1,555
Back Wall	112.6	117.9	123.8	126.6	127.7	125.7	125.5	128.1	128.9	128.0	129.4	130.7	130.3
Side Wall	69.9	70.8	71.5	72.2	72.6	72.8	73.1	73.6	74.1	74.3	74.6	74.8	75.1
Upper Wall	81.0	84.0	86.0	87.5	88.7	89.2	89.5	90.1	90.6	90.9	91.3	91.7	92.1
Discharge Air	89.8	88.7	87.6	90.5	93.7	90.4	93.5	93.9	92.8	93.4	93.4	92.8	93.5
Pressures													
Inlet (in. w.c.)	8.3	8.3	8.3	8.2	8.3	8.2	8.1	8.3	8.2	8.2	8.2	8.2	8.2
Manifold (in. w.c.)	4.2	4.2	4.2	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3

Rated Input Test (Tuned with Gas 8)

Table of Averages
Half Size Gravity Vented Wall Furnace
Rated Input Test (Tuned with Gas 8)
December 7, 2005

Gases	**8**	**3**	**6**	**7**	**8**	**2**	**5A**	**5**	**8**	**Base**	**4A**	**4**	**8**
HHV (Btu/cf)	1,066	1,150	1,106	1,143	1,066	974	1,100	1,099	1,066	988	1,135	1,145	1,066
Wobbe (Btu/cf)	1,342	1,433	1,408	1,396	1,342	1,269	1,374	1,373	1,342	1,279	1,362	1,370	1,342
Input Rate (Btu/hr)	12,323	13,365	12,926	12,967	12,244	11,519	12,705	12,622	12,387	11,673	12,873	13,147	12,273
Corrected Gas Flow (scfh)	11.6	11.6	11.7	11.3	11.5	11.8	11.6	11.5	11.6	11.8	11.3	11.5	11.5
Emissions (not from certified tests)													
O_2 (%)	8.0	7.2	7.3	7.2	7.8	8.7	7.9	7.6	7.9	8.7	7.7	8.2	8.0
CO_2 (%)	7.5	8.1	8.0	8.2	7.7	7.2	7.8	7.9	7.7	7.2	8.0	7.6	7.6
CO (ppm @ 0% O_2)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HC (ppm @ 0% O_2)	0.3	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.0
NO_X (ppm @ 0% O_2)	90.7	97.1	96.8	97.9	93.5	83.1	91.5	92.8	92.0	83.7	92.8	88.2	91.7
Ultimate CO_2 (%)	12.2	12.3	12.3	12.4	12.3	12.3	12.5	12.5	12.3	12.3	12.7	12.4	12.3
Equivalence Ratio (Φ)	0.64	0.68	0.68	0.68	0.65	0.61	0.65	0.66	0.65	0.61	0.65	0.64	0.64
Temperatures (°F)													
Ambient	71.6	72.2	73.2	73.3	73.4	73.8	74.1	74.5	74.7	74.8	74.8	74.9	74.8
Gas	71.9	72.4	73.0	73.4	73.8	74.2	74.5	74.9	75.1	75.4	75.6	75.7	75.8
Stack	362.1	366.0	366.3	365.9	364.9	361.3	362.8	364.6	365.0	363.5	366.2	365.4	363.7
Flame	1,496	1,545	1,543	1,542	1,511	1,451	1,497	1,515	1,502	1,450	1,510	1,483	1,492
Back Wall	120.0	123.2	126.9	127.8	128.5	127.7	126.5	128.0	128.9	128.5	127.8	129.2	129.0
Side Wall	71.8	72.5	73.3	73.7	73.9	74.2	74.3	74.7	75.0	75.2	75.2	75.6	75.7
Upper Wall	89.2	90.9	92.4	92.9	93.8	94.3	94.4	95.2	95.7	95.6	95.2	95.9	95.5
Discharge Air	92.2	89.3	92.2	98.5	95.0	95.4	96.8	94.5	95.9	89.8	92.1	93.1	91.1
Pressures (in. w.c.)													
Inlet	8.4	8.3	8.3	8.3	8.3	8.4	8.4	8.3	8.3	8.3	8.0	8.3	8.3
Manifold	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	4.0	3.9	3.9

Appendix C: Test Gases

Gas Sample Date	Baseline 8/1/2005	2 8/5/2004	3 7/1/2005	4 8/5/2004	4A 7/15/2005	5 8/18/2004	5A 7/19/2004	6 7/1/2005	7 6/20/2005	8 8/5/2005
COMPONENTS	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**
C6 + 57/28/14	0.025	0.031	0.000	0.186	0.014	0.074	0.044	0.000	0.023	0.001
NITROGEN	2.704	1.087	0.128	1.061	1.117	0.800	0.778	0.274	3.025	3.839
METHANE	93.393	95.871	86.549	84.971	85.103	88.814	90.809	91.168	86.466	89.998
CARBON DIOXIDE	1.595	2.997	0.035	3.001	3.079	1.407	1.413	0.003	0.034	0.120
ETHANE	1.454	0.000	9.480	4.785	0.000	5.299	0.023	5.747	0.312	0.000
PROPANE	0.321	0.014	2.725	2.402	10.588	2.605	6.918	1.727	9.946	5.997
i-BUTANE	0.062	0.000	1.034	1.194	0.044	0.002	0.011	0.534	0.094	0.041
n-BUTANE	0.059	0.000	0.000	1.207	0.025	0.842	0.005	0.531	0.061	0.000
NEOPENTANE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
i-PENTANE	0.019	0.000	0.000	0.594	0.004	0.157	0.000	0.000	0.019	0.001
n-PENTANE	0.013	0.000	0.000	0.600	0.004	0.000	0.000	0.000	0.016	0.001
OXYGEN	0.356	0.000	0.049	0.000	0.021	0.000	0.000	0.016	0.004	0.003
TOTAL	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**
Compressibility Factor	0.9979	0.9980	0.9972	0.9969	0.9970	0.9974	0.9974	0.9975	0.9971	0.9976
HHV (Btu/real cubic foot)	**987.80**	**974.40**	**1150.00**	**1145.13**	**1135.30**	**1099.38**	**1099.82**	**1106.00**	**1142.00**	**1066.30**
LHV (Btu/real cubic foot)	890.00	877.27	1039.90	1035.92	1027.50	993.10	993.61	998.90	1033.40	963.10
Specific Gravity	0.5968	0.5895	0.6442	0.6989	0.6946	0.6407	0.6410	0.6167	0.6697	0.6312
WOBBE Index	**1278.66**	**1269.12**	**1432.81**	**1369.72**	**1362.21**	**1373.49**	**1373.72**	**1408.37**	**1395.49**	**1342.13**

Appendix D: Zero, Span and Linearity Tables

As Received Test (with Base Gas)

	Zero, Span & Linearity Data Half Size Gravity Vented Wall Heater As Received Test (with Base Gas) November 22, 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 -12:16:20 PM	0.09	0.06	0.8	0.24	0.15
	Zero Drift Check - 15:31:43 PM	0.08	0.08	0.05	0.18	0.43
	Total Drift Over Test Period	**0.01**	**0.02**	**0.75**	**0.06**	**0.28**
	Was the Zero Drift Within Allowable Deviation?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Span	**Span Calibration Gas (High-Range Values)**	**20.10**	**11.99**	**181.00**	**443.00**	**85.20**
	Allowable Span Drift (Less Than ± 3% of Range)	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
	Span Calibration -12:29:25 PM	20.11	12.06	181.33	443.17	85.60
	Span Drift Check - 15:28:36 PM	20.09	12.06	181.00	442.99	87.34
	Total Drift Over Test Period	**0.02**	**0.00**	**0.33**	**0.18**	**1.74**
	Was the Span Drift Within Allowable Deviation?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**8.97**	**9.22**	**82.00**	**443.00**	**44.70**
	Allowable Linearity Drift (Less Than ±1% of Range)	**0.25**	**0.20**	**2.00**	**10.00**	**1.00**
	Linearity Check - 8:02:34 AM	8.99	9.37	80.68	441.39	44.18
	Difference From Mid-Range Values	**0.02**	**0.15**	**1.32**	**1.61**	**0.52**
	Was the Linearity Within Allowable Deviation?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

Rated Input Test (Tuned with Base Gas)

	Zero, Span & Linearity Data Half Size Gravity Vented Wall Heater Rated Input Test (Tuned with Base Gas) December 6, 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**
Zero	**Allowable Zero Drift (Less Than ± 3% of Range)**	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
Zero	Zero Calibration -7:50:48 AM	0.08	0.06	0.39	0.01	0.15
Zero	Zero Drift Check - 1:09:20 PM	0.06	0.14	-3.72	-0.24	0.90
Zero	**Total Drift Over Test Period**	**0.02**	**0.08**	**4.11**	**0.25**	**0.75**
Zero	**Was the Zero Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Span	**Span Calibration Gas (High-Range Values)**	**20.10**	**11.99**	**181.00**	**443.00**	**85.20**
Span	**Allowable Span Drift (Less Than ± 3% of Range)**	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
Span	Span Calibration 7:59:46 PM	20.29	12.06	181.59	443.90	85.64
Span	Span Drift Check - 12:57:39 PM	20.42	12.14	179.13	450.21	85.76
Span	**Total Drift Over Test Period**	**0.13**	**0.08**	**2.46**	**6.31**	**0.12**
Span	**Was the Span Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**8.97**	**9.22**	**82.00**	**443.00**	**44.70**
Linearity	**Allowable Linearity Drift (Less Than ±1% of Range)**	**0.25**	**0.20**	**2.00**	**10.00**	**1.00**
Linearity	Linearity Check - 08:10:13 AM	9.14	9.44	78.10	444.19	44.03
Linearity	**Difference From Mid-Range Values**	**0.17**	**0.22**	**3.90**	**1.19**	**0.67**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**No**	**No**	**Yes**	**Yes**
Linearity	Linearity Check - 01:03:32 PM	9.13	9.46	77.17	449.26	44.33
Linearity	**Difference From Mid-Range Values**	**0.16**	**0.24**	**4.83**	**6.26**	**0.37**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**No**	**No**	**Yes**	**Yes**

Rated Input Test (Tuned with Gas 3)

	Zero, Span & Linearity Data Half Size Gravity Vented Wall Heater Rated Input Test (Tuned with Gas 8) December 7, 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**
Zero	**Allowable Zero Drift (Less Than ± 3% of Range)**	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
Zero	Zero Calibration -7:29:38 AM	0.08	0.06	0.02	0.12	0.06
Zero	Zero Drift Check - 12:00:51 PM	0.07	0.13	-0.87	-0.78	0.78
Zero	**Total Drift Over Test Period**	**0.01**	**0.07**	**0.89**	**0.90**	**0.72**
Zero	**Was the Zero Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Span	**Span Calibration Gas (High-Range Values)**	**20.10**	**11.99**	**181.00**	**443.00**	**85.20**
Span	**Allowable Span Drift (Less Than ± 3% of Range)**	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
Span	Span Calibration 7:39:25 AM	20.19	12.06	183.05	442.53	85.71
Span	Span Drift Check - 11:52:29 AM	20.10	12.17	182.11	440.88	86.20
Span	**Total Drift Over Test Period**	**0.09**	**0.11**	**0.94**	**1.65**	**0.49**
Span	**Was the Span Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**8.97**	**9.22**	**82.00**	**443.00**	**44.70**
Linearity	**Allowable Linearity Drift (Less Than ±1% of Range)**	**0.25**	**0.20**	**2.00**	**10.00**	**1.00**
Linearity	Linearity Check - 07:46:41 AM	9.02	9.41	80.62	442.23	43.38
Linearity	**Difference From Mid-Range Values**	**0.05**	**0.19**	**1.38**	**0.77**	**1.32**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**No**
Linearity	Linearity Check - 11:57:19 AM	8.99	9.48	80.43	440.99	43.92
Linearity	**Difference From Mid-Range Values**	**0.02**	**0.26**	**1.57**	**2.01**	**0.78**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**No**	**Yes**	**Yes**	**Yes**

Appendix E: Calculations

Emission Concentrations

Corrected to O_2 Standard (3% O_2)

$$\text{CO, HC \& NO}_x \text{ Concentrations (corrected to 3\% O}_2\text{)} = \text{Raw Concentrations (ppm)} \times \left[\frac{20.9 - 3}{20.9 - \%\,O_2} \right]$$

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 below lists the constituents found in natural gas, the balanced chemical equations for each constituent and their respective theoretical air and theoretical flue gas molar quantities.

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

The theoretical air value for each constituent is the sum of moles for both O_2 and N_2 on the reactants side of the balanced chemical equation (ex: For Methane, 2 moles of O_2 plus 7.56 moles of N_2 = 9.56 moles of Theoretical Air). The theoretical flue value for each constituent is the sum of moles for both CO_2 and N_2 on the product side of the balanced chemical equation (ex: For Methane, 1 mole of CO_2 plus 7.56 moles of N_2 = 8.56 moles of Theoretical Flue Gas).

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

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

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

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:

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

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 an average 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 average 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.

2 CU. FT. BELL NO. 4087 CPUC CERTIFICATE OF BELL PROVER ACCURACY # 1004							
Model Number: DTM-200A **Meter Number:** U258696				**Date:** August 1, 2004 **Prepared By:** Joe Garcia			
Prover Flow Rate cfh	**Gas Meter Error Percentage** Test #1	Test #2	Test #3	Test #4	Test #5	**Average Meter Error**	**Gas Meter Flow Rate** cfh
50	0.78%	0.67%	0.48%	0.58%	0.53%	**0.61%**	**50.30**
100	0.57%	0.58%	0.66%	0.72%	0.66%	**0.64%**	**100.64**
150	0.85%	0.84%	0.95%	1.18%	1.11%	**0.99%**	**151.48**
200	0.78%	1.03%	0.90%	0.87%	0.88%	**0.89%**	**201.78**

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 the average 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 110.0 actual cubic feet per hour (acfh), the gas meter flow rate range would be 100.64 to 151.48 acfh and the average meter error range (divided by 100) would be 0.0064 to 0.0099. Using this information, the meter error (y) is:

$$y = \frac{0.0099 - 0.0064}{151.48\ \text{acfh} - 100.64\ \text{acfh}}(110.0\ \text{acfh} - 100.64\ \text{acfh}) + 0.0064 = 0.007021$$

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

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

$$F_{meter} = \frac{110.0\ \text{acfh}}{(1 + 0.007021)} = 109.2331\ \text{acfh}$$

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 supply pressure (psig)

P_1 = Average pressure in Pico Rivera at an average elevation of 161 ft (psia)

$P_{standard}$ = Standard atmospheric pressure (14.735 psia @ 60°F)

$T_{standard}$ = Standard atmospheric temperature (519.67 R @ 1 atm)

T_{Fuel} = Fuel temperature (°F)

Input Rate (Btu/cf)

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

Where

HHV = Higher Heating Value (Btu/cf)

Wobbe Number (Btu/cf)

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

Where

W_0 = Wobbe Number (Btu/cf)

HHV = Higher Heating Value (Btu/cf)

G = Specific gravity of gas sample

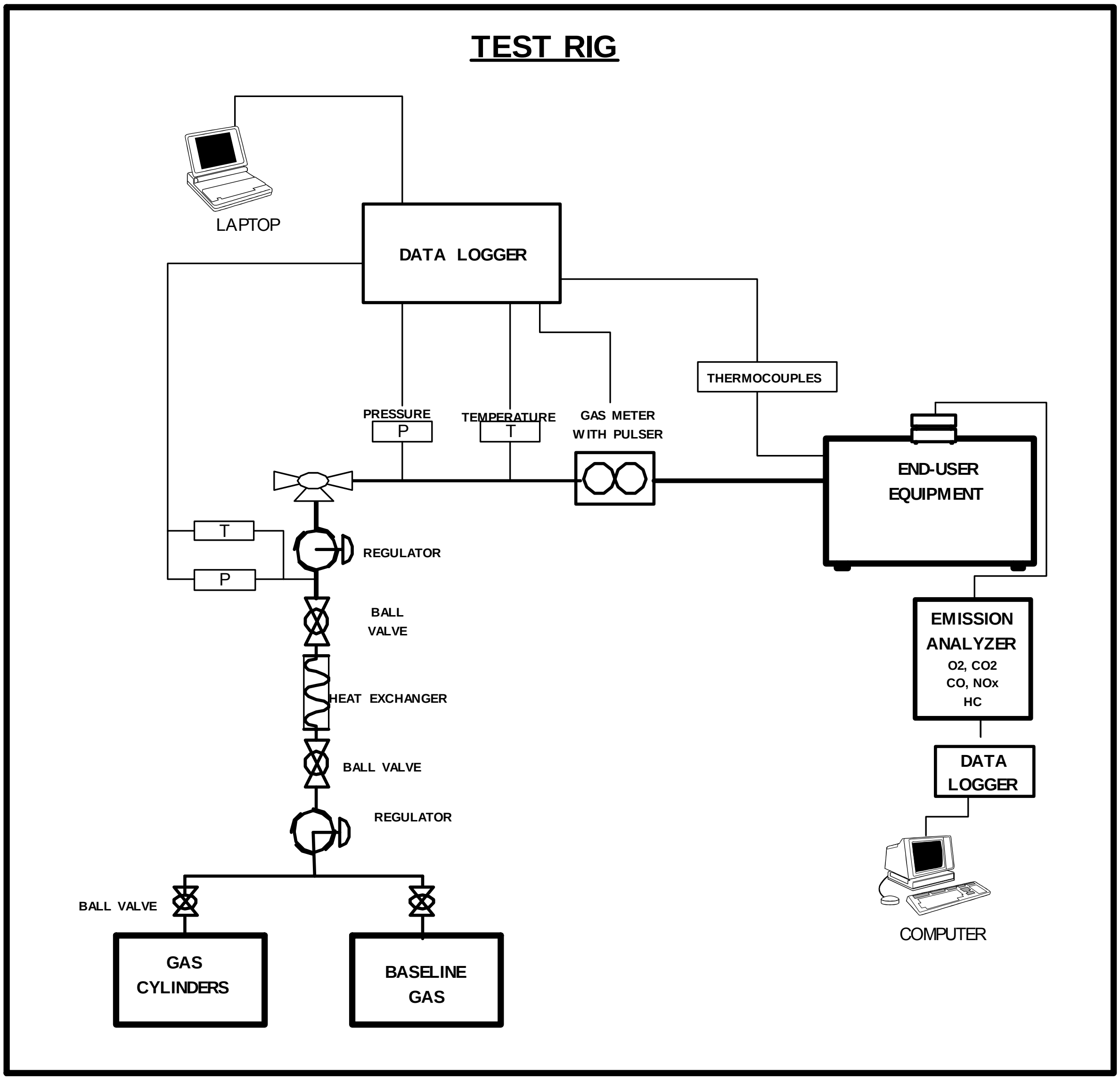
Appendix F: Test Equipment

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

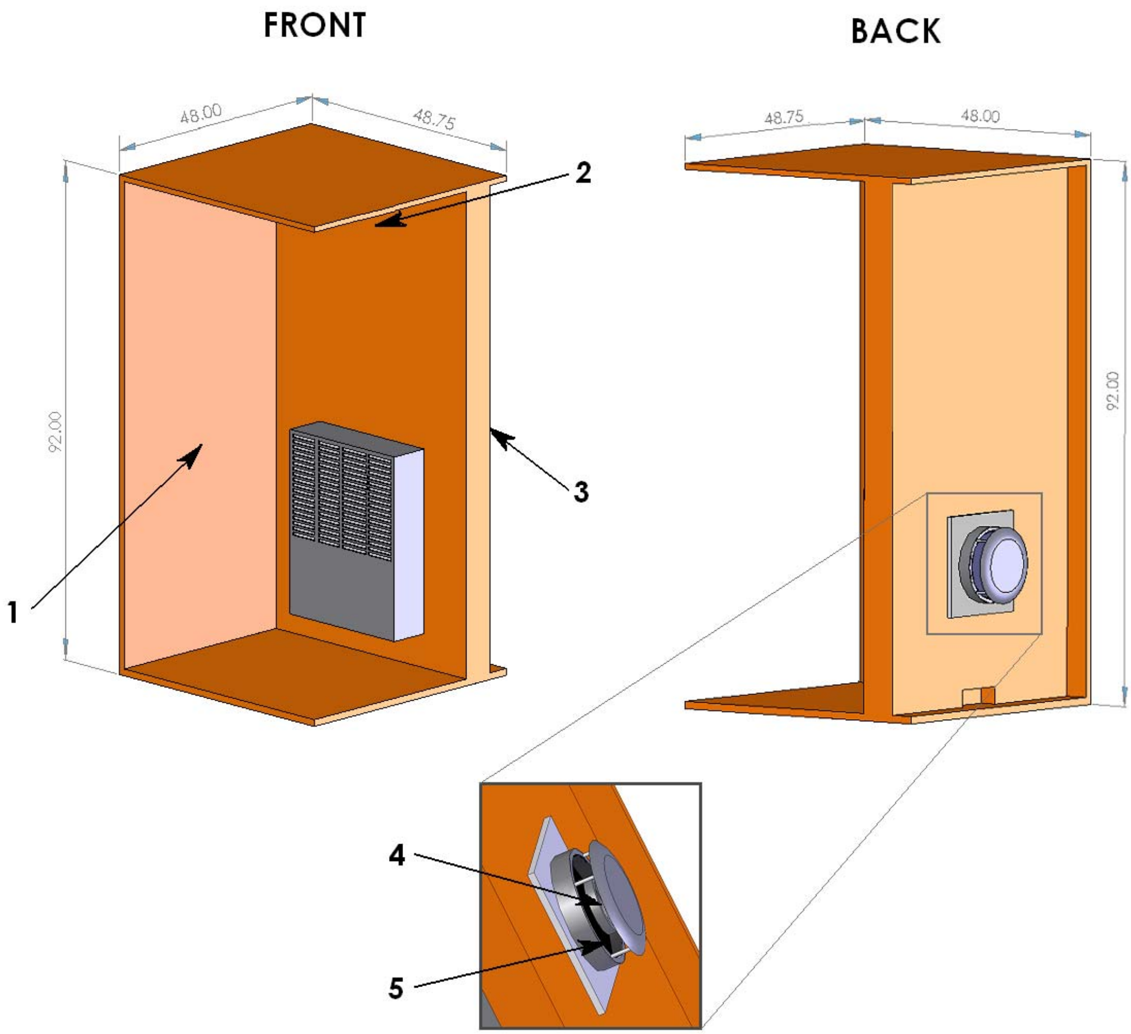
Emissions Analyzer				
Analyzer	Manufacturer	Model	Type	Accuracy
NO/NO_X	Thermo Environmental Instruments Inc.	10AR	Chemiluminescent	± 1% of full scale
CO	Thermo Environmental Instruments Inc.	48	Nondispersive infrared (NDIR) gas analyzer	± 1% of full scale
CO_2	Fuji	ZRH	Nondispersive infrared (NDIR) gas analyzer	± 1% of full scale
HC	California Analytical Instruments, Inc.	300 HFID	Flame ionization detector (FID)	± 1% of full scale
O_2	Teledyne	326RA	Electrochemical cell	± 1% of full scale
Calibration & Span Gases				
Gas	Manufacturer	Type		Accuracy
Calibration	Scott Specialty Gases	Certified Master Class - 0 %		± 2%
NO/NO_X	Scott Specialty Gases	Certified Master Class - 18.95 ppm		± 2%
CO	Scott Specialty Gases	Certified Master Class - 79.3 ppm		± 2%
CO_2	Scott Specialty Gases	Certified Master Class -12.1 %		± 2%
HC	Scott Specialty Gases	Certified Master Class - 0.5 ppm		± 2%
O_2	Scott Specialty Gases	Certified Master Class - 9.1 %		± 2%
Test Equipment				
Equipment	Manufacturer		Model	Accuracy
Datalogger	Delphin		D51515	n/a
Gas Chromatograph	Agilent		6890	± 0.5 BTU/scf
K	Omega Engineering Co.		KMQSS	2.2°C or 0.75%
J	Omega Engineering Co.		JMQSS	2.2°C or 0.75%
T	Omega Engineering Co.		TMQSS	2.2°C or 0.75%
Dry Test Gas Meter 200 cf/h max	American Meter Company		DTM-200A	@ 200 cf/h – 100.1 % @60 cf/h – 99.9 %
Gas Meter Pulser 2 pulses per 1/10 cf	Rio Tronics		4008468	n/a
Gas Pressure Regulator	Fisher		299H	± 1.0 %
Differential Pressure Transmitter	Dwyer		607-4	±0.25 -0.50%
Pressure Transducer	Omega		PX205-100GI	±0.25% of full scale

Appendix G: Test Set-Up/Schematic

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



Appendix H: Half Size Wall Furnace Setup



1	**Side Wall Temperature**
2	**Upper Wall Temperature**
3	**Back Wall Temperature**
4	**Exhaust Gas Discharge**
5	**Inlet Air to Burner**