LNG Research Study

Instantaneous Water Heater

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Disclaimer

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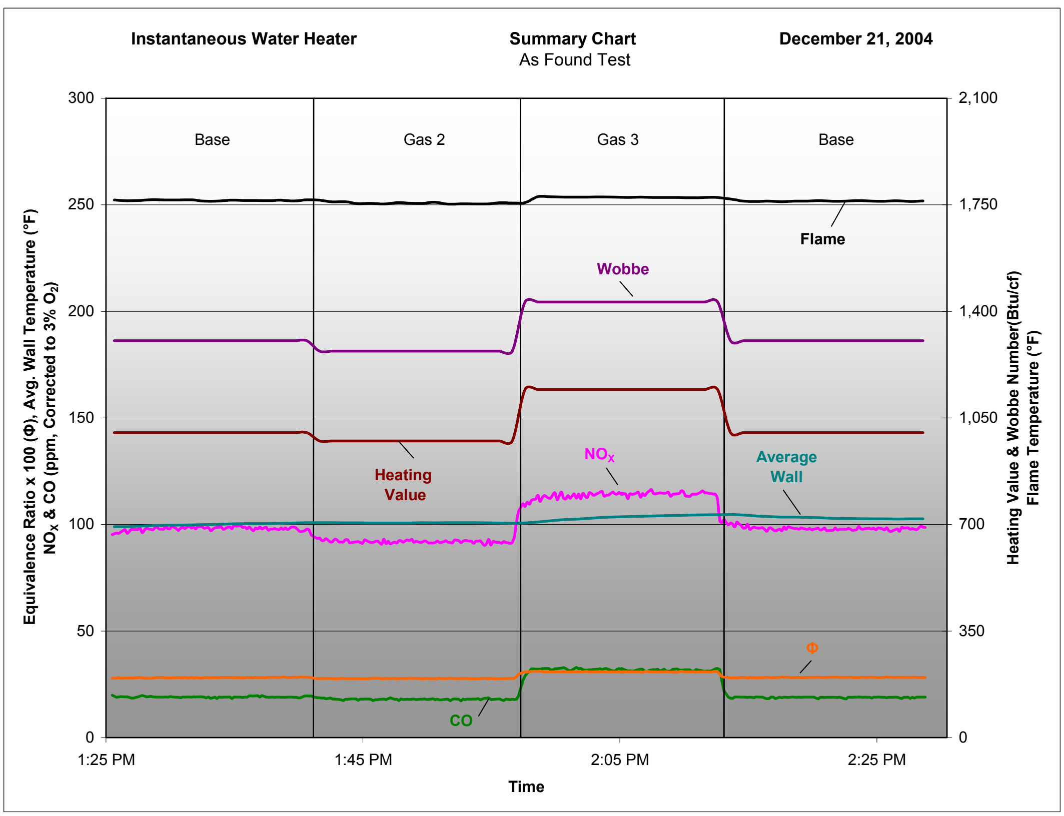
Results Summary

During a demonstration experiment performed with this unit, emissions results contradicted initial CO emissions findings. Closer analysis determined that the pressure regulator located downstream of the Gas Delivery System was defective. This pressure regulator is interchangeable and was only used during the first set of testing. After this problem was fixed, a second set of tests were conducted to address contradictions in CO emissions results.

Results obtained from the second set of tests at normal supply pressure revealed that (a) There were no operational, ignition or flame stability problems with any of the test gases; (b) Stack temperature, flame length, orange tinting of the flame, average NO_X and CO emissions values equivalence ratio followed the same pattern as the Wobbe Number and (d) Average CO emissions values were below 84 ppm and average NO_x emissions values were above 90 ppm for all tests performed.

As Found Test

Results reveal average CO emissions values were below 35 ppm (corrected to 3% O_2), average NO_X emissions values exceeded 91 ppm (corrected to 3% O_2) and flame temperature ranged between 1,756°F and 1,774°F for all gases tested.

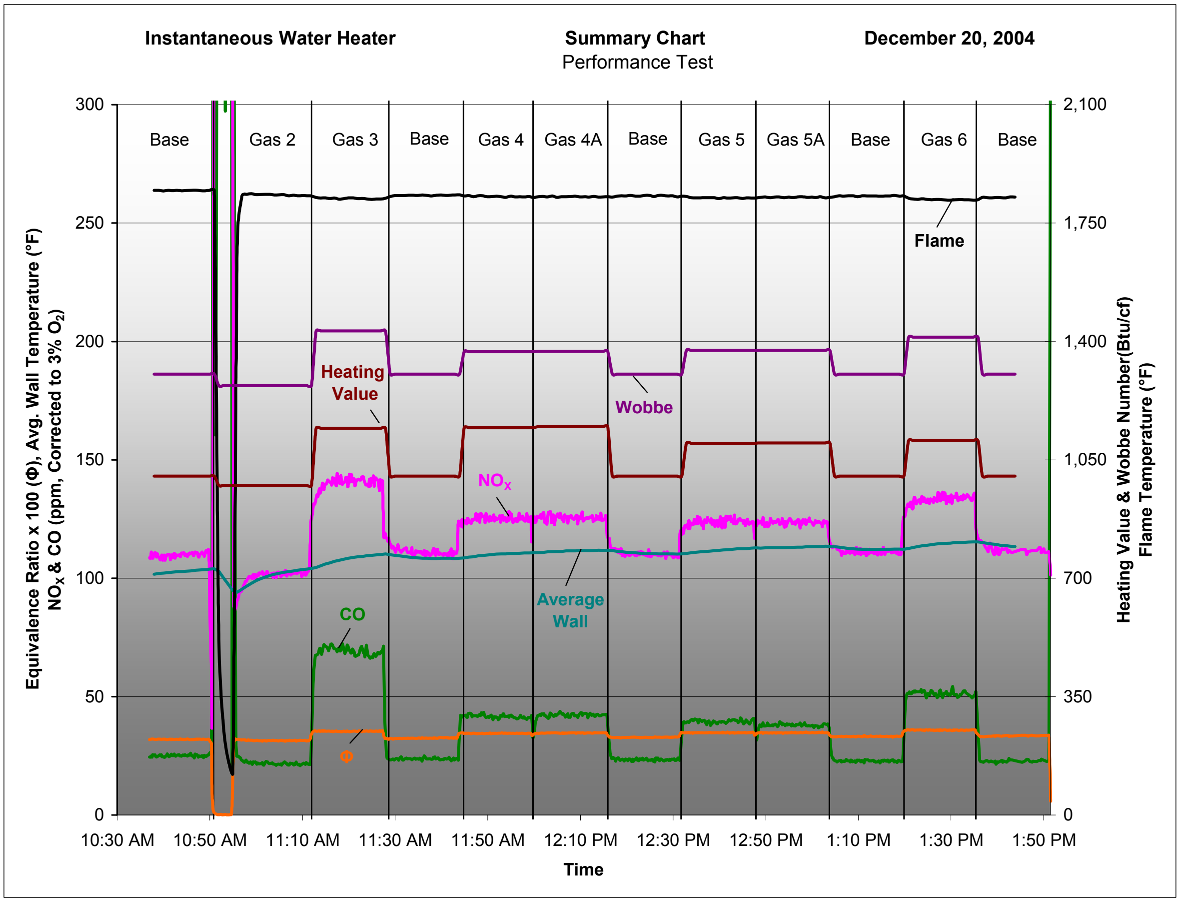


NOTE: Emission test results are for information purposes. They were not the result of certified tests.

Performance Test

Average CO emissions values did not exceed 66 ppm (corrected to 3% O_2), average NO_x emissions values exceeded 100 ppm (corrected to 3% O_2) and flame temperatures ranged from 1,823°F and 1,846°F for all gases tested

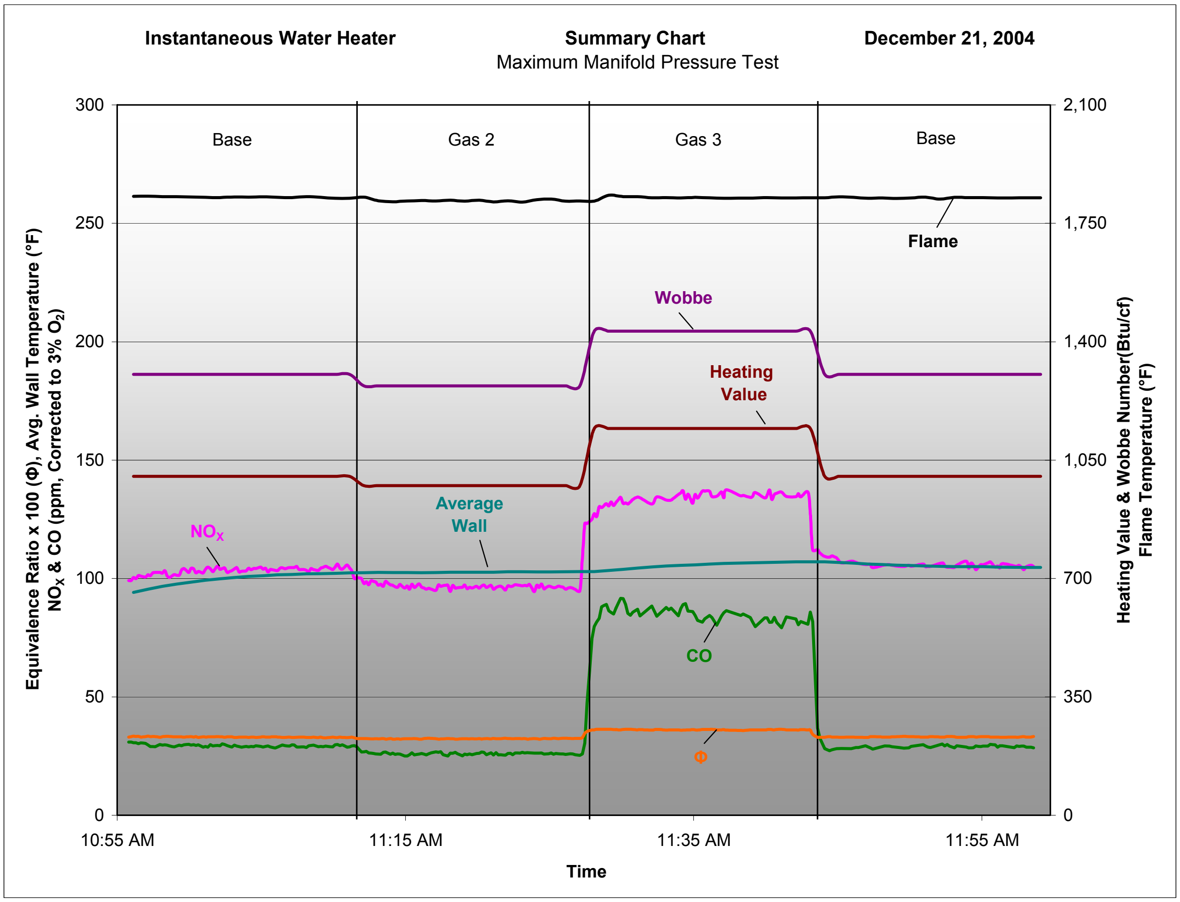
A closed valve in the second Gas Delivery System (GDS) caused the instantaneous water heater shut off at the beginning of Gas 2 run.



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

Maximum Manifold Pressure Test

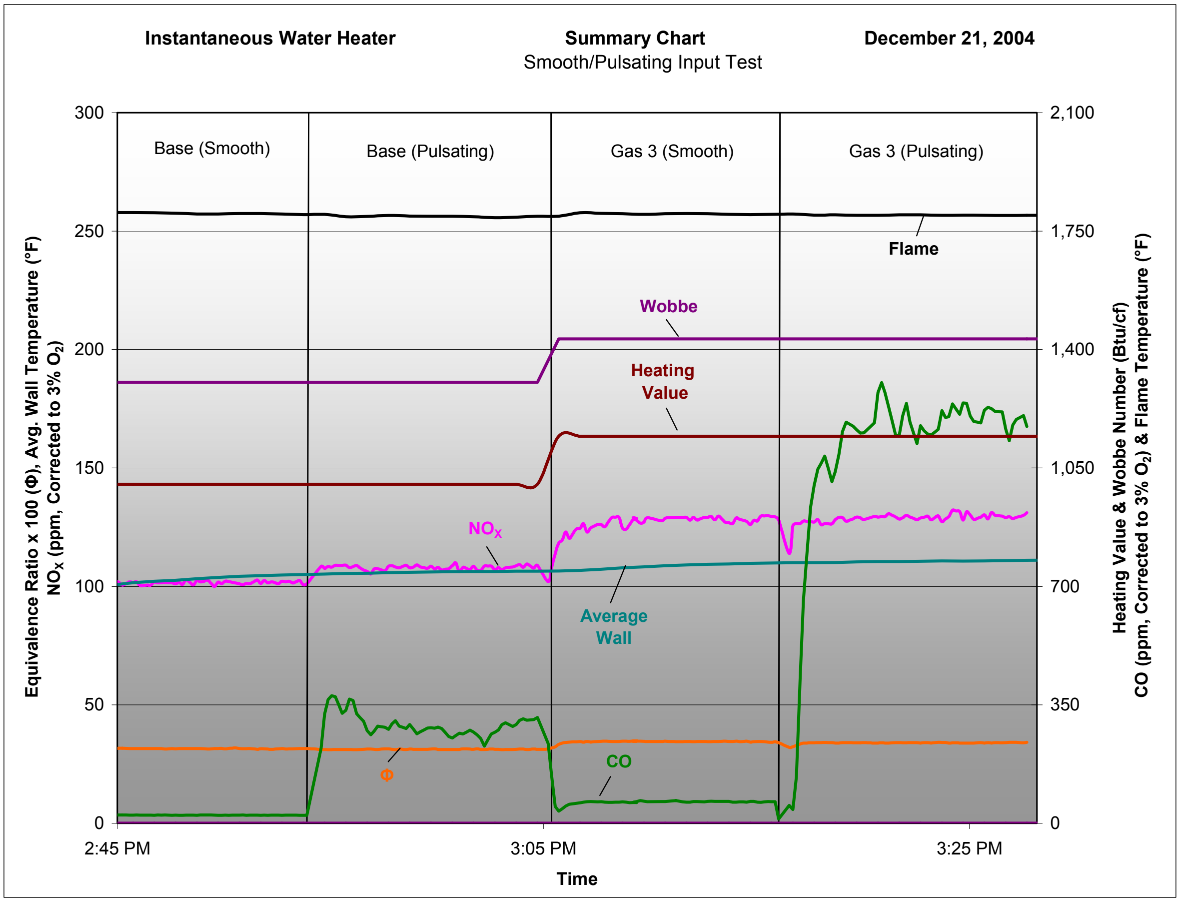
Average NO_X and CO emissions values (corrected to 3% O_2) decreased with Gas 2 but increased with Gas 3. Flame temperature ranged between 1,817°F and 1,828°F. The input recorded with Baseline Gas at the maximum achievable manifold pressure was 120,089 Btu/hr, which is 2.6% higher than the rated input. This test was not meant to be the over fire test required by ANSI standards; which is 6.25% over the rated input.



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

Smooth/Pulsating Input Test

CO emissions values were critically sensitive to fluctuations in supply pressure. Average CO emissions values for Baseline Gas and Gas 3 Smooth Runs were below 63 ppm; however, average CO emissions values for Baseline Gas and Gas 3 Pulsating Runs were 290 ppm and 1,095 ppm. The pulsating supply pressure did not affect average NO_X emissions values.



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

Equipment Selection Criteria

Initial data presented by manufacturers of instantaneous water heaters indicated that these units should operate properly with gases with a higher heating value ranging from 994 Btu/cf (Wobbe 1301 Btu/cf) to 1315 Btu/cf (Wobbe 1567 Btu/cf). These high-end units have a computer control system that adjusts the input rate and air flow, thus maintaining a fairly constant air to fuel ratio, depending on the outlet water temperature. The unit selected is a low-end unit sold in our service territory that doesn't have the computer control system. This unit uses a high firing intensity atmospheric burner (~ 1,835 Btu/hr-in^2) and the unit is very compact - like typical instant water heaters. As a result, this instantaneous water heater may have the following issues with high-energy content gases: 1) A longer flame can easily be quenched by the heat exchanger and generate high CO or damage the heat exchanger, 2) If the flame shape and spacing between the flames change, combustion equilibrium may be altered; increasing CO and NO_X emissions values, 3) CO and NO_X emissions can easily increase since the amount of combustion air is fixed, and 4) The cabinet temperatures can increase above what is recommended by the manufacturer.

In addition, this unit was selected because it is the only instantaneous water heater sold in Southern California with an atmospheric burner that has the SCAQMD low NO_X approval. Rule 1146.2 limits NO_X and CO on water heaters ranging from 75,000 to 400,000 Btu/hr. The ANSI Z21.10.3 and UL standards cover safety, construction and performance, which have a combustion section that limits the CO emissions.

Equipment Specification

- **Description:** Automatic Instantaneous Water Heater
- **Burner:** High firing intensity atmospheric burner
- **Maximum input rating:** ~117,000 Btu/hr
- **Minimum input rating:** ~28,000 Btu/hr
- **Type of fuel:** Natural Gas
- **Required gas supply pressure:** 7" w.c.

Standards

A detailed description of the protocol and some of the rationale used to develop the test procedures are included in Appendix A. The test protocol was developed based on the following test standards.

- ANSI Z21.10.3, Standard for Gas-Fired Water Heaters Volume III. Storage, with Input Rating above 75,000 Btu/hr, Circulating and Instantaneous Water Heaters.
- South Coast Air Quality Management District Rule 1146.2, Emission of NO_X from Large Water Heaters and Small Boilers, adopted January 9, 1998.
- South Coast Air Quality Management District Protocol, NO_X Compliance Testing for Natural Gas-fired Water Heaters and Small Boilers, last amended January 1998.
- South Coast Air Quality Management District – Instrumental analyzer procedure for continuous gaseous emissions - District Method 100.1.

Installation

The water heater was installed according to the manufacturer specifications for indoor installation. The heater outlet water temperature was set at 135 ± 5°F to insure steady state operation and prevent cycling while performing the tests.

Instrumentation was installed following the above test standards and input from consultants. Thermocouples were installed to measure flame, inlet and outlet water, flue gas, ambient and gas temperatures. Also, top and bottom back wall temperatures were measured throughout the test. Pressure transducers were installed to measure manifold and supply pressures. A gas meter was set to measure the gas flow and an emissions probe was built and placed in the flue vent of the heater.

Test Gases

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

- **Baseline Gas** (Gas 1) - Low Wobbe (1,330 Btu/cf), low heat content gas (1,002 Btu/cf)
- **Gas 2** - Lowest-Wobbe (1,269 Btu/cf), lowest-heat content gas (974 Btu/cf)
- **Gas 3** - Highest-Wobbe (1,431 Btu/cf), highest-heat content gas (1,143 Btu/cf)
- **Gas 4** - Medium-Wobbe (1,370 Btu/cf), highest-heat content gas (1,145 Btu/cf)
- **Gas 4A** (4 component mix) - Medium-Wobbe (1,371 Btu/cf), highest-heat content gas (1,148 Btu/cf)
- **Gas 5** - Medium-Wobbe (1,374 Btu/cf), high-heat content gas (1,099 Btu/cf)
- **Gas 5A** (4 component mix) - Medium-Wobbe (1,374 Btu/cf), high-heat content gas (1,100 Btu/cf)
- **Gas 6** - High Wobbe (1,413 Btu/cf), high-heat content gas (1,107 Btu/cf)

Re-Test Procedure

Test Procedures were developed following the above test standards. When the test standards were difficult to meet due to limited resources and time restrictions, input from manufacturers and consultants was requested to determine simplified test alternatives.

Before every test the following steps were performed:

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

During every test, the following steps were performed:

- Baseline and Substitute Gases were run continuously with switching between gases taking less than 14 seconds.
- Emissions, pressure and temperature data was observed and recorded before, during and after changeover.

After every test the following steps were performed:

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

As Found Test

- Did not change manifold or supply pressures.
- Ran heater on Baseline Gas for 25 minutes.
- Verified proper heater operation.

As Found Test 2

- Began testing with Baseline Gas for the first 15 minutes of the test.
- Switched to Gas 2 for 15 minutes.
- Switched to Gas 3 for 15 minutes.
- Concluded testing with Baseline Gas for 15 minutes.

Rated Input Performance Test

Using Baseline Gas, the manifold pressure was adjusted to allow for a rated input of 117,000 Btu/hr ± 2%. Once readings were stable, testing and collection of temperature, pressure and emissions data began. During this test, the gases were run in the following order:

- Baseline Gas for 15 minutes.
- Switched to Gas 2 for 15 minutes.
- Switched to Gas 3 for 15 minutes.
- Reestablished Baseline Gas for 15 minutes.
- Switched to Gas 4 for 15 minutes.
- Switched to Gas 4A for 15 minutes.
- Reestablished Baseline Gas for 15 minutes.

- Switched to Gas 5 for 15 minutes
- Switched to Gas 5A for 15 minutes
- Reestablished Baseline Gas for 15 minutes
- Switched to Gas 6 for 15 minutes.
- Conclude testing with Baseline Gas for 15 minutes.

Maximum Manifold Pressure Test

Using Baseline Gas, the manifold pressure was adjusted to achieve the highest achievable input rate. Once readings were stable, testing and collection of temperature, pressure and emissions data began. During this test, the gases were run in the following order:

- Baseline Gas for 15 minutes
- Switched to Gas 2 for 15 minutes.
- Switched to Gas 3 for 15 minutes.
- Conclude testing with Baseline Gas for 15 minutes.

Note: This test was not meant to be the over fire test required by ANSI standards.

Smooth/Pulsating Input

Using Baseline Gas, the manifold pressure was adjusted to allow for a rated input of 117,000 Btu/hr ± 2% at smooth and pulsating condition. Once the input rate was within range, the gases were run in the following order:

- Began test with Baseline Gas (smooth regulator) for 15 minutes.
- Switched to Baseline Gas (pulsating regulator) for 15 minutes.
- Switched to Gas 3 (smooth regulator) for 15 minutes.
- Conclude testing with Gas 3 (pulsating regulator) for 15 minutes.

Cold Ignition Test

Using Baseline Gas, the manifold pressure was adjusted to allow for a rated input of 117,000 Btu/hr ± 2%. The following steps were followed:

- The gas delivery system was purged with Gas 3.
- The water heater was ignited (using Gas 3) from a cold start and data was collected for one minute. For each time the heater was ignited, visual observations of the flame and ignition delays were documented. This test was repeated 2 more times.
- The gas delivery system was purged with Gas 2.
- The water heater was ignited (using Gas 2) from a cold start and data was collected for one minute. For each time the heater was ignited, visual observations of the flame and ignition delays were documented. This test was repeated 2 more times.

Hot Ignition Test

Using Baseline Gas, the manifold pressure was adjusted to allow for a rated input of 117,000 Btu/hr ± 2%. The following steps were followed:

- The gas delivery system was purged with Gas 3.
- The water heater was ignited (using Gas 3) and data was collected for one minute. For each time the heater was ignited, visual observations of the flame and ignition delays were documented. This test was repeated 2 more times with no more than one minute elapsing between tests.
- The gas delivery system was purged with Gas 2.
- The water heater was ignited (using Gas 2) and data was collected for one minute. For each time the heater was ignited, visual observations of the flame and ignition delays were documented. This test was repeated 2 more times with no more than one minute elapsing between tests.

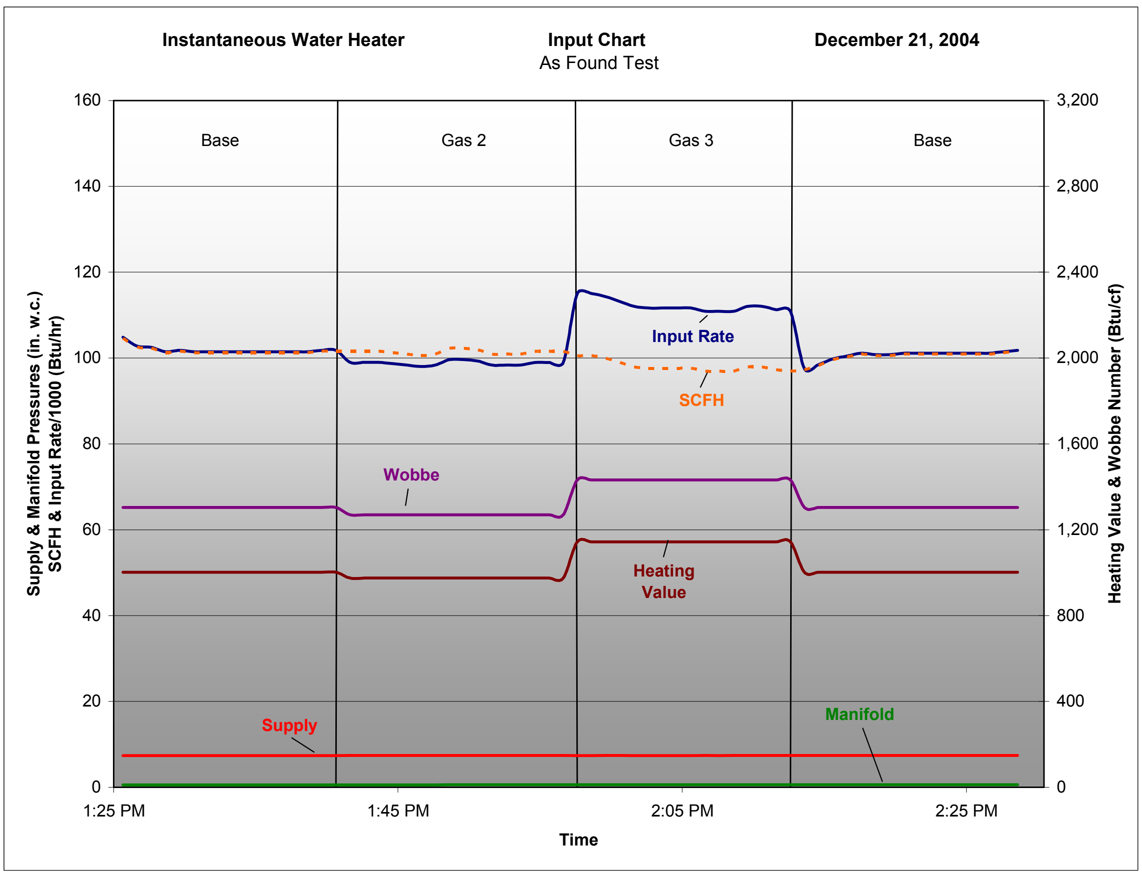
Results[1,2]

As Found Test

Input

The instantaneous water heater operated an input rate of 101,892 Btu/hr during the 1st Baseline Gas run; which is 13% below the rated input. Input rate increased as the heating value for all the gases tested increased. The highest input rate was achieved with Gas 3 (112,182 Btu/hr), followed with Baseline Gas (101,892 Btu/hr - 1st run). Gas 2 (98,570 Btu/hr) had the lowest input rate.

The supply pressure (7.4" w.c.) differed slightly from the limit set in the test protocol but remained stable throughout the test.



[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.

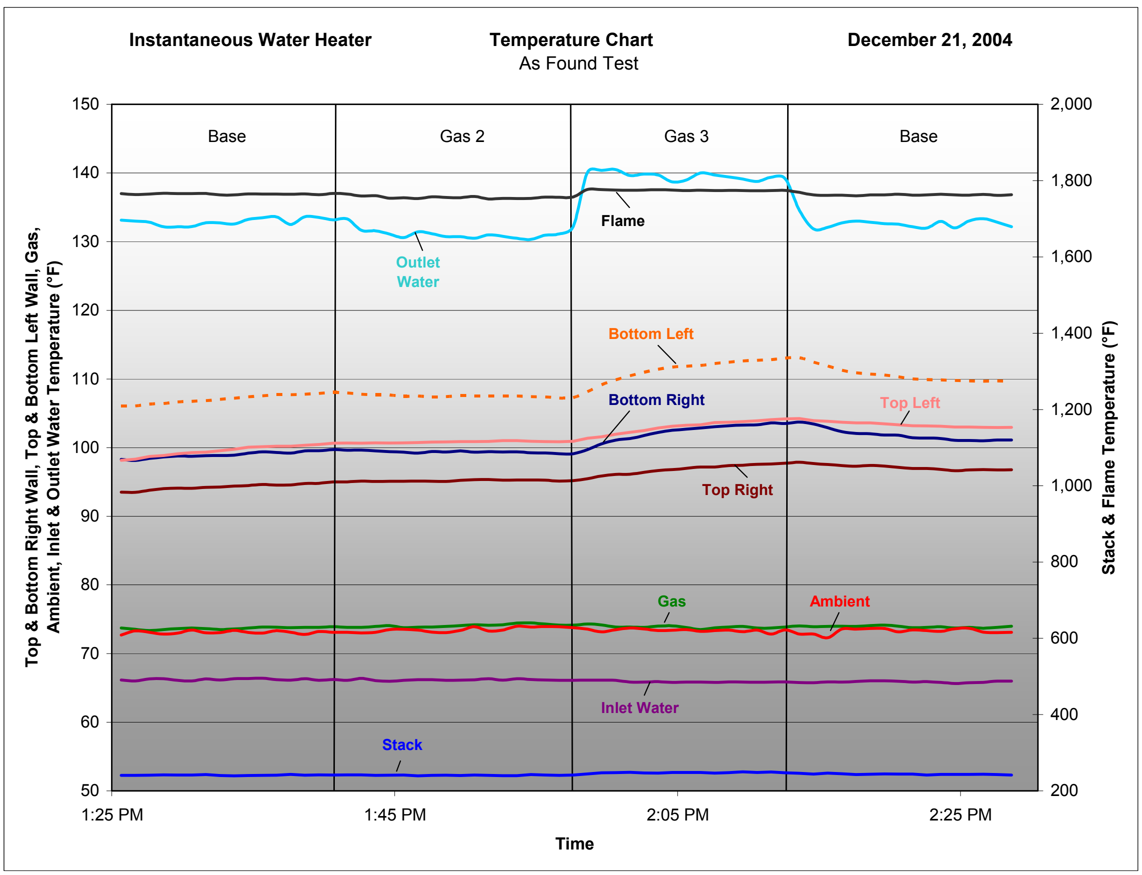
Temperatures

The highest flame temperature was observed with Gas 3 (1,774°F), followed by the 1st Baseline Gas run (1,765°F). Although the flame temperature, as measured with a fixed thermocouple tip, fluctuated when different test gases were introduced. Some of the temperature fluctuations were due to the changes of flame height and shape with respect to the thermocouple tip, which was not moved during the series of tests. The thermocouple tip was installed, during the instrumentation set up, in the secondary cone of the flame when the equipment was operating with Baseline Gas.

Stack temperature was highest with Gas 3 (248°F), followed by the last Baseline Gas run (243°F). Outlet water temperature reacted to all of the gases tested; however, it remained within the limit set in the test protocol (135 ± 5°F). The highest outlet water temperature was observed with Gas 3 (139°F); whereas, the lowest outlet water temperature was observed with Gas 2 (132°F). Inlet water temperature remained stable at 66 ± 1°F for the entire test period.

All wall temperatures followed the same patterns throughout the test period. Bottom wall probes recorded higher temperatures due to the radiant heat transfer from the burner. The maximum wall temperature observed was 111°F for the bottom left probe during operation with Gas 3.

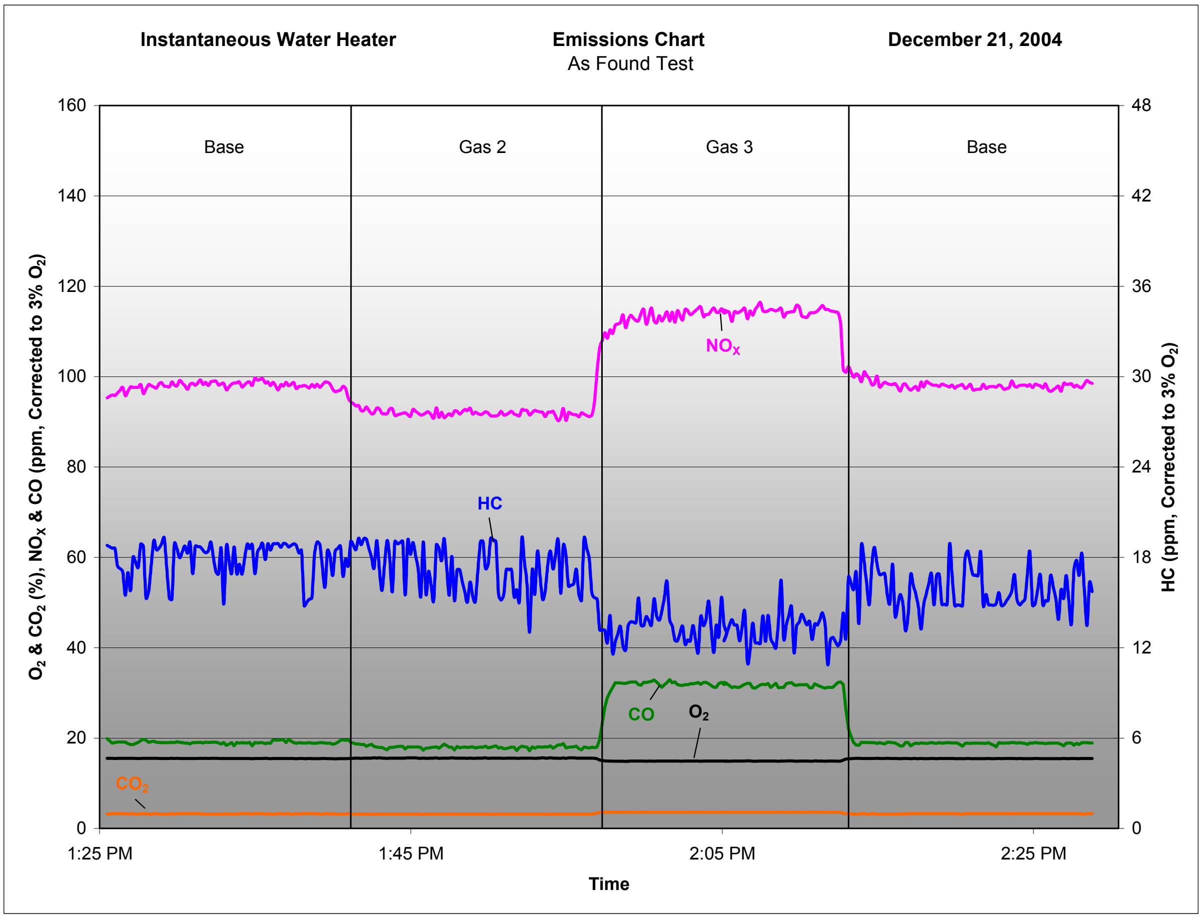
Ambient and gas temperatures remained stable during the test and averaged 74 ± 1°F.



Emissions

NO_x emissions values exceeded 91 ppm for all gases tested. The highest NO_x emissions value was observed with Gas 3 (113 ppm) while Gas 2 (92 ppm) had the lowest NO_x emissions value. Baseline Gas NO_X emissions values remained in the 98 ± 1 ppm range throughout the test period.

The highest CO emissions values were observed with Gas 3 (31 ppm) whereas the lowest CO emissions value observed was with Gas 2 (18 ppm).



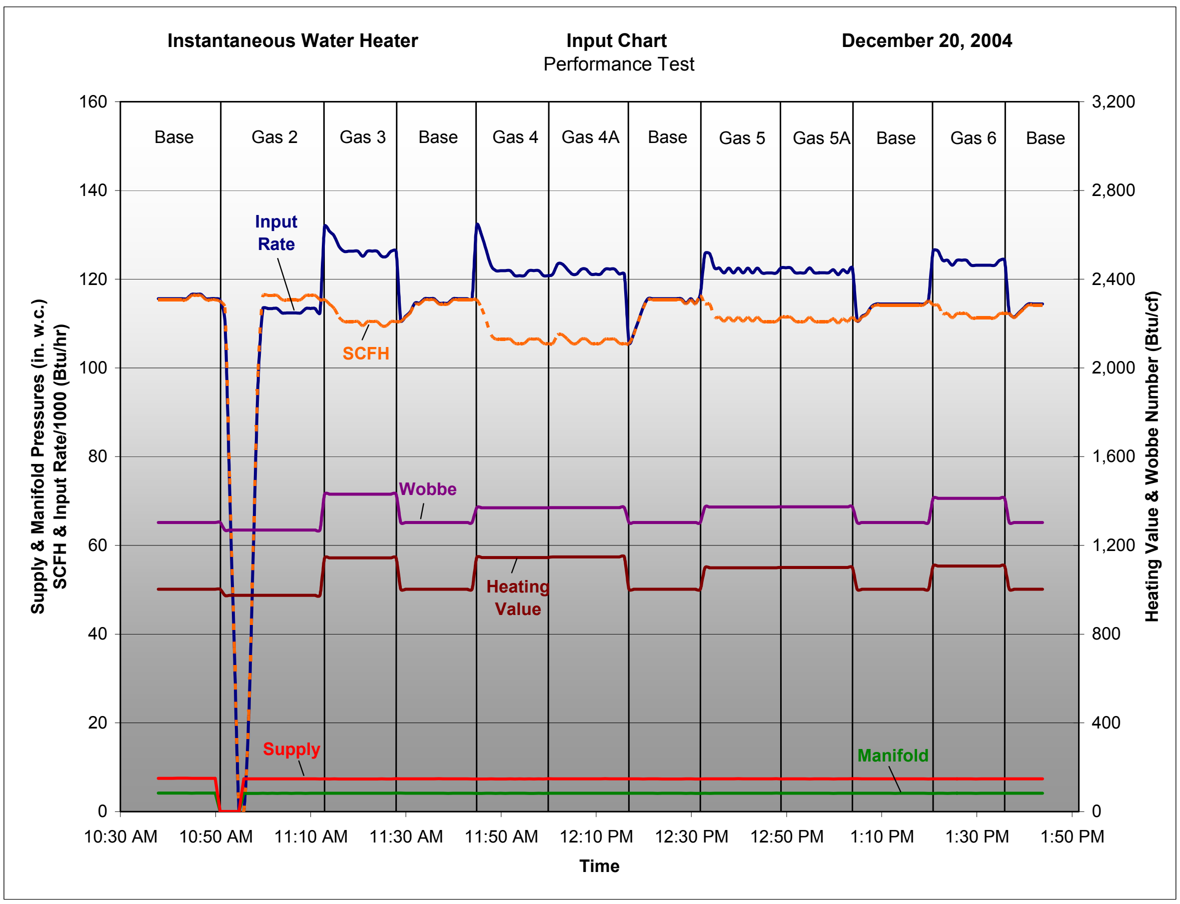
NOTE: Emission test results are for information purposes. They were not the result of certified tests.

Performance Test

Input

The instantaneous water heater operated an input rate of 115,794 Btu/hr during the 1st Baseline Gas run; which is 1% below the rated input. Input rate was highest with Gas 3 (127,014 Btu/hr), followed by Gas 6 (124,041 Btu/hr). The lowest input rate was obtained with Gas 2 (112,937 Btu/hr). Both manifold and supply pressures remained stable during the test period.

A closed valve in the second Gas Delivery System (GDS) caused the instantaneous water heater to shut off at the beginning of Gas 2 run.



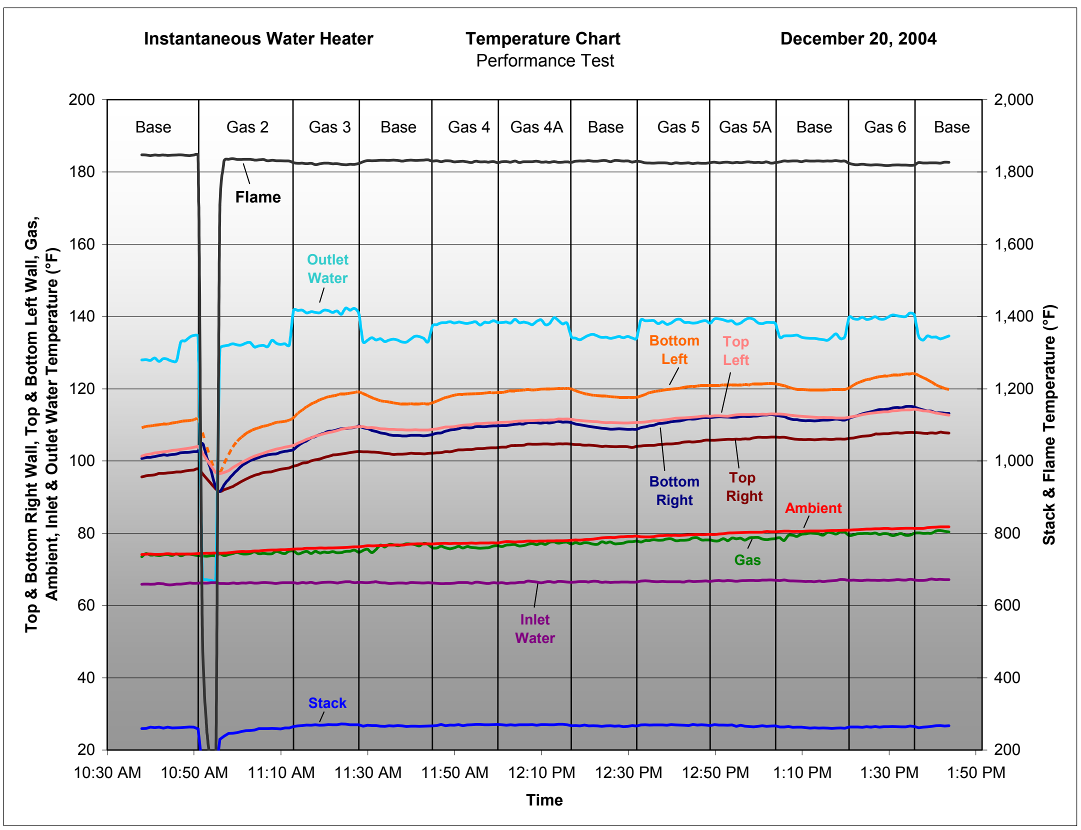
Temperatures

The highest flame temperature was observed during the 1st Baseline Gas run (1,846°F) whereas Gas 3 (1,823°F) had the lowest flame temperature. Although the flame temperature reacted to changes with the gases tested, these values depended on the location of the fixed thermocouple tip in the flame region. Therefore, the drop in the flame temperatures with Gas 4, 4A, 5, 5A, and 6 are related to the gases' flame length and where the thermocouple tip was located within the flame region.

Stack temperature was highest with Gas 4A (270°F) followed by Gases 3 and 4 (269°F). Baseline Gas stack temperature ranged between 262°F (1st run) and 267°F (2nd run). Ambient and gas temperatures increased gradually during the test and ranged between 74°F and 82°F.

Outlet water temperature remained within the limit set in the test protocol (135 ± 5°F) with the exception of Gas 3 where outlet water temperature averaged 141°F. The lowest outlet water temperature was recorded with Gas 2 (129°F). Inlet water temperature remained stable at 66 ± 1°F for the entire test period.

All wall temperatures followed the same patterns throughout the test period. Bottom wall probes recorded higher temperatures due to the radiant heat transfer from the burner. The maximum wall temperature recorded was 123°F for the bottom left probe during operation with Gas 6.

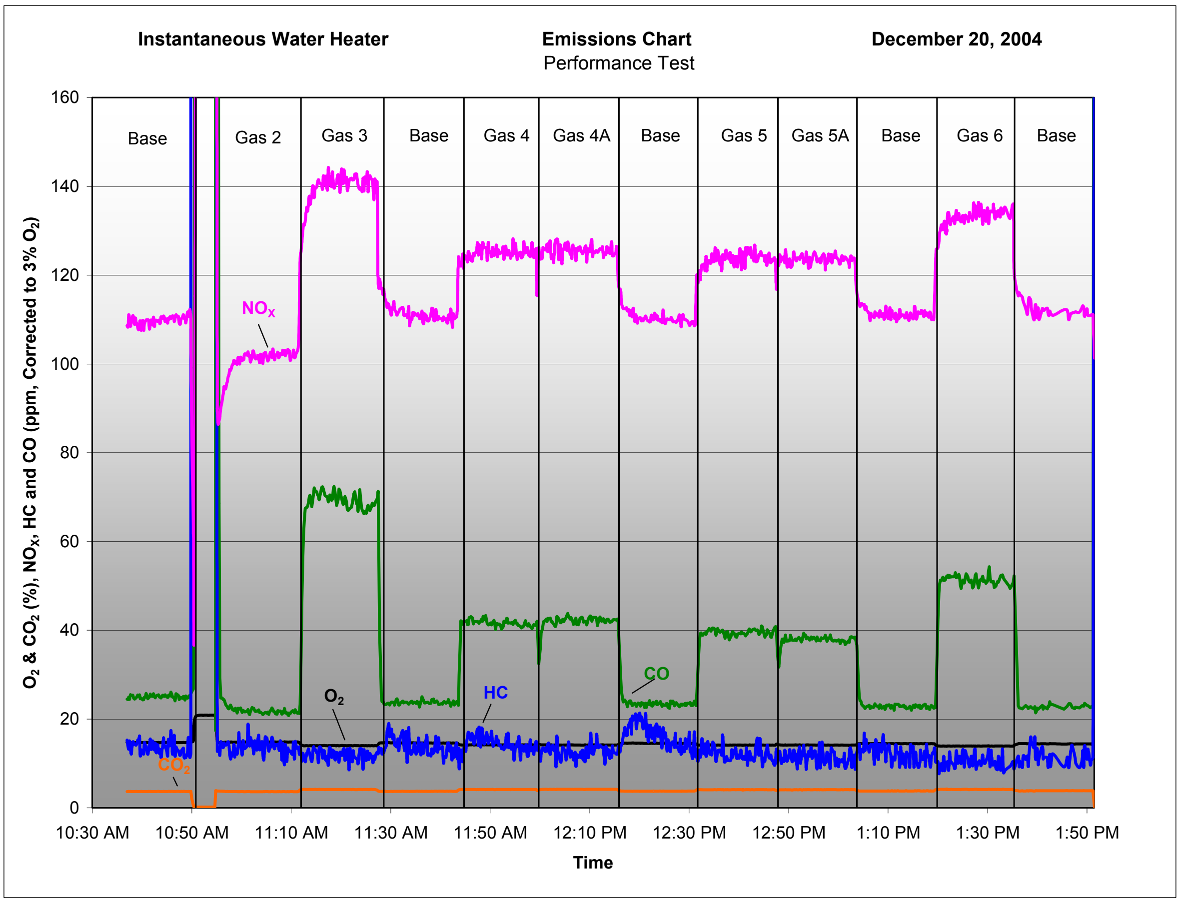


Emissions

NO_x emissions values exceeded 100 ppm for all gases tested ranging between 101 ppm (Gas 2) and 138 ppm (Gas 3). Baseline Gas NO_x emissions values remained in the 110 $\pm$ 2 ppm range throughout the test period.

CO emissions values obtained with Gas 3 and 6 were 66 ppm and 51 ppm, respectively. On the other hand, CO emissions values for Gas 2, 4, 4A, 5 and 5A ranged between 22 ppm (Gas 2) and 42 ppm (Gas 4A). Baseline Gas CO emissions values ranged between 23 ppm (4th run) and 34 ppm (1st run). The differences in the results with Gases 4, 4A, 5 and 5A were insignificant and inconsistent to draw any conclusions.

Another important point worth mentioning is that NO_x emissions followed the same pattern as CO emissions.



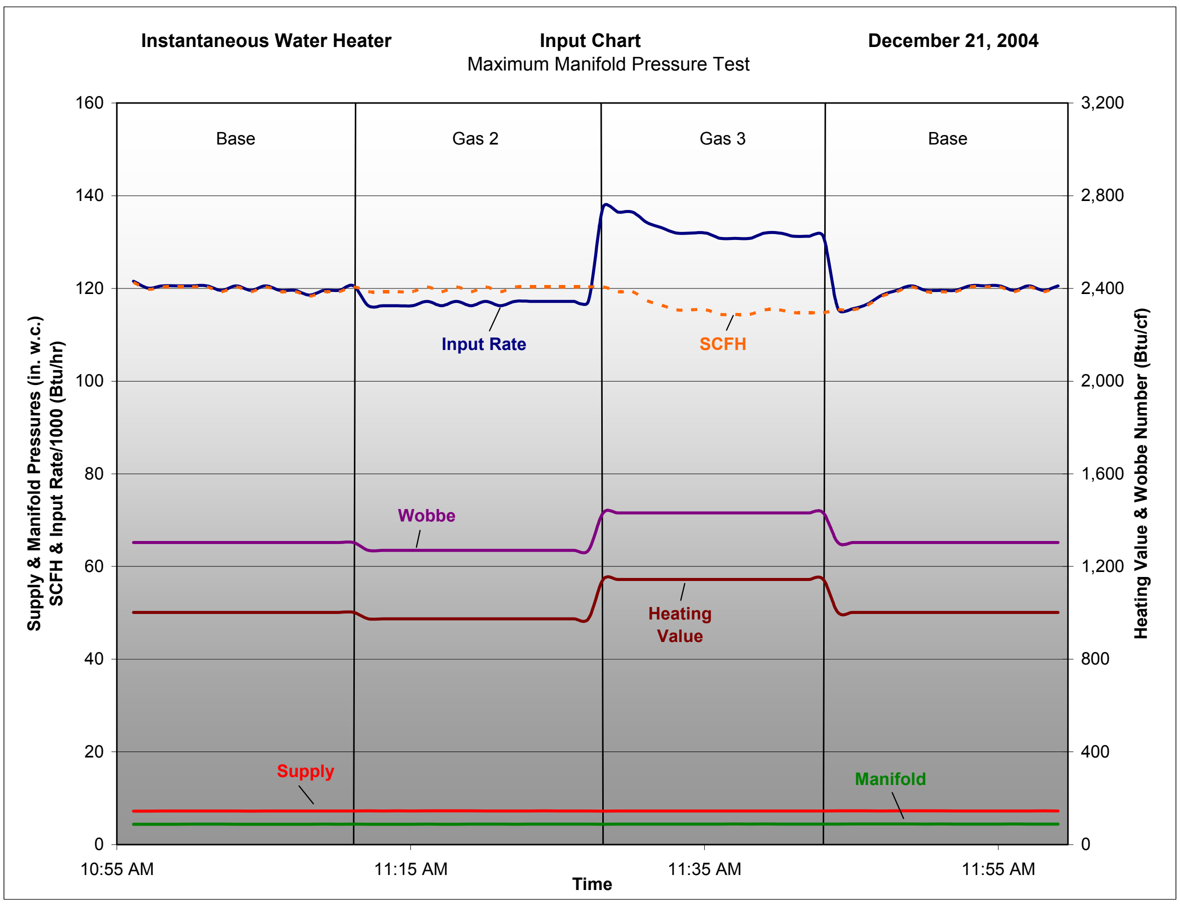
NOTE: Emission test results are for information purposes. They were not the result of certified tests.

Maximum Manifold Pressure Test

Input

The instantaneous water heater operated an input rate of 120,089 Btu/hr during the 1st Baseline Gas run; which was 2.6% above the rated input. Input rate was highest with Gas 3 (132,738 Btu/hr) and lowest with Gas 2 (116,806 Btu/hr). Baseline Gas input rate ranged between 119,193 Btu/hr (last run) and 120,089 Btu/hr (1st run).

Both manifold and supply pressures remained stable during the test period. This test was not meant to be the over-fire test required by ANSI standards.

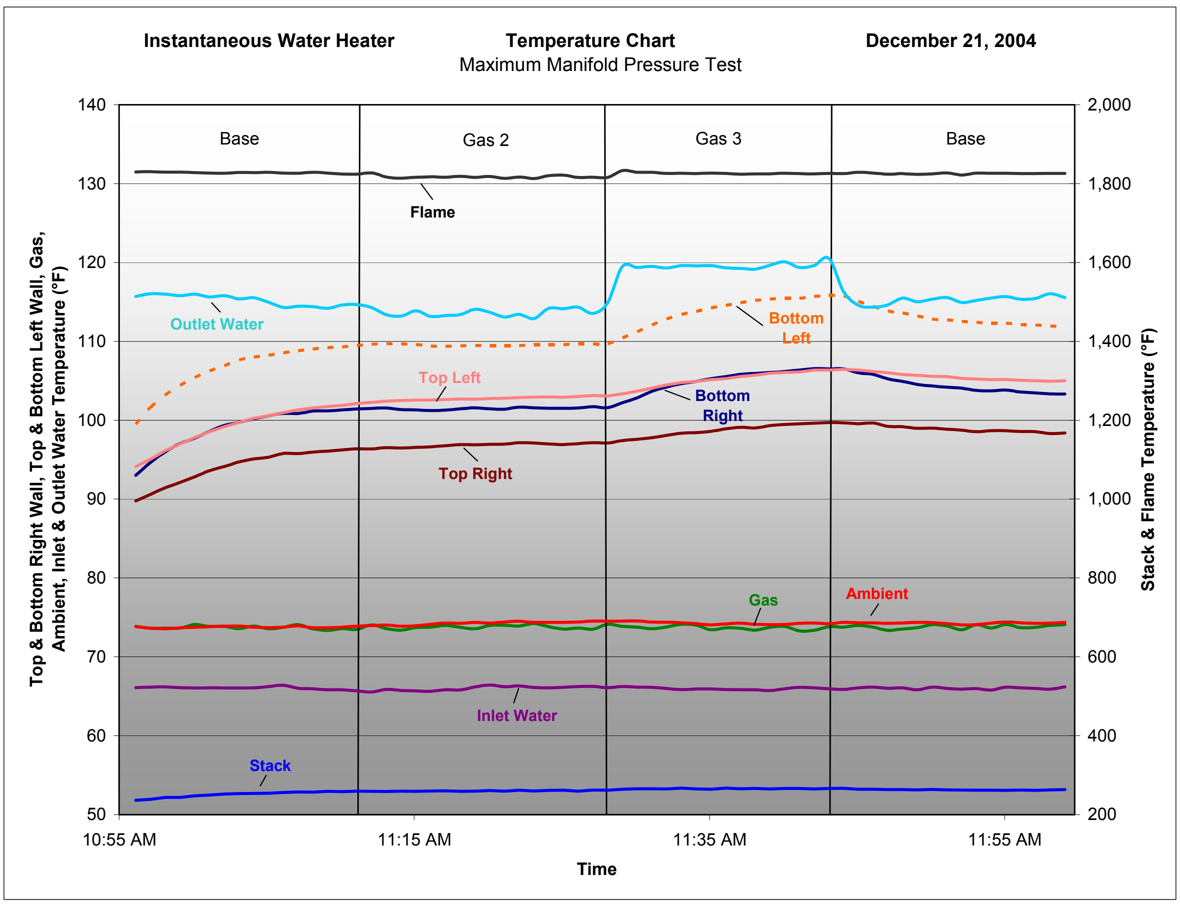


Temperatures

The highest flame temperature was observed with the 1st Baseline Gas run (1,828°F), followed by the 2nd Baseline Gas run and Gas 3 (1,826°F). Outlet water temperature ranged between 113°F (Gas 2) and 119°F (Gas 3). Inlet water temperature remained stable at 66°F for the entire test period.

All wall temperatures followed the same patterns throughout the test period. Bottom wall probes recorded higher temperatures due to the radiant heat transfer from the burner. The maximum wall temperature recorded was 114°F for the bottom left probe during operation with Gas 3.

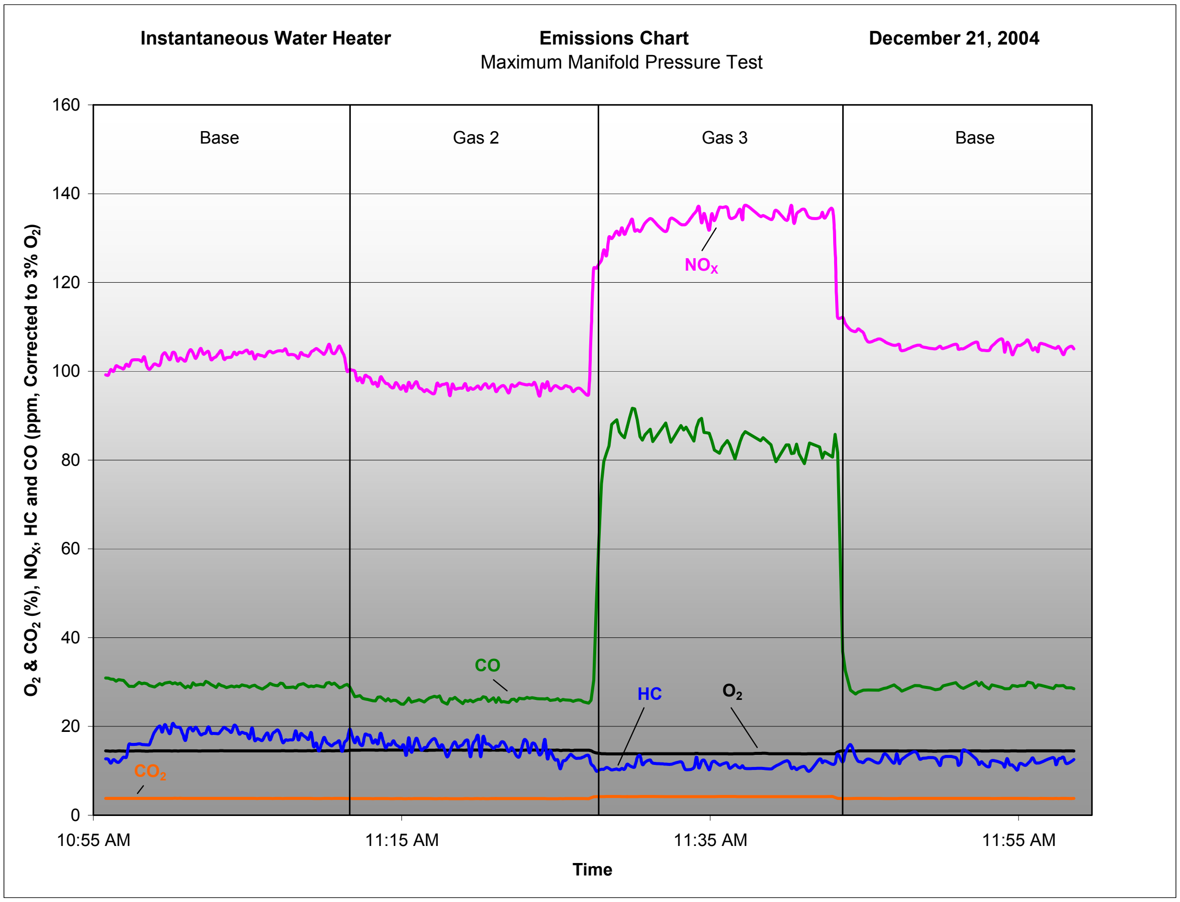
Stack temperature was highest with Gas 3 (266°F) and lowest with the 1st Baseline Gas (251°F) run. Ambient and gas temperatures remained stable at 74 ± 1°F throughout the test period.



Emissions

NO_x emissions values exceeded 97 ppm for all gases tested including Baseline Gas. NO_x emissions values for Gas 3 and Gas 2 were 133 ppm and 97 ppm. Baseline Gas NO_x emissions values ranged between 103 ppm (1st run) and 106 ppm (2nd run).

The highest CO value was observed with Gas 3 (84 ppm); whereas Gas 2 (26 ppm) had the lowest value.



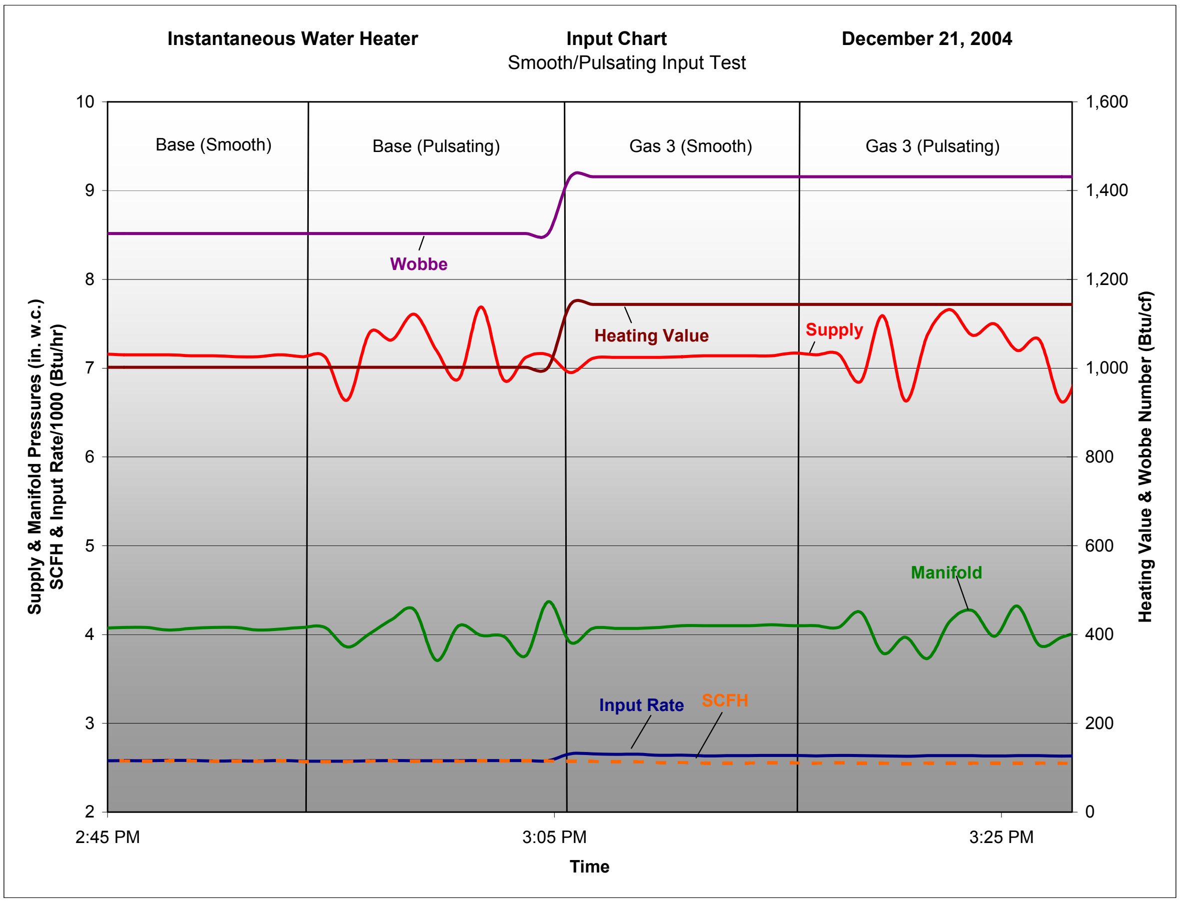
NOTE: Emission test results are for information purposes. They were not the result of certified tests.

Smooth/Pulsating Input Test

Input

The smooth/pulsating input rate was highest with the smooth runs and recorded 115,863 Btu/hr with Baseline Gas and 128,711 Btu/hr with Gas 3.

Both manifold and supply pressures remained stable during the smooth runs whereas the manifold and supply pressures varied about ± 0.5" w.c. during the pulsating runs.

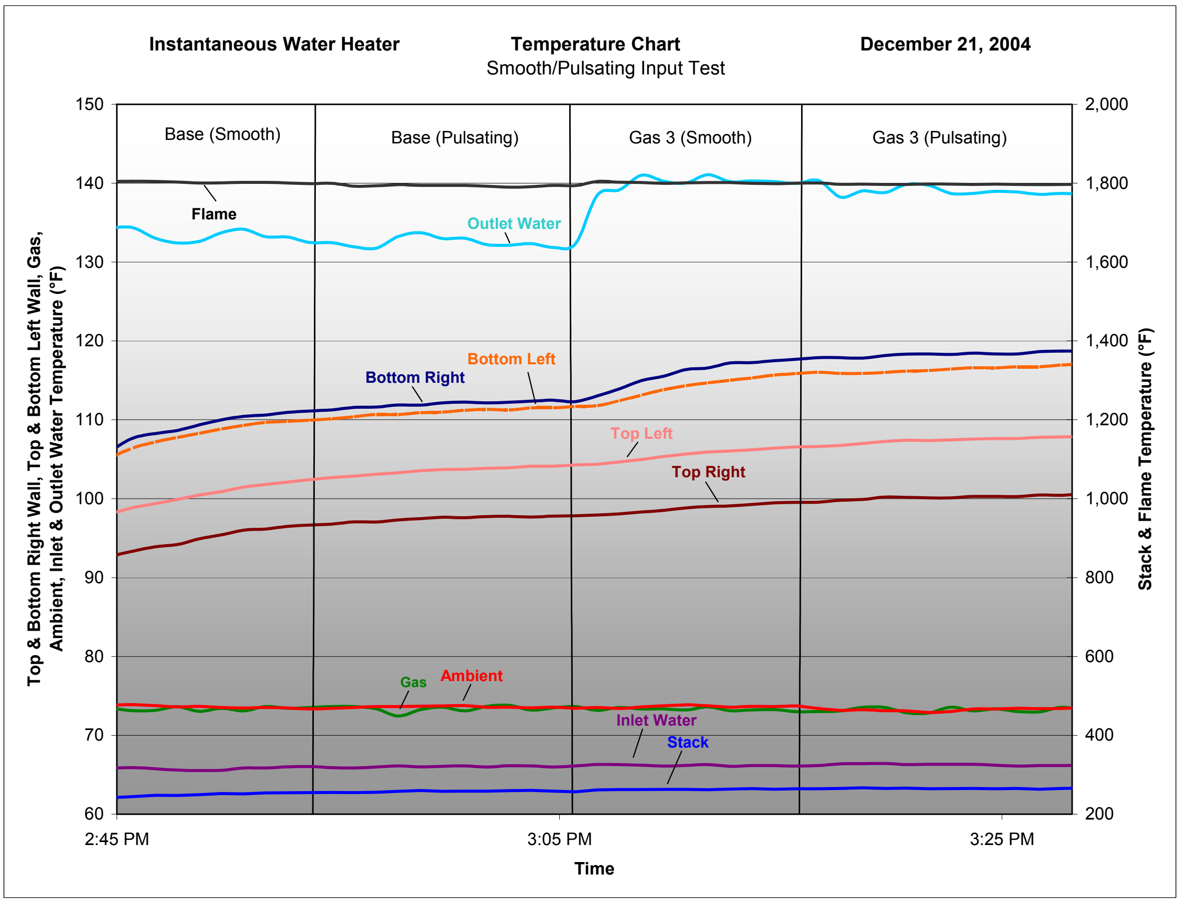


Temperatures

The flame temperature was stable and stayed in the 1,796 ± 5°F range throughout the test period. Pulsating runs had minor effect on the outlet water temperature. Inlet water temperature remained stable at 66 ± 1°F for the entire test period.

All wall temperatures followed the same patterns throughout the test period. Bottom wall probes recorded higher temperatures due to the radiant heat transfer from the burner. The maximum wall temperature recorded was 118°F for the bottom right probe while performing the Gas 3 Pulsating Run.

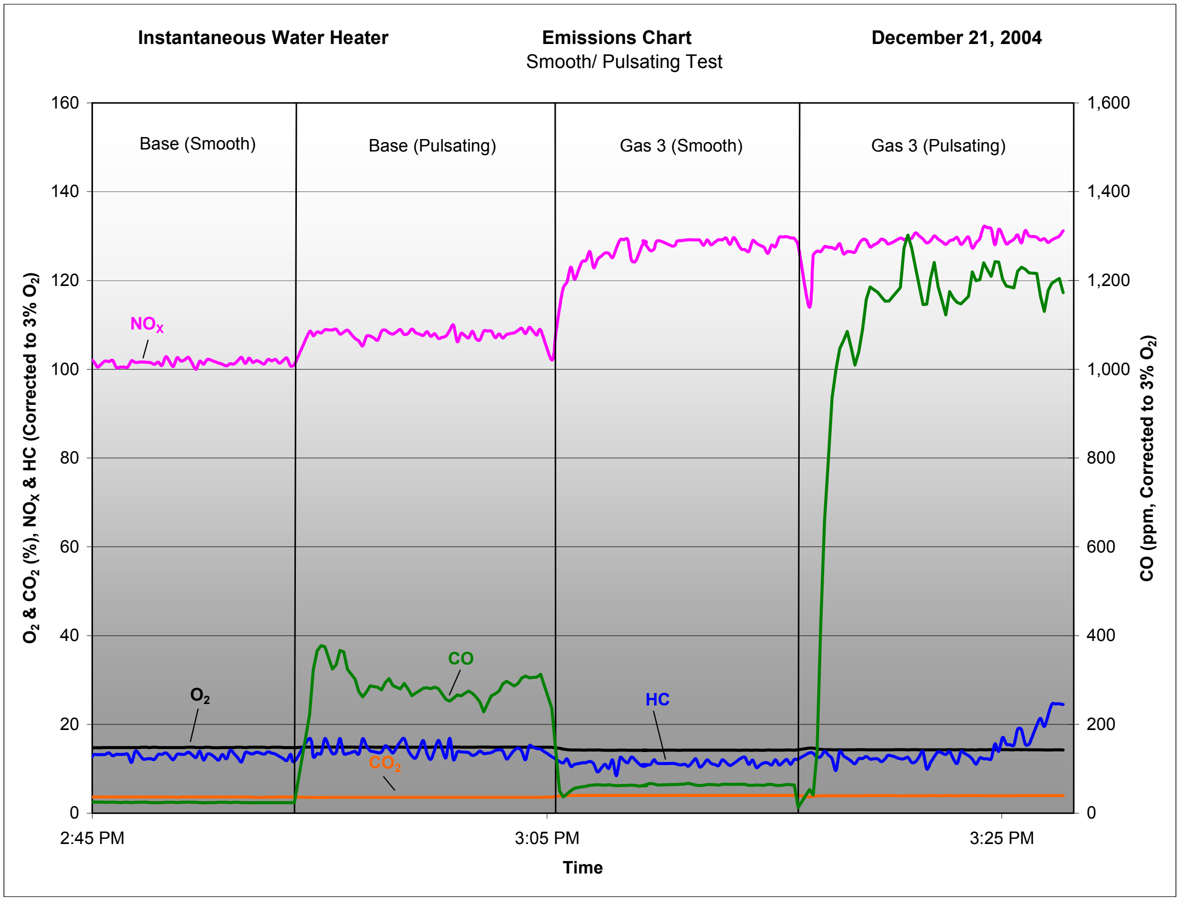
Stack temperature was highest with Gas 3 Pulsating Run (265°F) and lowest with the Baseline Gas Smooth Run (249°F). Ambient and gas temperatures remained stable at 73 ± 1°F throughout the test period.



Emissions

NO_x emissions values exceeded 100 ppm for all gases tested. NO_x emissions values slightly increased when the pulsating runs were performed. Baseline Gas NO_x emissions values for both smooth and pulsating runs were 102 and 108 ppm. Gas 3 NO_x emissions values for both Smooth and Pulsating Runs were 127 and 129 ppm.

Pulsating inlet pressure had major effects on the CO emissions values. CO emissions values for Baseline Gas and Gas 3 Smooth Runs were 25 and 63 ppm. On the other hand, CO emissions values increased substantially for Baseline Gas and Gas 3 Pulsating Runs to 289 and 1,095 ppm.



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Cold Ignition Test

Orange tipping is normally luminance associated to high temperatures and not related with incomplete combustion.

Cold Ignition Test			
Gas	**Ignition**	**Start-Up #**	**Comments & Observations**
3	Normal and without delays	1	Flame had orange tint to it.
		2	Flame had orange tint to it.
		3	Flame had orange tint to it.
2	Normal and without delays	1	Less orange tint than Gas 3 & shorter flames.
		2	Less orange tint than Gas 3 & shorter flames.
		3	Less orange tint than Gas 3 & shorter flames.

Hot Ignition Test

Orange tipping is normally luminance associated to high temperatures and not related with incomplete combustion.

Hot Ignition Test			
Gas	**Ignition**	**Start-Up #**	**Comments & Observations**
3	Normal and without delays	1	Flame had orange tint to it.
		2	Flame had orange tint to it.
		3	Flame had orange tint to it.
2	Normal and without delays	1	Less orange tint than Gas 3 & shorter flames.
		2	Less orange tint than Gas 3 & shorter flames.
		3	Less orange tint than Gas 3 & shorter flames.

Appendix A: Test Protocol

1. Standards

- ANSI Z21.10.3-2001, Standard for Gas-Fired Water Heaters, Volume III.
- South Coast Air Quality Management District Rule 1146.2, Emission of NO_X from Large Water Heaters and Small Boilers, adopted January 9, 1998.
- South Coast Air Quality Management District Protocol, NO_X Compliance Testing for Natural Gas-fired Water Heaters and Small Boilers, last amended January 1998.
- South Coast Air Quality Management District – Instrumental analyzer procedure for continuous gaseous emissions - District Method 100.1

2. Water Heater Description

- Description: Automatic Instantaneous Water Heater
- Burner: High firing intensity atmospheric burner
- Maximum input rating: ~117,000 Btu/hr
- Minimum input rating: ~28,000 Btu/hr
- Type of fuel: Natural Gas
- Required gas supply pressure: 7" w.c.

3. Test Arrangement

3.1. Basic setup - The heater is to be mounted on a stand that simulates a wall. Fuel gas, electrical power, and water are to be provided at rates and conditions required by the test standards and manufacturer specifications. Combustion products are to be sampled in a vent stack constructed per emission measurement standards.

3.2. Mounting - A stand is to be constructed such that the heater can be wall-mounted in accordance with the manufacturer's instructions. The wall portion is to be of ¾" plywood, painted black. The bottom of the heater is to be at the minimum distance above the floor permitted by the manufacturer's instructions. The wall width is to be at least 12 inches wider than the heater (six inches each side) and is to extend 12 inches above the top of the heater.

3.3. Water flow and piping - Provide water at the flow rate and temperature required by the test standards and manufacturer specifications. If necessary, provide a supply water pump, a re-circulating pump and valves necessary to adjust water flow rate and temperatures. Maintain water pressure at a level sufficient to assure proper heater operation.

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

3.5. Fuel gas - Fuel gases are to be provided at the pressures required by test methods specified later in this protocol. Pressure is to be measured at the inlet pressure tap of the heater gas control.

3.6. Electrical power – Not required.

3.7. Water, mounting surface and other temperatures - In addition to data required for firing rate provide thermocouples as follows:

3.7.1. Inlet and outlet water - Provide thermocouples in inlet and outlet water piping as prescribed in Figure 8 of the AQMD protocol, as close to the heater as possible.

3.7.2. Wall temperature - Provide three or four thermocouples on the wooden wall at locations most likely to be hot during operation. Locate one or more at one to two inches above burner port level. Locate one or more at the flue collector level. Locate one or more at the heater-to-wall contact points.

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

3.8. Instrumentation - Instrumentation is to be per the SCAQMD Protocol for Rule 1146.2 and SCAQMD – Instrumental analyzer procedure for continuous gaseous emissions - District Method 100.1.

3.9. 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 heater operation.

4. Test Gases

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

- **Baseline Gas** (Gas 1) - Low Wobbe (1,330 Btu/cf), low heat content gas (1,002 Btu/cf)
- **Gas 2** – Lowest Wobbe (1,269 Btu/cf), lowest-heat content gas (974 Btu/cf)
- **Gas 3** – Highest Wobbe (1,431 Btu/cf), highest-heat content gas (1,143 Btu/cf)
- **Gas 4** – Medium Wobbe (1,370 Btu/cf), highest-heat content gas (1,145 Btu/cf)
- **Gas 4A** (4 component mix) – Medium Wobbe (1,371 Btu/cf), highest-heat content gas (1,148 Btu/cf)
- **Gas 5** – Medium Wobbe (1,374 Btu/cf), high-heat content gas (1,099 Btu/cf)
- **Gas 5A** (4 component mix) – Medium Wobbe (1,374 Btu/cf), high-heat content gas (1,100 Btu/cf)
- **Gas 6** - High Wobbe (1.413 Btu/cf), high-heat content gas (1,107 Btu/cf)

5. **Basic Operating Condition -** Unless required otherwise by specific test requirements, the following are to apply:

   5.1. **Room temperature** - Hold between 65 and 85°F. Room temperature is to be measured as specified in Sections 7.2.6 & 7.1.6 of the AQMD Protocol.

   5.2. **Gas supply pressure** - 7.0” ± 0.3” w.c., measured during steady operation.

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

   5.4. **Water flow, temperature and pressure**

      5.4.1. **Supply water** - Provide water flow and treat inlet water as necessary to maintain heater inlet temperature at 72 ± 4°F.

      5.4.2. **Outlet water** - Adjust water flow rate to provide outlet water at 135 ± 5°F by adjusting heater controls to a higher temperature and reducing water flow as necessary to reach this temperature.

6. **Testing**

   6.1. **Startup Run -** Operate heater on Baseline Gas for one hour at maximum input under “as-received” conditions (i.e. with gas orifices received in the heater and manifold pressure at the rating plate value ± 0.2” w.c.). Record firing rate data, NO_X, HC, O_2, CO_2 and CO emission. Also record ambient, flame, stack, inlet water and outlet water temperatures.

   Experiment with the heater gas and water temperature controls to determine what procedures should be used to start and operate the heater at both maximum and minimum firing rates. Verify proper operation of all equipment and instrumentation.

   6.2. **Base case at rated input** - Adjust heater to operate at the rating plate input, holding manifold pressure within 10% of that specified on the rating plate and changing gas orifices if necessary. This establishes and defines the “basic firing setup” referred to in Section 5.3 above. Record input and combustion data and verify that the firing rate is within 2% of rated input (with Baseline Gas). Determine the firing rate and record combustion data.

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

7. Steady operation testing

Steady operation tests – Baseline and substitute gases

7.1.1. Performance Test

7.1.1.1. Steady operation with Baseline gas –

Starting with Baseline gas, operate heater at the basic operating condition. Verify that firing rate is at ± 2% of rated input and record combustion data as required by the ANZI Protocol. Do not conduct "over fire" test.

Continue operation to establish that stack temperature changes by no more than ± 5°F in 15 minutes and that inlet and outlet water temperatures remain within acceptable limits. Record stack temperature, mounting surface temperatures and that of other components identified in Section 3.7.3.

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

7.1.1.2. Gas changeover and steady operation with substitute gases –

Continue steady heater operation with Baseline Gas and conduct a high-speed switch to Gas 2. Record data before, during and after changeover and observe transient phenomena. Possible phenomena include flame color change, flame lifting, flashback or rollout, pilot burner instability or outage, etc. (Note that the firing rate is not to be adjusted and that heater controls must not be allowed to adjust manifold pressure in response to an outlet water temperature increase. Pre-adjust the controls so that manifold pressure is at maximum with the Baseline Gas and remains at that value for all gases). Record all operating data including firing rate, stack temperature, mounting surface temperature and other temperatures per section 3.7. Continue operation and record combustion data as required by the AQMD Protocol.

During the testing observe flames and note yellow tipping and flame lifting or flashback phenomena or lack of the same. With the heater continuing to operate at steady state with Gas 2, conduct a high-speed switch to Gas 3 and record observations and data per above.

Continue steady-state heater operation with Gas 3 and then conduct a high-speed switch to reestablish Baseline Gas. Continue data acquisition (per above) while operating with Baseline Gas, observing changes in data before, during and after change. The remaining Substitute Gases will be tested in the following order:

- Gas 4 (Medium Wobbe: 1,370 Btu/cf)
- Gas 4A (Medium Wobbe: 1,371 Btu/cf)
- Reestablish Baseline Gas (Low Wobbe: 1,302 Btu/cf)
- Gas 5 (Medium Wobbe: 1,374 Btu/cf)
- Gas 5A (Medium Wobbe: 1,374 Btu/cf)
- Reestablish Baseline Gas (Low Wobbe: 1,302 Btu/cf)

- Gas 6 (High Wobbe: 1,412 Btu/cf)
- Conclude with Baseline Gas (Low Wobbe: 1,302 Btu/cf)

When testing has been conducted with all gases, shut down heater and examine flue collector and vent connection area for presence of soot by means of the swab technique specified in section 6.2. 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.

7.1.2. Maximum Manifold Pressure Test

7.1.2.1. Steady operation with Baseline gas

Starting with Baseline gas, adjust heater controls and water flow rate to assure firing at maximum input. Verify that firing rate is below 106.25% of the rated input and record combustion data as required by the ANZI Standard. Do not conduct over fire test.

Continue operation to establish that stack temperature changes by no more than ± 5°F in 15 minutes and that inlet and outlet water temperatures remain within acceptable limits. Record stack temperature, mounting surface temperatures and that of other components identified in Section 3.7.3.

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

7.1.2.2. Gas changeover and steady operation with substitute gases

Continue operation with Baseline Gas and conduct a high-speed switch to Gas 2. Record all operating data including firing rate, stack temperature, mounting surface temperature and other temperatures per section 3.7. Continue operation and record combustion data as required by the AQMD Protocol.

With the heater continuing to operate at steady state with Gas 2, conduct a high-speed switch to Gas 3 and record observations and data per above. Continue steady-state heater operation with Gas 3 and then conduct a high-speed switch to reestablish Baseline Gas. Continue data acquisition (per above) while operating with Baseline Gas, observing changes in data before, during and after change.

7.1.3. Normal/Pulsating Input

7.1.3.1. Steady operation with Baseline gas - Conduct testing as in section 7.1.1.1 except that both normal and pulsating gas regulators are adjusted to operate at normal input rate.

7.1.3.2. Gas changeover and steady operation with substitute gases - Conduct testing as in section 7.1.1.2 except that Gas 3 is only to be used. (Note: Verify maintenance of normal input by monitoring of manifold pressure. Concurrent slight adjustment of water flow may be necessary in conjunction with gas changeover.)

8. Burner and ignition operating characteristics

Note: Instantaneous water heaters typically have gas controls that modulate between high and low firing rate. Ignition occurs at whatever condition those controls dictate for the circumstances. To conduct testing at full or minimum flow rate requires special manipulation of the controls in conjunction with the water flow rate.

8.1. Operation with Baseline Gas

8.1.1. Full input

8.1.1.1. Cold operation - Verify or adjust heater operation to the basic operating condition with Baseline Gas. Allow heater to cool to room temperature and initiate burner operation by means of the heater controls. Allow the burners to operate at normal manifold pressure for five seconds then turn them off. Repeat three times. Observe and record operation with respect to:

a. Immediate ignition and carryover to all burners
b. Flashback. If flashback is noted, allow burners to operate for 30 seconds to determine if clearing occurs.
c. Flame rollout
d. Instability of the main or pilot burner flames

Note: For the purpose of improving test time efficiency, cold operation data may be gathered at startup in other parts of the test protocol.

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

8.2. **Operation with substitute gases** - Without adjustment of heater, return to the full input condition and switch to Gas 2. When steady state conditions are achieved, turn the burners off and on three times. Observe and record observations per preceding section. In particular, note variation from operation with Baseline Gas and behavior with respect to areas that were of concern with the Baseline Gas. Repeat the sequence for Gas 3. If unusual phenomena are noted with either of the gases, conduct cold operation testing with that gas, per sections 7.1.1.1 and 7.1.2.1.

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

10. **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.

11. **Calculations –** CO, HC & NO_x emission are to be calculated per the AQMD protocol for Rule 1146.2 (ppm, Corrected to 3% O_2).

Rationale - Test Setup and Procedure

Firing rate:

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

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

Burner and ignition operating characteristics:

Substitute gas compositions do not indicate likely problems and full-blown testing of burner and ignition systems per the safety standards would be more extensive than the program allows for. The testing specified in this protocol provides for observation of deviant phenomena, but does not include investigation of pilot and valve turndown characteristics, ignition system timing, etc.

Vent pipe choice:

ANSI Standard Z21.10.3 specifies that no vent pipe be used during combustion testing. The AQMD protocol specifies a 5ft vent pipe. In some cases, a manufacturer may specify minimum vent length longer than 5ft.

Vent pipe height is specified at 5ft for all testing to minimize test time and because in some cases longer lengths may not be possible because of laboratory ceiling height. Compromises of the manufacturer's minimum length are to be made with due consideration by the test team, the basic requirement being that performance is not to be materially affected. Since the same setup is to be used for all testing, the effect of gas fuel blend is evaluated on a consistent and comparable basis.

Water temperature:

ANSI Standard Z21.10.3 specifies that supply water temperature be 70 ± 2^{o}F. Outlet water temperature is specified at 130 ± 5^{o}F for combustion tests.

The AQMD protocol specifies supply temperature at 72 ± 4^{o}F and an outlet temperature of 135 ± 5^{o}F for heaters with firing rates less than 200,000 Btu/h and 140 ± 2^{o}F for heaters with higher input.

In the belief that the differences in these specifications do not have significant effect on performance and in the interest of testing economy, water temperatures are specified at the same values for all testing. Supply water is to be 72 ± 4^{o}F. Outlet water is to be 135 ± 5^{o}F.

Appendix B: Tables of Averages

As Found Test

Table of Averages Instantaneous Water Heater As Found Test December 20, 2004				
Gases	**Base**	**2**	**3**	**Base**
HHV (Btu/cf)	1,002	974	1,144	1,002
Wobbe (Btu/cf)	1,303	1,269	1,431	1,303
Input Rate (Btu/hr)	101,892	98,804	112,182	100,634
Corrected SCFH	101.0	100.7	97.5	99.8
Emissions (not from certified tests)				
Raw O_2 (%)	15.5	15.6	14.9	15.5
Raw CO_2 (%)	3.2	3.2	3.6	3.2
CO (ppm @ 3% O_2)	19.0	18.0	31.3	18.8
HC (ppm @ 3% O_2)	17.9	17.2	13.4	15.9
NO_X (ppm @ 3% O_2)	97.9	92.2	113.2	98.1
Ultimate CO_2 (%)	12.4	12.5	12.5	12.5
Equivalence Ratio (Φ)	0.3	0.3	0.3	0.3
Temperatures (°F)				
Ambient	73.7	74.1	73.9	73.9
Flame	1,765	1,756	1,774	1,763
Gas	73.1	73.5	73.4	73.3
Stack	241.3	241.0	247.5	243.8
Inlet Water	66.2	66.2	65.9	65.9
Outlet Water	132.9	131.1	139.1	132.7
Wall (Top Left)	99.6	100.8	102.9	103.4
Wall (Top Right)	94.3	95.2	96.7	97.1
Wall (Bottom Left)	107.1	107.5	111.2	110.6
Wall (Bottom Right)	99.0	99.4	102.1	101.9
Pressures				
Supply (in. w.c.)	7.4	7.4	7.4	7.4
Manifold (in. w.c.)	3.2	3.2	3.2	3.2

Performance Test

Table of Averages Instantaneous Water Heater Performance Test December 20, 2004												
Gases	**Base**	**2**	**3**	**Base**	**4**	**4A**	**Base**	**5**	**5A**	**Base**	**6**	**Base**
HHV (Btu/cf)	1,002	974	1,144	1,002	1,145	1,148	1,002	1,099	1,100	1,002	1,107	1,002
Wobbe (Btu/cf)	1,303	1,269	1,431	1,303	1,370	1,371	1,303	1,374	1,374	1,303	1,413	1,303
Input Rate (Btu/hr)	115,794	112,937	127,014	114,559	123,069	121,856	114,003	122,361	121,851	113,899	124,041	114,091
Corrected SCFH	114.8	115.2	110.3	113.6	106.8	105.4	113.0	110.6	110.1	112.9	111.3	113.1
Emissions (not from certified tests)												
Raw O_2 (%)	14.9	14.8	14.1	14.6	14.2	14.1	14.5	14.1	14.1	14.5	13.9	14.5
Raw CO_2 (%)	3.5	3.7	4.1	3.7	4.1	4.2	3.8	4.1	4.1	3.8	4.1	3.8
CO (ppm @ 3% O_2)	34.0	22.0	65.8	24.7	41.5	42.0	23.9	39.4	37.8	23.1	51.0	29.5
HC (ppm @ 3% O_2)	97.8	13.7	11.9	13.6	14.5	12.7	16.1	12.1	11.5	12.3	10.3	16.0
NO_X (ppm @ 3% O_2)	109.8	101.1	138.0	112.0	125.1	125.5	110.8	123.6	123.4	111.6	132.7	112.0
Ultimate CO_2 (%)	12.0	28.5	12.5	12.4	12.9	12.9	12.4	12.5	12.6	12.4	12.4	12.2
Equivalence Ratio (Φ)	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.3
Temperatures (°F)												
Ambient	74.2	75.0	75.9	76.8	77.2	77.8	78.7	79.4	80.1	80.7	81.2	81.7
Flame	1,846	1,833	1,823	1,832	1,829	1,828	1,830	1,825	1,827	1,830	1,820	1,826
Gas	74.0	74.6	74.8	76.4	76.1	77.0	77.3	78.2	78.4	79.7	79.7	80.4
Stack	261.9	257.1	269.5	266.8	269.5	270.0	267.1	269.4	267.4	262.1	264.4	265.8
Inlet Water	66.0	66.3	66.4	66.3	66.2	66.5	66.5	66.7	66.9	66.8	67.0	67.2
Outlet Water	129.8	128.5	141.5	133.6	138.2	138.5	134.3	138.6	138.7	134.2	139.8	134.5
Wall (Top Left)	102.8	101.9	107.4	108.8	109.9	111.2	110.9	111.6	112.8	112.3	113.4	112.9
Wall (Top Right)	96.7	96.4	100.9	102.2	103.0	104.5	104.2	104.9	106.2	106.1	107.3	107.6
Wall (Bottom Left)	110.4	109.2	116.8	116.5	118.1	119.7	118.2	119.9	121.2	120.0	123.0	120.5
Wall (Bottom Right)	101.8	100.9	107.3	107.6	108.9	110.4	109.3	110.8	112.4	111.5	113.9	113.2
Pressures												
Supply (in. w.c.)	7.5	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4
Manifold (in. w.c.)	4.2	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1

Maximum Manifold Pressure Test

Table of Averages Instantaneous Water Heater Maximum Manifold Pressure Test December 21, 2004				
Gases	**Base**	**2**	**3**	**Base**
HHV (Btu/cf)	1,002	974	1,144	1,002
Wobbe (Btu/cf)	1,303	1,269	1,431	1,303
Input Rate (Btu/hr)	120,089	116,806	132,738	119,193
Corrected SCFH	119.1	119.1	115.3	118.2
Emissions (not from certified tests)				
Raw O_2 (%)	14.5	14.6	13.9	14.5
Raw CO_2 (%)	3.8	3.8	4.2	3.8
CO (ppm @ 3% O_2)	29.4	26.3	83.5	28.9
HC (ppm @ 3% O_2)	17.3	15.1	11.2	12.3
NO_X (ppm @ 3% O_2)	103.3	97.4	132.8	105.9
Ultimate CO_2 (%)	12.4	12.5	12.4	12.3
Equivalence Ratio (Φ)	0.3	0.3	0.4	0.3
Temperatures (°F)				
Ambient	73.8	74.3	74.3	74.3
Flame	1,828	1,817	1,826	1,826
Gas	73.7	73.8	73.7	73.8
Stack	251.2	260.1	265.5	263.1
Inlet Water	66.0	66.0	66.0	66.0
Outlet Water	115.2	113.6	119.3	115.3
Wall (Top Left)	99.3	102.7	105.1	105.5
Wall (Top Right)	94.1	96.8	98.6	98.9
Wall (Bottom Left)	106.6	109.6	113.8	113.1
Wall (Bottom Right)	99.0	101.5	104.9	104.4
Pressures				
Supply (in. w.c.)	7.2	7.2	7.2	7.2
Manifold (in. w.c.)	4.4	4.4	4.4	4.4

Smooth/Pulsating Input Test

Table of Averages Instantaneous Water Heater Smooth/Pulsating Input Test December 21, 2004				
Gases	**Base (Smooth)**	**Base (Pulsating)**	**Gas 3 (Smooth)**	**Gas 3 (Pulsating)**
HHV (Btu/cf)	1,002	1,002	1,144	1,144
Wobbe (Btu/cf)	1,303	1,303	1,431	1,431
Input Rate (Btu/hr)	115,863	115,555	128,711	126,882
Corrected SCFH	114.9	114.6	111.8	110.2
Emissions (not from certified tests)				
Raw O_2 (%)	14.8	14.9	14.2	14.3
Raw CO_2 (%)	3.6	3.6	4.0	3.9
CO (ppm @ 3% O_2)	24.7	289.4	62.6	1095.4
HC (ppm @ 3% O_2)	13.0	14.1	11.3	14.3
NO_X (ppm @ 3% O_2)	101.6	107.9	126.7	128.7
Ultimate CO_2 (%)	12.4	12.4	12.5	12.4
Equivalence Ratio (Φ)	0.3	0.3	0.3	0.3
Temperatures (°F)				
Ambient	73.6	73.6	73.6	73.3
Flame	1,802	1,794	1,800	1,797
Gas	73.4	73.4	73.3	73.2
Stack	248.8	257.9	262.4	265.0
Inlet Water	65.8	66.0	66.2	66.3
Outlet Water	133.4	132.5	139.4	139.0
Wall (Top Left)	100.3	103.5	105.5	107.4
Wall (Top Right)	94.7	97.4	98.7	100.2
Wall (Bottom Left)	107.8	111.0	114.0	116.4
Wall (Bottom Right)	108.8	112.0	115.7	118.3
Pressures				
Supply (in. w.c.)	7.1	7.2	7.1	7.2
Manifold (in. w.c.)	4.1	4.0	4.1	4.0

Appendix C: Test Gases

Gas Analysis Sample Date	Baseline 9/14/04	Gas 2 8/5/04	Gas 3 7/27/04	Gas 4 8/5/04	Gas 4A 7/27/04	Gas 5 8/18/04	Gas 5A 7/19/04	Gas 6 8/7/04
COMPONENTS	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**
C6 + 57/28/14	0.0237	0.0307	0.0297	0.1858	0.0406	0.0737	0.0435	0.0000
NITROGEN	1.7762	1.0866	0.0609	1.0608	1.0782	0.8003	0.7777	0.0000
METHANE	94.4210	95.8713	86.7978	84.9713	84.3951	88.8139	90.8094	91.6800
CARBON DIOXIDE	1.3219	2.9973	0.0000	3.0005	3.0516	1.4074	1.4130	0.0000
ETHANE	1.6841	0.0000	9.3416	4.7846	0.0220	5.2987	0.0230	5.5300
PROPANE	0.3253	0.0141	2.7663	2.4015	11.3998	2.6048	6.9175	1.7500
i-BUTANE	0.0569	0.0000	1.0037	1.1936	0.0094	0.0022	0.0113	0.5200
n-BUTANE	0.0562	0.0000	0.0000	1.2074	0.0033	0.8424	0.0046	0.5200
NEOPENTANE	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
i-PENTANE	0.0176	0.0000	0.0000	0.5944	0.0000	0.1567	0.0000	0.0000
n-PENTANE	0.0122	0.0000	0.0000	0.6001	0.0000	0.0000	0.0000	0.0000
OXYGEN	0.3050	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
TOTAL	**100.0001**	**100.0000**	**100.0000**	**100.0000**	**100.0000**	**100.000**	**100.0000**	**100.0000**
Compressibility Factor	0.997	0.998	0.997	0.996	0.997	0.997	0.997	0.997
HHV (Btu/real cubic foot)	**1002.1**	**974.45**	**1151.6**	**1145.1**	**1148.3**	**1099.4**	**1099.8**	**1107.1**
LHV (Btu/real cubic foot)	902.9	957.5	1141.3	1035.9	1039.5	993.1	993.6	999.8
Specific Gravity	0.5911	0.5893	0.6434	0.6989	0.7018	0.6407	0.641	0.6143
WOBBE Index	**1303.41**	**1269.38**	**1435.69**	**1369.73**	**1370.72**	**1373.50**	**1373.68**	**1412.53**

Appendix D: Zero, Span and Linearity Tables

December 21, 2004 (As Found Test)

	Zero, Span & Linearity Data As Found Test December 21, 2004	O_2 (%)	CO_2 (%)	CO (ppm)	HC (ppm)	NO_x (ppm)
	Analyzer Emission Ranges	**0 - 25**	**0 - 20**	**0 - 500**	**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 Drift Check - 12:15 PM	0.07	0.06	0.02	-0.46	-0.01
Zero	Zero Drift Check - 3:36 PM	0.10	0.06	0.10	-0.28	-0.22
Zero	**Total Drift Over Test Period**	**0.03**	**0.00**	**0.08**	**0.18**	**0.21**
Zero	**Was the Zero Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Span	**Span Calibration Gas (High-Range Values)**	**20.90**	**12.20**	**397.80**	**443.71**	**84.37**
Span	**Allowable Span Drift (Less Than ± 3% of Range)**	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
Span	Span Drift Check - 12:20 PM	20.89	12.05	182.21	443.89	84.45
Span	Span Drift Check - 3:30 PM	20.92	12.05	181.40	441.48	84.70
Span	**Total Drift Over Test Period**	**0.03**	**0.00**	**0.81**	**2.41**	**0.25**
Span	**Was the Span Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**9.03**	**9.22**	**182.20**	**443.00**	**17.80**
Linearity	**Allowable Linearity Drift (Less Than ±1% of Range)**	**0.25**	**0.20**	**5.00**	**10.00**	**1.00**
Linearity	Linearity Check - 12:23 PM	9.14	8.01	78.62	444.34	18.00
Linearity	**Difference From Mid-Range Values**	**0.11**	**1.21**	**103.58**	**1.34**	**0.20**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**No**	**No**	**Yes**	**Yes**
Linearity	Linearity Check - 3:33 PM	9.18	8.01	78.31	440.59	17.90
Linearity	**Difference From Mid-Range Values**	**0.15**	**1.21**	**103.89**	**2.41**	**0.10**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**No**	**No**	**Yes**	**Yes**

December 20, 2004 (Performance Test)

Zero, Span & Linearity Data
Performance Test
December 20, 2004

		O_2 (%)	CO_2 (%)	CO (ppm)	HC (ppm)	NO_x (ppm)
	Analyzer Emission Ranges	**0 - 25**	**0 - 20**	**0 - 500**	**0 - 1000**	**0 - 100**
Zero	**Zero Calibration Gas (Low-Range Values)**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
	Allowable Zero Drift (Less Than ± 3% of Range)	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
	Zero Calibration - 10:08 AM	0.11	0.04	0.07	0.05	0.02
	Zero Drift Check - 2:09 PM	0.10	0.09	-0.21	-0.73	1.86
	Total Drift Over Test Period	**0.01**	**0.05**	**0.28**	**0.78**	**1.84**
	Was the Zero Drift Within Allowable Deviation?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Span	**Span Calibration Gas (High-Range Values)**	**20.90**	**12.20**	**397.80**	**443.71**	**84.37**
	Allowable Span Drift (Less Than ± 3% of Range)	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
	Span Calibration - 10:15 AM	20.91	12.07	182.45	443.51	84.42
	Span Drift Check - 2:04 PM	20.77	12.07	180.32	449.61	85.51
	Total Drift Over Test Period	**0.14**	**0.00**	**2.13**	**6.10**	**1.09**
	Was the Span Drift Within Allowable Deviation?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**9.03**	**9.22**	**182.20**	**443.00**	**17.80**
	Allowable Linearity Drift (Less Than ±1% of Range)	**0.25**	**0.20**	**5.00**	**10.00**	**1.00**
	Linearity Check - 10:19 AM	9.15	8.03	78.83	443.42	17.91
	Difference From Mid-Range Values	**0.12**	**1.19**	**103.37**	**0.42**	**0.11**
	Was the Linearity Within Allowable Deviation?	**Yes**	**No**	**No**	**Yes**	**Yes**
	Linearity Check - 2:06 PM	9.12	8.04	77.88	449.70	19.51
	Difference From Mid-Range Values	**0.09**	**1.18**	**104.32**	**6.70**	**1.71**
	Was the Linearity Within Allowable Deviation?	**Yes**	**No**	**No**	**Yes**	**No**

December 21, 2004 (Maximum Manifold Pressure Test)

	Zero, Span & Linearity Data Maximum Manifold Pressure Test December 21, 2004	O_2 (%)	CO_2 (%)	CO (ppm)	HC (ppm)	NO_x (ppm)
	Analyzer Emission Ranges	**0 - 25**	**0 - 20**	**0 - 500**	**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 - 9:04 AM	0.11	0.05	0	-0.32	0.02
Zero	Zero Drift Check - 12:10 PM	0.10	0.06	0.37	-0.32	0.00
Zero	**Total Drift Over Test Period**	**0.01**	**0.01**	**0.37**	**0.00**	**0.02**
Zero	**Was the Zero Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Span	**Span Calibration Gas (High-Range Values)**	**20.90**	**12.20**	**397.80**	**443.71**	**84.37**
Span	**Allowable Span Drift (Less Than ± 3% of Range)**	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
Span	Span Calibration - 9:20 AM	20.91	12.05	182.20	443.25	84.50
Span	Span Drift Check - 12:05 PM	20.89	12.01	187.93	444.34	84.73
Span	**Total Drift Over Test Period**	**0.02**	**0.04**	**5.73**	**1.09**	**0.23**
Span	**Was the Span Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**9.03**	**9.22**	**182.20**	**443.00**	**17.80**
Linearity	**Allowable Linearity Drift (Less Than ±1% of Range)**	**0.25**	**0.20**	**5.00**	**10.00**	**1.00**
Linearity	Linearity Check - 9:26 AM	9.18	8.03	78.55	443.63	17.98
Linearity	**Difference From Mid-Range Values**	**0.15**	**1.19**	**103.65**	**0.63**	**0.18**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**No**	**No**	**Yes**	**Yes**
Linearity	Linearity Check - 12:08 PM	9.16	7.98	80.97	443.83	18.02
Linearity	**Difference From Mid-Range Values**	**0.13**	**1.24**	**101.23**	**0.83**	**0.22**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**No**	**No**	**Yes**	**Yes**

December 21, 2004 (Normal/Pulsating Input Test)

	Zero, Span & Linearity Data Smooth/Pulsating Input Test December 21, 2004	O_2 (%)	CO_2 (%)	CO (ppm)	HC (ppm)	NO_x (ppm)
	Analyzer Emission Ranges	**0 - 25**	**0 - 20**	**0 - 500**	**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 Drift Check - 12:15 PM	0.07	0.06	0.02	-0.46	-0.01
Zero	Zero Drift Check - 3:36 PM	0.10	0.06	0.10	-0.28	-0.22
Zero	**Total Drift Over Test Period**	**0.03**	**0.00**	**0.08**	**0.18**	**0.21**
Zero	**Was the Zero Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Span	**Span Calibration Gas (High-Range Values)**	**20.90**	**12.20**	**397.80**	**443.71**	**84.37**
Span	**Allowable Span Drift (Less Than ± 3% of Range)**	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
Span	Span Drift Check - 12:20 PM	20.89	12.05	182.21	443.89	84.45
Span	Span Drift Check - 3:30 PM	20.92	12.05	181.40	441.48	84.70
Span	**Total Drift Over Test Period**	**0.03**	**0.00**	**0.81**	**2.41**	**0.25**
Span	**Was the Span Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**9.03**	**9.22**	**182.20**	**443.00**	**17.80**
Linearity	**Allowable Linearity Drift (Less Than ±1% of Range)**	**0.25**	**0.20**	**5.00**	**10.00**	**1.00**
Linearity	Linearity Check - 12:23 PM	9.14	8.01	78.62	444.34	18.00
Linearity	**Difference From Mid-Range Values**	**0.11**	**1.21**	**103.58**	**1.34**	**0.20**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**No**	**No**	**Yes**	**Yes**
Linearity	Linearity Check - 3:33 PM	9.18	8.01	78.31	440.59	17.90
Linearity	**Difference From Mid-Range Values**	**0.15**	**1.21**	**103.89**	**2.41**	**0.10**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**No**	**No**	**Yes**	**Yes**

Appendix E: Calculations

Emission Concentrations

Corrected to 3% O_2

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

Where

ppm = Measured CO, HC & NO_x concentrations, by volume

% O_2 = Measured O_2 Concentration

Ultimate CO_2

$$\text{Ult. CO}_2 = \text{Raw CO}_2 \times \left[\frac{20.9}{20.9 - \text{Raw O}_2}\right]$$

Where

Ult. CO_2 = Ultimate CO_2 (%)

Raw CO_2 = Measured CO_2 Concentration (%)

Raw O_2 = Measured O_2 Concentration (%)

% Excess Air

Constituent	Balanced Chemical Composition	Theo. Air	Theo. Flue Gas
Methane (CH_4)	$CH_4 + 2O_2 + 2(3.78)N_2$ ==> $1CO_2 + 2H_2O + 2(3.78)N_2$	9.56	8.56
Ethane (C_2H_6)	$C_2H_6 + 3.5O_2 + 3.5(3.78)N_2$ ==> $2CO_2 + 3H_2O + 3.5(3.78)N_2$	16.73	15.23
Propane (C_3H_8)	$C_3H_8 + 5O_2 + 5(3.78)N_2$ ==> $3CO_2 + 4H_2O + 5(3.78)N_3$	23.90	21.90
i-Butane (C_4H_{10})	$C_4H_{10} + 6.5O_2 + 6.5(3.78)N_2$ ==> $4CO_2 + 5H_2O + 6.5(3.78)N_5$	31.07	28.57
n-Butane (C_4H_{10})	$C_4H_{10} + 6.5O_2 + 6.5(3.78)N_2$ ==> $4CO_2 + 5H_2O + 6.5(3.78)N_6$	31.07	28.57
i-Pentane (C_5H_{12})	$C_5H_{12} + 8O_2 + 8(3.78)N_2$ ==> $5CO_2 + 6H_2O + 8(3.78)N_7$	38.24	35.24
n-Pentane (C_5H_{12})	$C_5H_{12} + 8O_2 + 8(3.78)N_2$ ==> $5CO_2 + 6H_2O + 8(3.78)N_8$	38.24	35.24
Hexanes (C_6H_{14})	$C_6H_{14} + 9.5O_2 + 9.5(3.78)N_2$ ==> $6CO_2 + 7H_2O + 9.5(3.78)N_9$	45.41	41.91

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).

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:

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

Air/Fuel Ratio

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

Equivalence Ratio (Φ)

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

Gas Meter Correction

To determine the corrected SCFH for each appliance tested, the accuracy of the DTM-200 gas meter was checked to determine the correction factor for each meter (Tables shown below).

Given the range of the input rate, the slope (m) of the line was determined setting y = average correction percentage and x = cubic feet per hour (cfh). Next, the y-intercept/correction factor (b) was determined using the y-intercept equation (y = mx + b). Once the correction factor (b) is known, the y-intercept equation was used again to calculate the corrected SCFH; this time x = uncorrected SCFH value.

Model Number: DTM-200A **Date:** August 1, 2004 **Meter Number:** U258696 **Prepared By:** Joe Garcia 2 CU. FT. BELL NO. 4087 CPUC CERTIFICATE OF BELL PROVER ACCURACY # 1004						
REPEATABILITY						
CFH	**% CORR.**	**% CORR.**	**% CORR.**	**% CORR.**	**% CORR.**	**Average**
50	0.78	0.67	0.48	0.58	0.53	**0.61**
100	0.57	0.58	0.66	0.72	0.66	**0.64**
150	0.85	0.84	0.95	1.18	1.11	**0.99**
200	0.78	1.03	0.90	0.87	0.88	**0.89**

Barometric Pressure Correction

Using the Standard Atmosphere Data for Altitudes to 60,000 ft Table (Table 3, *ASHRAE Fundamentals Handbook - 1989*, pg. 6.12) the barometric pressure at the test facility elevation was determined by linear interpolation. This value was subtracted from the barometric pressure value at sea level (29.921 in. Hg or 14.696 psia) to obtain the correction value. The correction value was subtracted from the barometric pressure reading specific to the hour and day of testing and then it was converted to absolute pressure (psia) using the following equation:

$$\text{Baro. Press (in.Hg)} \times \left[\frac{14.696 \text{ psia}}{29.921 \text{ in. Hg}}\right] = \text{Baro.Press (psia)}$$

SCFH (Uncorrected)

$$\text{SCFH} = \text{ACFH} \times \left[\frac{P_{Fuel}(\text{psig}) + P_{Barometric}(\text{psia})}{P_{standard}}\right] \times \left[\frac{T_{standard}}{T_{Fuel}(^{o}\text{F}) + 459.67}\right]$$

Where

SCFH = Standard Cubic Feet per Hour (Uncorrected)

ACFH = Actual Cubic Feet per Hour

P_{Fuel} = Gas Supply Pressure (psig)

$P_{Barometric}$ = Barometric Pressure (psia)

$P_{standard}$ = Standard Pressure (14.696 psia)

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

T_{Fuel} = Fuel Temperature (°F)

Corrected SCFH

$$\text{Corrected SCFH} = \text{SCFH} + \text{Meter Correction Factor}$$

Input Rate (Btu/cf)

$$\text{Input Rate} = \text{Corrected SCFH} \times \text{HHV}$$

Where

Corrected SCFH = Corrected Standard Cubic Feet per Hour (cf/hr.)

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

Carbon Number (Based on Heating Value)

$$C_f = \frac{2 \times HHV}{1771} - 0.130$$

Where

C_f = Carbon Number (dimensionless number)

HHV = Higher Heating Value (Btu/cf)

Heat Output (Instantaneous water heaters w/ input ratings above 75,000 Btu/hr)

$$H_o = C_{p,avg} \times (T_{del} - T_{in}) \times V \times D_i$$

Where

H_o = Heat Output (Btu)

$C_{p,avg}$ = Specific heat of water at $\frac{T_{del} + T_{in}}{2}$ (Btu/lb °F)

T_{del} = Average delivery/outlet temperature (°F)

T_{del} = Average inlet temperature (°F)

V = Volume of water withdrawn (gallons)

D_i = Density of water at the average inlet temperature (lb/gallon)

NO_X Emission (ng/J Heat Output)

$$N = \frac{5211 \times C_f \times P \times F}{H_o \times C}$$

Where

N = Emissions of NO_X as NO_2 (ng/J)

C_f = Carbon Number (dimensionless number)

P = NO_X concentration in flue gas (ppm; vol)

F = Volume of fuel burned (cf @ 30 in. Hg & 60°F)

H_o = Heat Output (Btu)

C = Concentration of CO_2 measured in flue gas (%)

Appendix F: Test Equipment

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 Chromatigraph	Agilent	6890	± 0.5 BTU/scf
K Thermocouple	Omega Engineering Co.	KMQSS	2.2°C or 0.75%
J Thermocouple	Omega Engineering Co.	JMQSS	2.2°C or 0.75%
R Thermocouple	Omega Engineering Co.	RMQSS	2.2°C or 0.75%
T Thermocouple	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 CFH at low pressure (~8" w.c.). The test rig is illustrated below