LNG Research Study

Legacy Residential Water Heater

November 2004

Prepared By:

The Southern California Gas Company
Engineering Analysis Center – Applied Technologies
Jorge Gutierrez
Firas Hamze
Juan R. Mora
Andre Saldivar

Acknowledgements

The authors express appreciation to the following associates whose efforts contributed much to the success of this project.

Monica Clemens
Alfonso Duarte
David Kalohi
Johnny Lozano
William F. Raleigh
Larry Sasadeusz
Rod Schwedler
Kevin Shea
Dale Tomlinson

Disclaimer

LEGAL NOTICE

- The Southern California Gas Company, its officers, employees, and contractors, make no warranty, expressed or implied, and assume no legal liability for accuracy of the information contained in this report; neither do they individually or collectively assume any liability with respect to the use of such information or report or for any damages which may result from the use of or reliance on any information, apparatus, methods, or process disclosed or described in or by this report.
- No information contained in this report can be copied, reported, quoted, or cited in any way in publications, papers, brochures, advertising, or other publicly available documents without the prior written permission of the Southern California Gas Company.

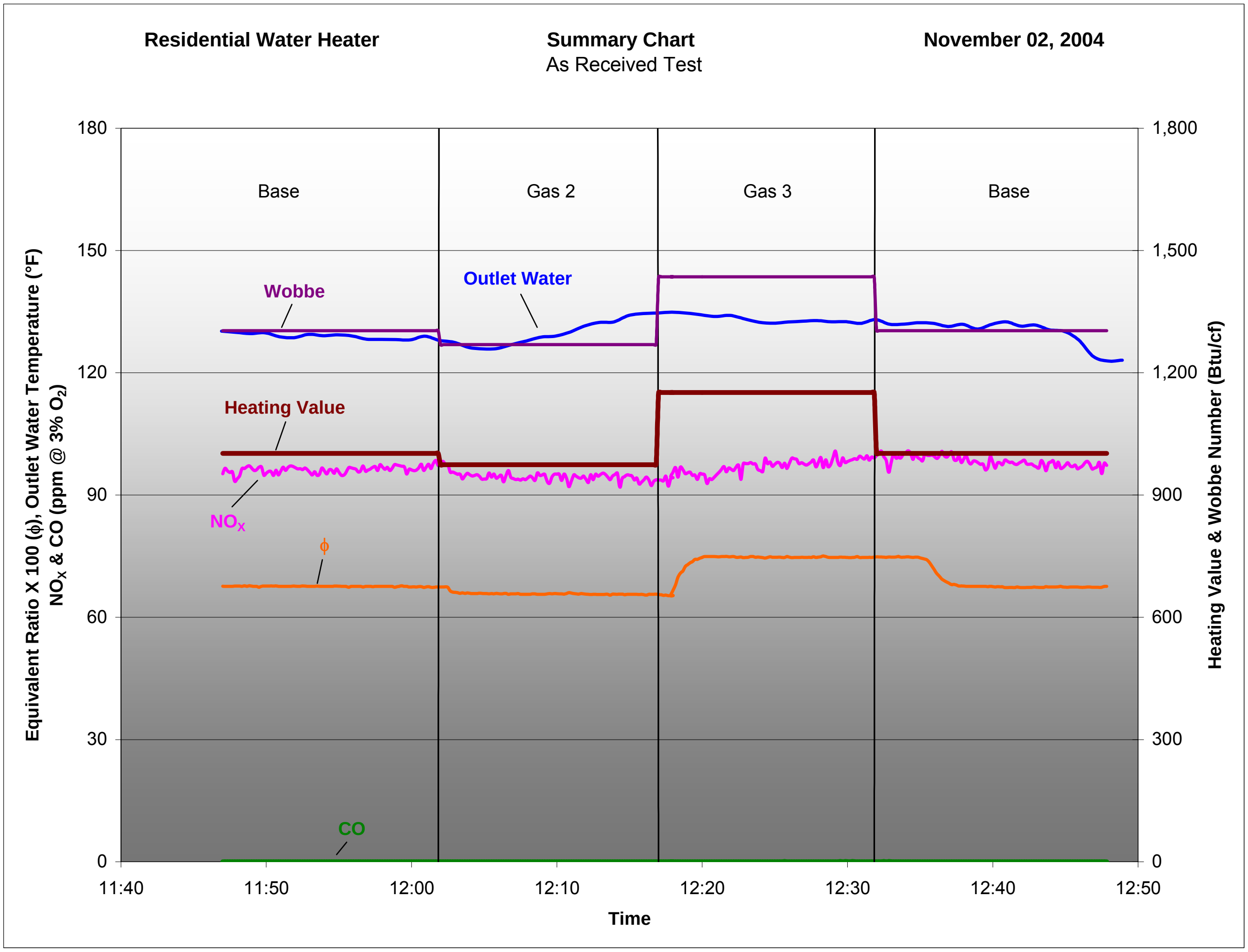
Table of Contents

Results Summary

Results obtained for all tests conducted with different gases reveal (a) there were no operational, ignition, flame stability, or safety problems during testing of each gas or during transitions between gases and (b) NO_X emissions did not exceed 100 ppm (corrected to 3% O_2).

As Received Test

NO_X values ranged from 94.4 ppm (Gas 2) to 97.5 ppm (Baseline Gas – 2nd run) while CO values were negligible. Along with Baseline Gas, only the lowest Wobbe/lowest heat content gas (Gas 2) and the highest Wobbe/highest heat content gas (Gas 3) were tested because no operational and/or safety problems were encountered while testing with these two Substitute Gases. Therefore, testing of all other Substitute Gases was not necessary (refer to Appendix A, Section 6.2).

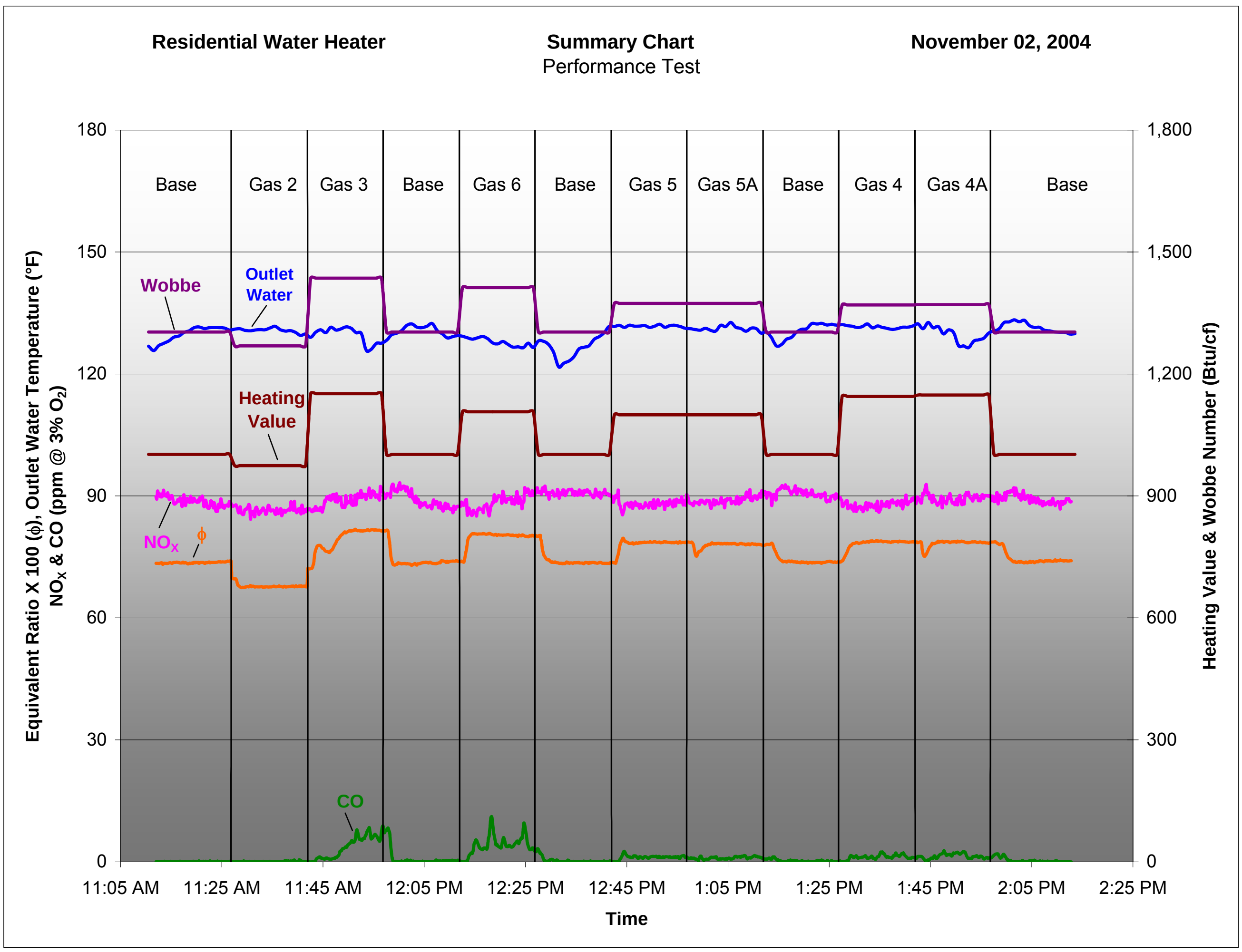


NOTE: Emission test results are for information purposes, they were not the result of certified tests.

Performance Test

NO_X values ranged from 86.5 ppm (Gas 2) to 90.8 ppm (Baseline Gas – 3rd run). Gas 2 and all Baseline Gas runs (low-heat content gases) had CO values that were neglegible while all high-heat content gases ranged from 1.0 ppm (Gas 5A) to 5.7 ppm (Gas 3 – highest CO value).

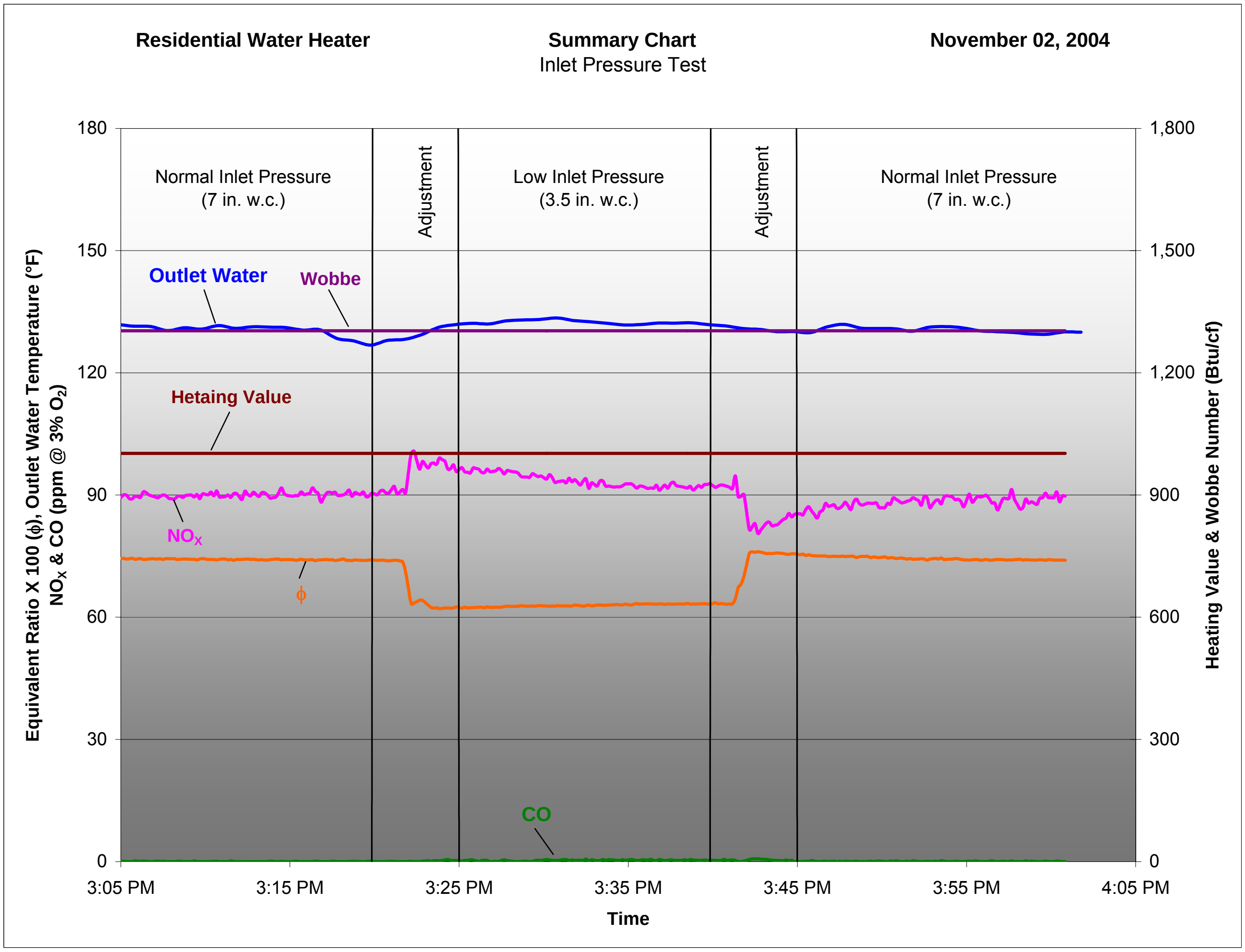
The water heater was under fired 3.93% (1st run) to 6.46% (5th run) during all Baseline Gas runs. All high-heat content gases over fired the appliance 1.75% (Gas 4A) to 7.97% (Gas 3).



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

Input Pressure Test

Using Baseline Gas only the Normal and Low Inlet Pressures were tested because the manifold pressure at Increased Inlet Pressure was not greater than the manifold pressure at Normal Inlet Pressure (refer to Appendix A, Section 6.4). The highest NO_X value was observed at Low Inlet Pressure (93.6 ppm) followed by the 1st and 2nd Normal Inlet Pressure runs (90.0 ppm and 88.2 ppm) while CO values were negligible.



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

Equipment Selection Criteria

A legacy water heater was selected due to their large volume in our territory and because we wanted to corroborate data from previous studies that showed these water heaters could operate on natural gases with a wide range of calorific values and compositions.

Equipment Specifications

- **Description:** 40 Gallon Residential Water Heater (Manufactured 1995)
- **Burner:** 4½ inch diameter atmospheric burner
- **Input rating:** 32,000 Btu/hr
- **Type of fuel:** Natural Gas
- **Required gas supply pressure:** 5 – 14" w.c.
- **Required manifold supply pressure:** 4" w.c.

Standards

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

- ANSI Z21.10.1-2001, Standard for Gas Water Heaters, Volume I
- South Coast Air Quality Management District Rule 1121, Control of NO_X Emission from Residential Type Natural Gas-Fired Water Heaters (last amended December 10, 1999)
- South Coast Air Quality Management District Protocol for Rule 1121 (last amended January 1998)

Installation

The residential water heater was installed according to the manufacturer's specifications without closet or alcove and tested inside an open laboratory. For easier access to the atmospheric burner, the water heater was placed on a level $20\frac{7}{8}" \times 20\frac{7}{8}" \times 18\frac{1}{4}"$ stand. A 30" × 30" piece of ¾" plywood was used as the top of the stand and painted flat black. Holes were made 4" from each corner of the top to allow for thermocouple placement (to measure floor temperature).

During each test, the inlet water temperature was maintained at 72 ± 4°F using a mixing valve and the outlet water temperature was maintained at 130 ± 5°F by continuously monitoring and manually adjusting outlet water flow. The appliance was set to the highest thermostat setting to prevent it from cycling off during testing.

Two gas delivery systems (identical in parts, assembly, and specifications) were utilized to supply Baseline and Substitute Gases to the water heater. A 3-way valve was used to connect both systems, allowing for interchangablility between various gases. Thermocouples were installed to measure the floor, inlet water, outlet water, tank, stack, flame gas and ambient temperatures. Pressure transducers were installed to measure the manifold pressure of the water heater and the supply pressure at the gas meter. A dry test gas meter was used to measure the gas flow and a water meter was installed to measure the inlet water flow.

No vent pipe was provided for the performance test and combustion product samples were taken with a single-point probe 3 inches inside the flue (of the water heater) just before the draft hood. All instrumantation and combustion product sampling was installed per standards mentioned in the previous section

Once all testing instruments were installed, the water heater was operated on Baseline Gas to verify the appliance and all instrumentation operated properly. Manifold pressure was not adjusted during set-up.

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 (1,303 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 (1,436 Btu/cf), highest-heat content gas (1,152 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 (1,373 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 (1,412 Btu/cf), high-heat content gas (1,107 Btu/cf)

Test Procedure

Test procedures were developed based on the above test standards. However, due to time limitations and variations between the different test standards, test procedures were simplified with input from consultants and information obtained from previous studies.

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:

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

After every test, the following steps were performed:

- Data was transferred from data logger to laptop.
- Linearity and drift inspections were performed on all emissions analyzers.

As Received Test

At normal inlet pressure (7.0 ± 0.3" w.c.), operate the water heater with Baseline Gas and verify the "as received" input rate 15 minutes after cold start. Once steady-state conditions were achieved, testing and collection of temperature, pressure and emissions data began. During this test, gases were run in the following order:

- Begin testing on Baseline Gas for 15 minutes
- Gas 2 for 15 minutes
- Gas 3 for 15 minutes
- Conclude testing by reestablishing Baseline Gas for 15 minutes

Since no operational and/or safety problems were encountered while testing with Gases 2 & 3, testing of all other Substitute Gases was not necessary.

Performance Test

Prior to the start of the test, the atmospheric burner was removed and a new gas orifice was made using a #37 drill to achieve water heater operation at rated input. The size of the orifice was determined using an Orifice Drill Size Chart from Southern California Gas Company established procedures.

At normal inlet pressure (7.0 ± 0.3" w.c.), the water heater was operated with Baseline Gas and the input rate was verified. Once steady-state conditions were achieved, testing and collection of temperature, pressure and emissions data began. During this test, gases were run in the following order:

- Begin testing on Baseline Gas for 15 minutes
- Gas 2 for 15 minutes
- Gas 3 for 15 minutes
- Reestablish Baseline Gas for 15 minutes
- Gas 6 for 15 minutes
- Reestablish Baseline Gas for 15 minutes
- Gas 5 for 15 minutes
- Gas 5A for 15 minutes
- Reestablish Baseline Gas for 15 minutes
- Gas 4 for 15 minutes
- Gas 4A for 15 minutes
- Conclude testing by reestablishing Baseline Gas for 15 minutes

Inlet Pressure Test

Prior to beginning the Inlet Pressure Test, the inlet test pressure was increased to 10" w.c. to determine if the manifold pressure at the increased inlet test pressure was greater than the manifold pressure at normal inlet test pressure. Since the manifold pressure remained unchanged, testing at the increased inlet pressure was not performed.

The water heater was adjusted back to normal inlet pressure (7.0" w.c.) while operating on Baseline Gas. Once steady-state conditions were achieved, testing and collection of temperature, pressure and emissions data began. During this test, Baseline Gas ran at the following inlet pressures:

- Normal Inlet Pressure (7.0" w.c.) for 15 minutes
- Adjustment to Low Inlet Pressure (3.5" w.c.) for 5 minutes
- Low Inlet Pressure (3.5" w.c.) for 15 minutes
- Adjustment to Normal Inlet Pressure (7.0" w.c.) for 5 minutes
- Conclude testing at Normal Inlet Pressure (7.0" w.c.) for 15 minutes

Cold Ignition Test

Using Baseline Gas, the water heater was adjusted to normal inlet pressure (7.0 ± 0.3" w.c.). The gas delivery system was purged of Baseline Gas with Gas 3. Using Gas 3, the water heater was ignited from a cold start and operated for one minute. Visual observations of the flame, ignition delays and other phenomena was documented. This process was repeated 2 more times, allowing the water heater to reestablish cold start conditions in between each ignition.

The gas delivery system was purged of Gas 3 with Gas 2. Using Gas 2, the water heater was ignited from a cold start and operated for one minute. Visual observations of the flame, ignition delays and other phenomena observed was documented. This process was repeated 2 more times, allowing the water heater to reestablish cold start conditions in between each ignition.

Hot Ignition Test

Using Baseline Gas, the water heater was adjusted to normal inlet pressure (7.0 ± 0.3" w.c.). The gas delivery system was purged of Baseline Gas with Gas 3. Using Gas 3, the water heater was ignited and operated for one minute. Visual observations of the flame, ignition delays and other phenomena was documented. This process was repeated 2 more times.

The gas delivery system was purged of Gas 3 with Gas 2. Using Gas 2, the water heater was ignited and operated for one minute. Visual observations of the flame, ignition delays and other phenomena was documented. This process was repeated 2 more times.

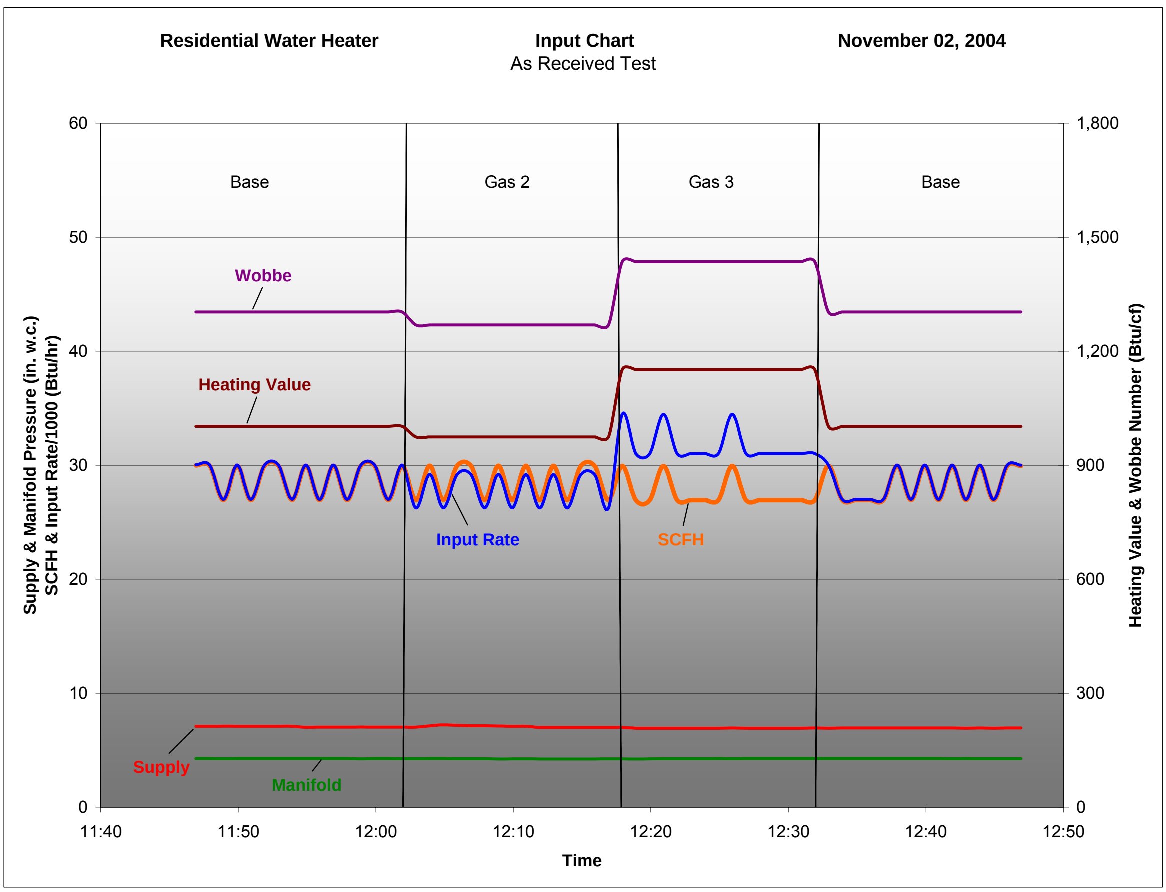
Results[1, 2]

As Received Test

Input

The residential water heater was received at approximately 9.73% below rated input. The highest input rate was observed for Gas 3 (31,706 Btu/hr) followed by Baseline Gas (28,886 Btu/hr - 1st run & 28,404 Btu/hr - 2nd run) and Gas 2 (27,813 Btu/hr). The gas flow rate for each of the gases tested fell within a range of 28 ± 1.0 scfh, with the highest gas flow rate observed during the 1st Baseline Gas run (28.8 scfh). Both manifold and supply pressures remained within the parameters set in the test protocol.

The fluctuation in gas flow (and input rate) originates from the number of pulses counted by the data logger during each minute. The number of pulses counted is dependant on the position of the dial relative to the location of the sensor and should vary no more than ± 0.05 cf per minute (since 1 pulse = 0.05 cf).



---

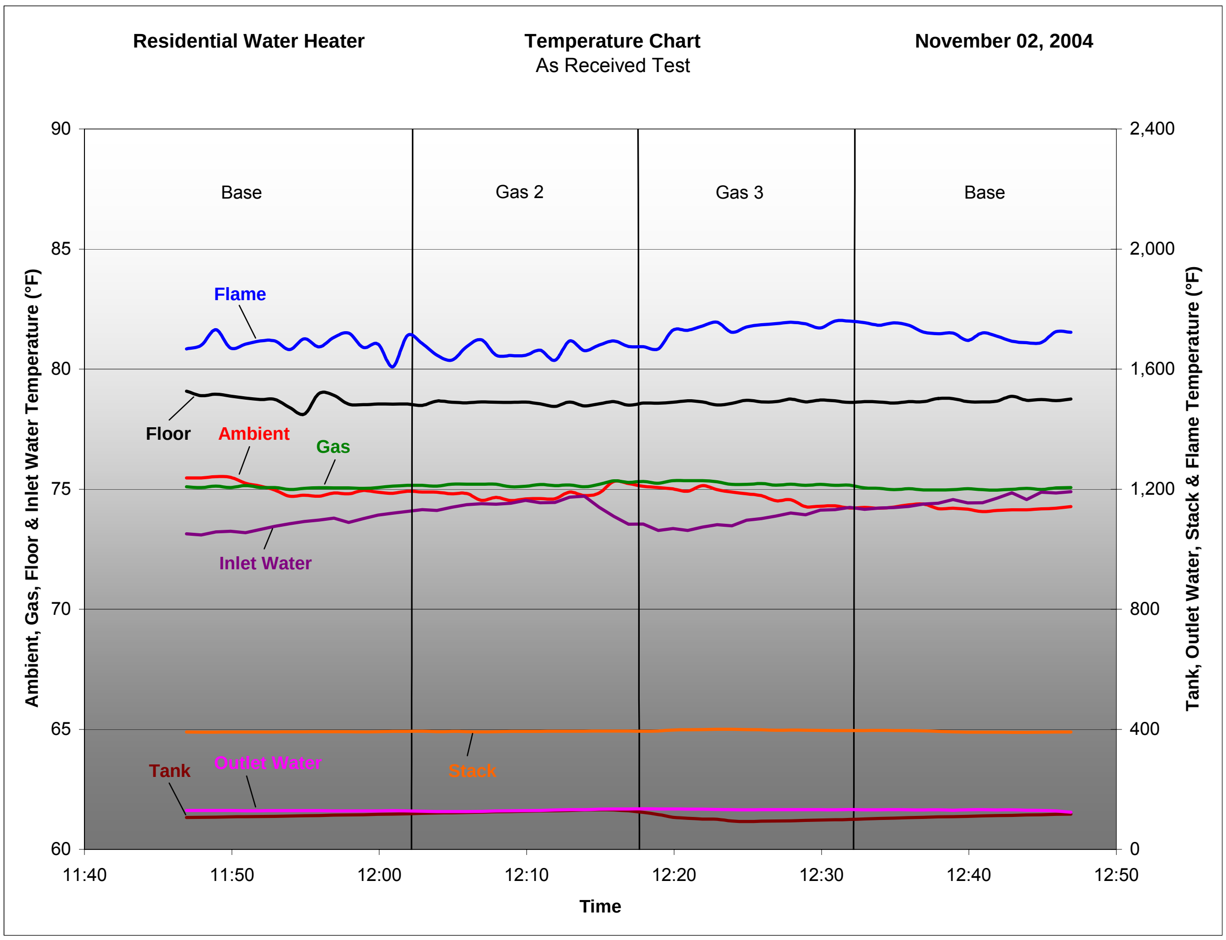
[1] All emissions, temperature and input values mentioned throughout the results section are average values.
[2] NO_X, CO & HC emissions values are corrected to 3% O_2.

Temperature

The highest flame temperature was observed with Gas 3 (1,735°F). Both Baseline Gas runs followed with temperatures of 1,720°F (2nd run) and 1,685°F (1st run) while the lowest flame temperature observed was with Gas 2 (1,665°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 (397.5°F) followed by Gas 2 (393.4°F). The lowest observed stack temperature was with Baseline Gas (391.7°F – 1st run). Tank temperature was highest with Gas 2 (126.5°F) and lowest with Gas 3 (101.1°F). Although most temperatures observed reacted to changes in gases tested, tank temperature values depended on the tank temperature prior to a switch in gas and the inlet and outlet water flow restrictions during each run.

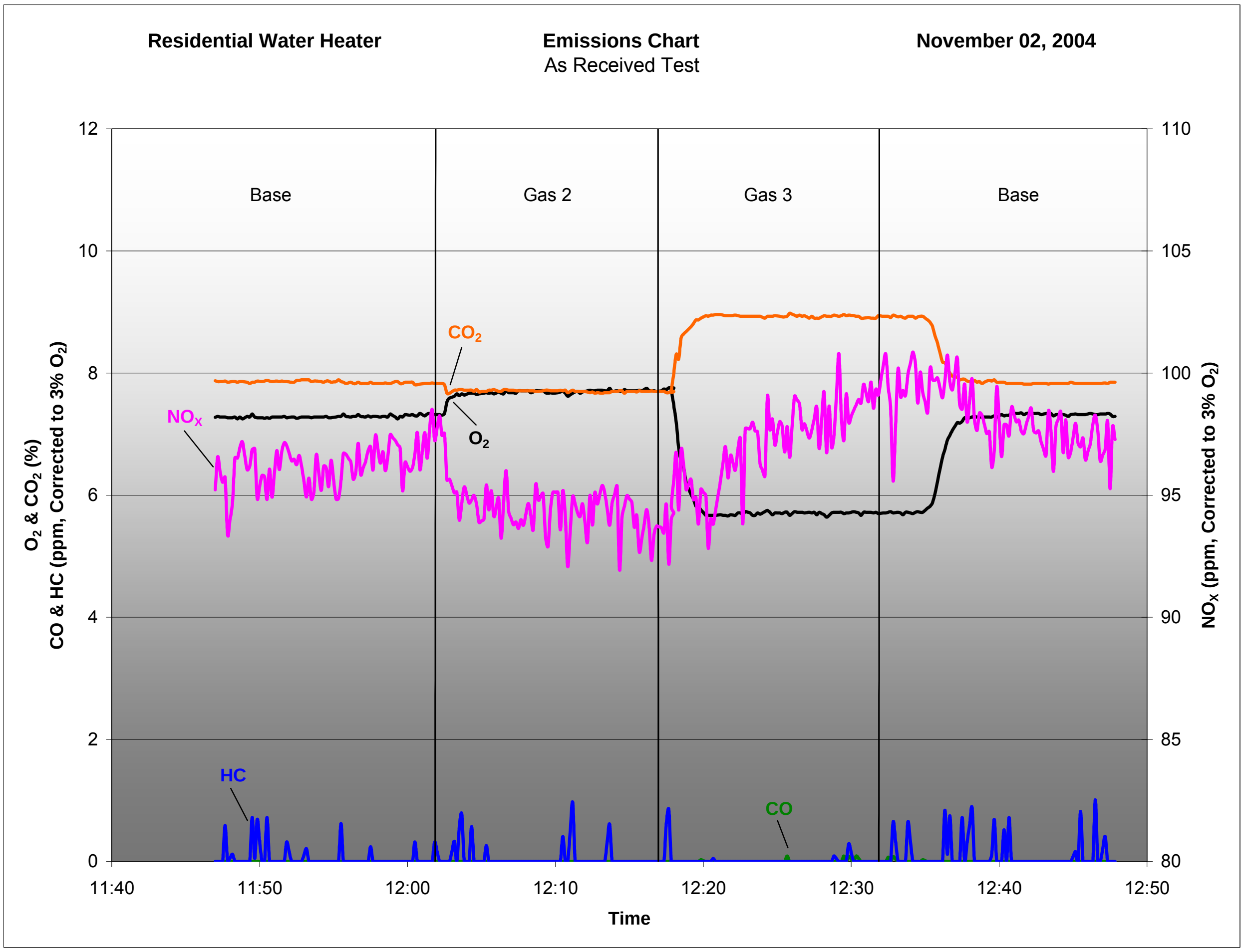
The floor temperatures varied slightly while ambient, inlet water and outlet water temperatures remained within the parameters set in the test protocol.



Emissions

NO_X emissions did not exceed 100 ppm with the highest values being observed with Baseline Gas (97.5 ppm – 2nd run) and Gas 3 (97.4 ppm). The lowest NO_X value was observed during the Gas 2 run (94.4 ppm). CO and HC emissions values were negligible.

High NO_X values during the beginning of the 2^{nd} Baseline Gas run may have been caused by the high combustion chamber temperatures produced during the Gas 3 run (highest Wobbe/highest-heat content gas run). The value referrenced in this section for the 2^{nd} Baseline Gas run does not include those values effected, rather, only values obtained once NO_X values became stable were evaluated. Gas 3 NO_X values did not reach steady-state conditions throughout the run, thus the average cited is approximately the midrange value.



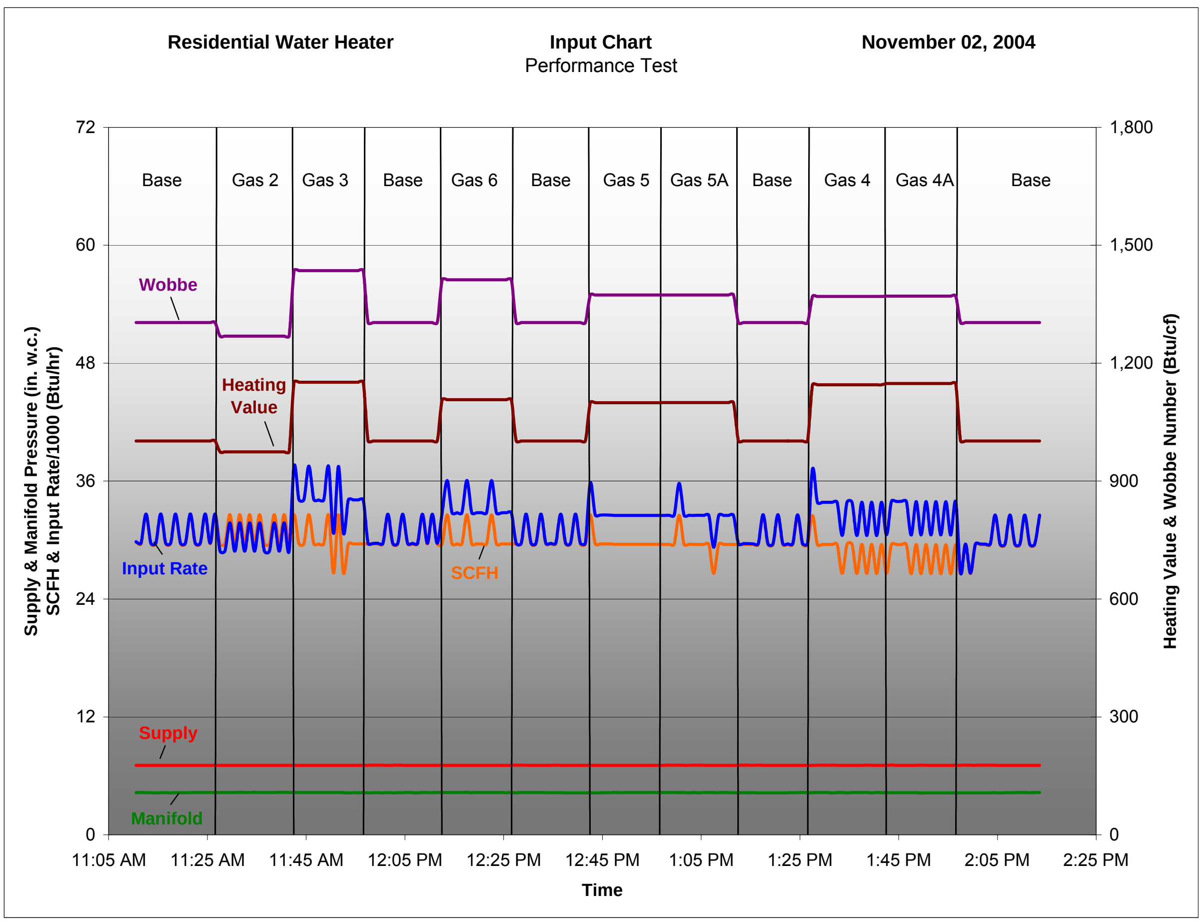
NOTE: Emission test results are for information purposes, they were not the result of certified tests.

Performance Test

Input

Once the gas orifice was changed, the water heater operated at approximately 3.93% below rated input. Some of the highest input rates observed were with Gas 3 (34,550 Btu/hr), Gas 6 (33,430 Btu/hr) and Gas 4 (33,167 Btu/hr). Baseline Gas runs ranged from 29,931 Btu/hr (5th run - lowest input rate) to 30,742 Btu/hr (1st run). The gas flow rate for each of the gases tested fell within a range of 28.4 scfh (Gas 4A – lowest gas flow rate) to 30.8 scfh (Gas 2 – highest gas flow rate). Also, both manifold and supply pressures remained within the parameters set in the test protocol.

The fluctuation in gas flow (and input rate) originates from the number of pulses counted by the data logger during each minute. The number of pulses counted is dependant on the position of the dial relative to the location of the sensor and should vary no more than ± 0.5 cf per minute (since 1 pulse = 0.5 cf).

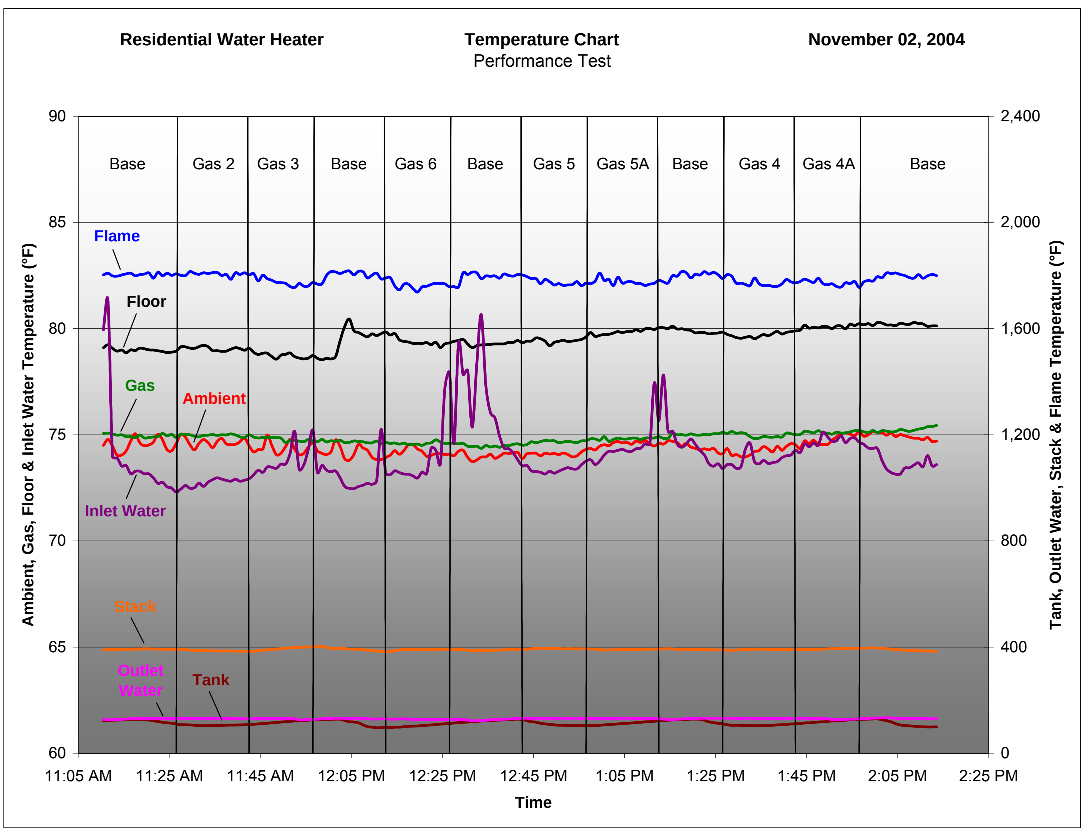


Temperature

The highest flame temperature was observed during the Gas 2 run (1,805°F), followed by all five Baseline Gas runs ranging from 1,803°F (1st run) to 1,795°F (3rd run). Flame temperatures ranging from 1,777°F (Gas 3) to 1,764°F (Gas 6 – lowest flame temperature) were observed for the high-heat content gases. 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 5 (393.8°F), Gas 3 (393.5°F) and Gas 4A (392.9°F). The lowest stack temperature was observed during the Gas 2 run (386.5°F) while Baseline Gas runs ranged from 389.2°F (3rd run) to 392.6°F (2nd run). Tank temperature was highest with the 4th Baseline Gas run (122.7°F) and lowest with Gas 6 (103.5°F). Although most temperatures observed reacted to changes in gases tested, tank temperature values depended on the tank temperature prior to a switch in gas and the inlet and outlet water flow restrictions during each run.

Floor temperatures ranged from 78.7°F (Gas 3) to 80.2°F (Baseline Gas – 5th run) while ambient and outlet water temperatures remained within the parameters set. For all runs, with the exception of the 3rd Baseline Gas run, inlet water temperature remained within the parameters set in the test protocol.

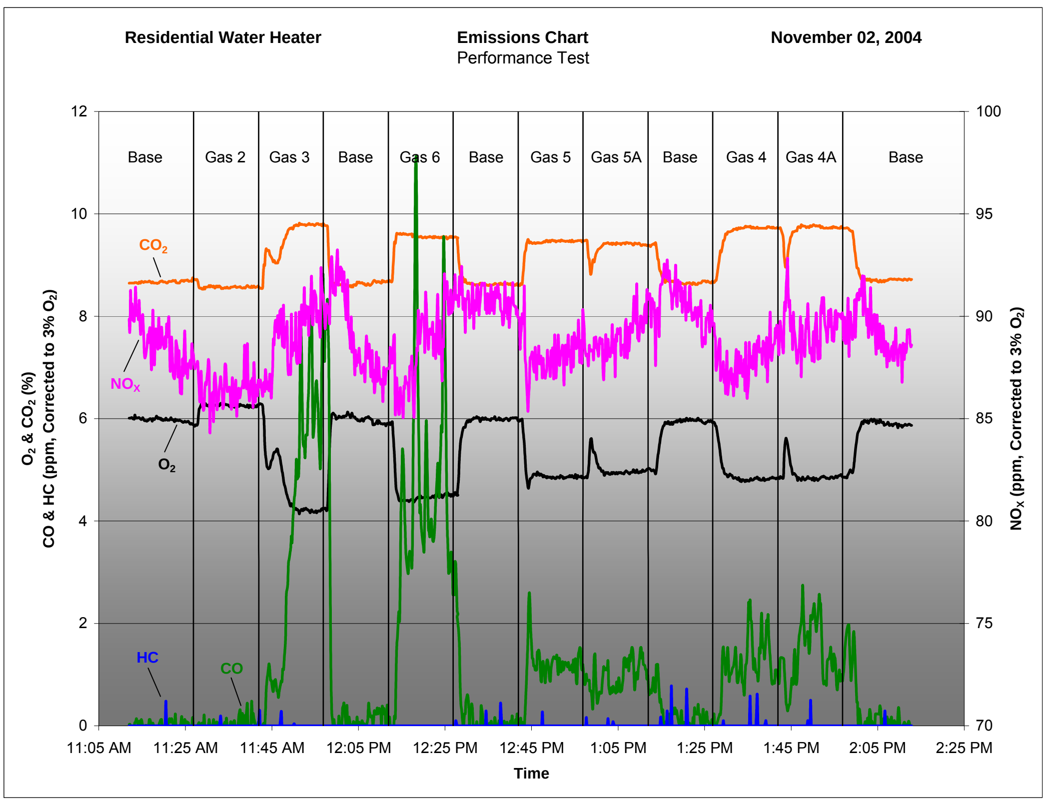


Emissions

NO_X emissions did not exceed 91 ppm for all gases tested. The highest values were observed with the 3rd and 4th Baseline Gas runs (90.8 ppm & 90.6 ppm), followed by Gas 4A (89.4 ppm). The lowest NO_X emissions value was observed with Gas 2 (86.5 ppm). High NO_X values during the beginning of the 2nd and 4th Baseline Gas runs may have been caused by the high combustion chamber temperatures generated from high the Wobbe/high-heat content gases. Also, NO_X values for Gases 3, 4, 5 and 5A did not reach steady-state conditions throughout the run, thus the average cited is approximately the midrange value.

Gas 2 and all Baseline Gas runs (low-heat content gases) had CO values of 0.4 ppm or less while all high-heat content gases ranged from 1.0 ppm (Gas 5A) to 5.7 ppm (Gas 3 – highest CO value). HC emissions values were neglegible.

During Gas 3, there was a gradual drop in O_2 emission values and a gradual increase in CO_2 emissions values. During runs with Gases 4A and 5A, there were sharp decreases in CO_2 emissions values and sharp increases in O_2 emissions values. Although reasons for these changes are unknown, the O_2 and CO_2 emissions averages taken for all three gases were during steady conditions and did not include values during these changes.



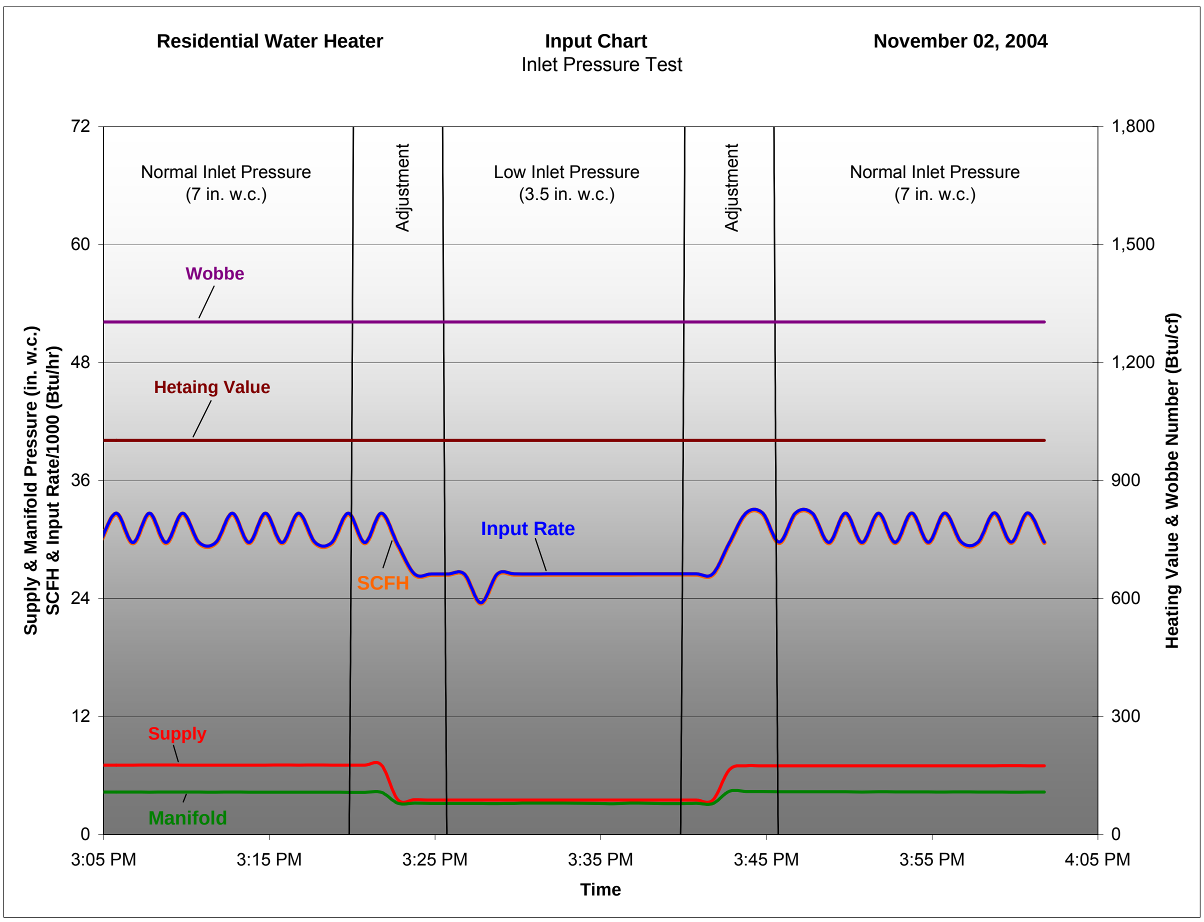
NOTE: Emission test results are for information purposes, they were not the result of certified tests.

Inlet Pressure Test

Input

The water heater operated at approximately 3.12% below rated input. The highest input and gas flow rates were observed during the 2nd Normal Inlet Pressure run (31,125 Btu/hr and 31.1 scfh) while the lowest input and gas flow rates were observed at Low Inlet Pressure (26,313 Btu/hr and 26.3 scfh). Manifold and supply pressures remained within the parameters set in the test protocol.

The fluctuation in gas flow (and input rate) originates from the number of pulses counted by the data logger during each minute. The number of pulses counted is dependant on the position of the dial relative to the location of the sensor and should vary no more than ± 0.5 cf per minute (since 1 pulse = 0.5 cf).

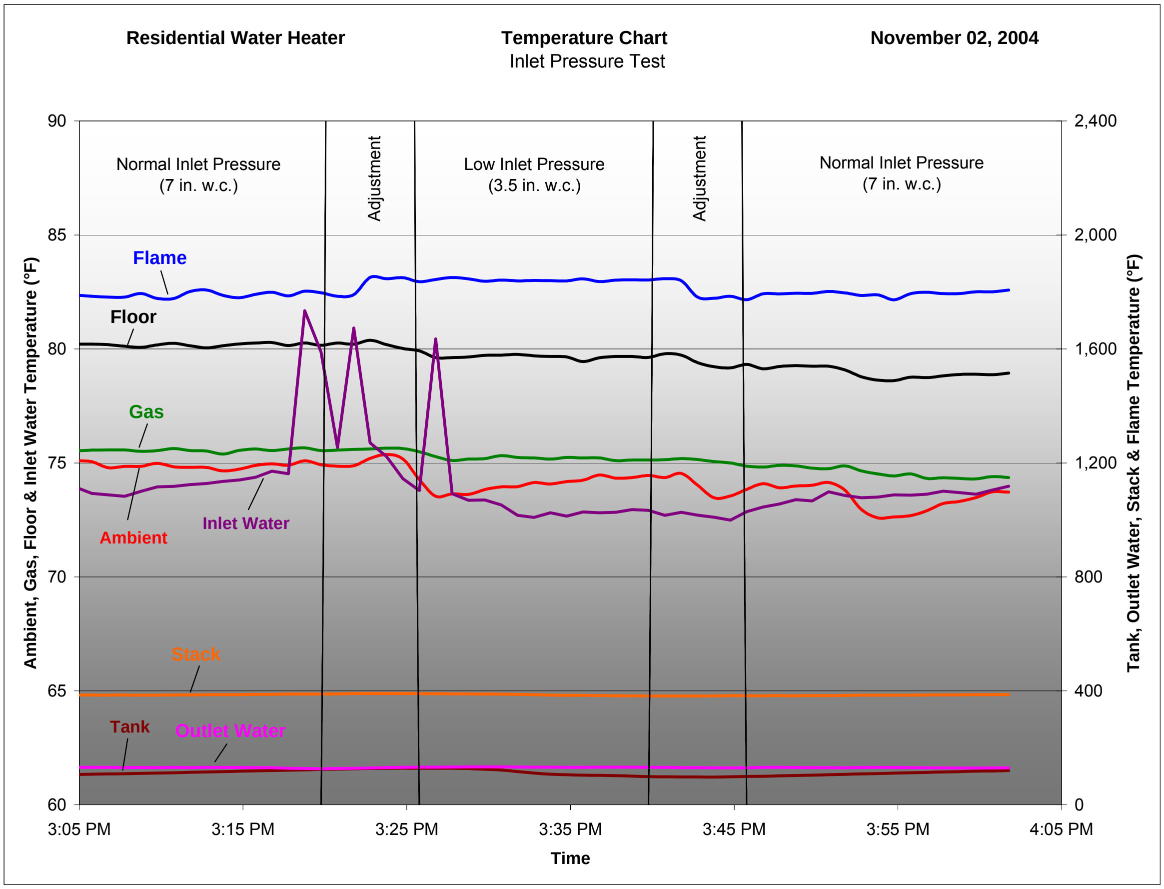


Temperature

The highest flame temperature was observed at Low Inlet Pressure (1,842°F), while the lowest flame temperature was observed during the 1st Normal Inlet Pressure run (1,790°F). Although most temperatures observed reacted to changes with the gases tested, the flame temperature depended on the location of the fixed thermocouple tip in the flame region.

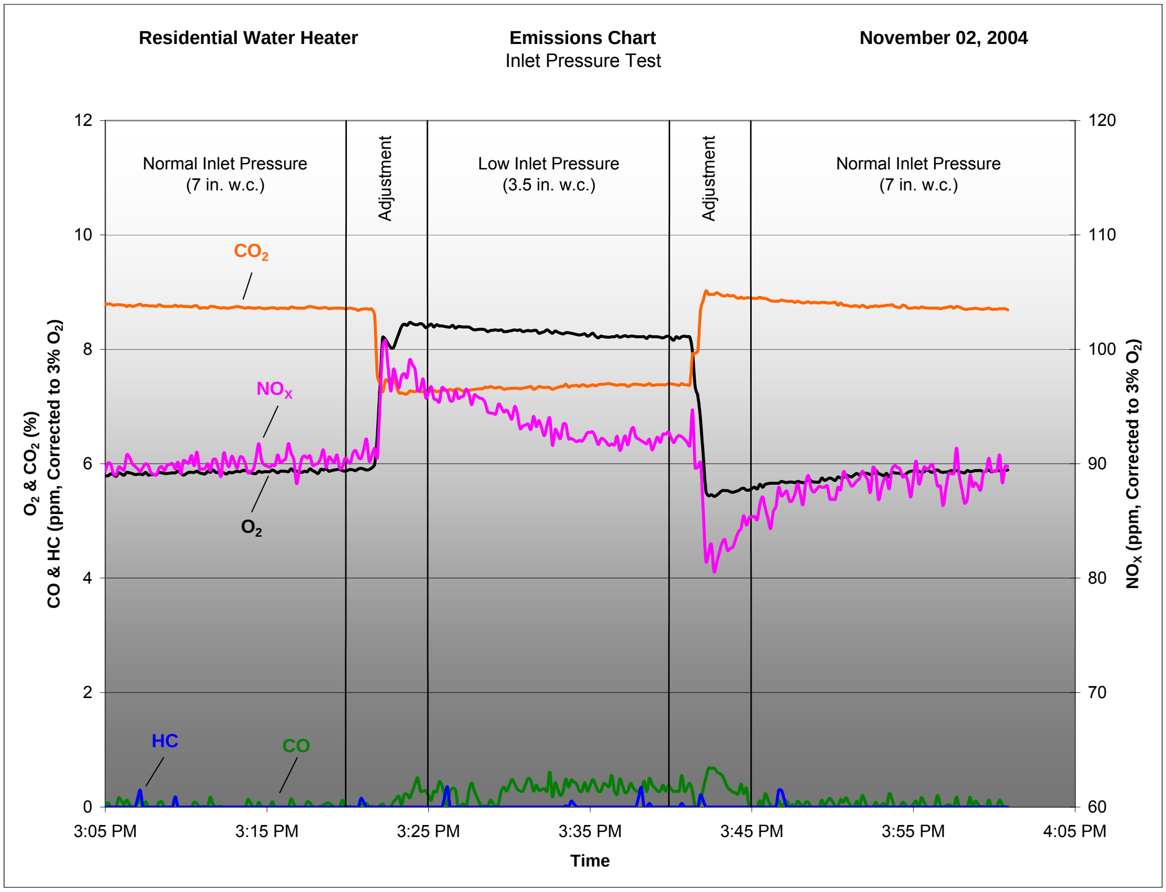
Tank temperature was highest during the 1st Normal Inlet Pressure run (114.9°F) and lowest during the 2nd Normal Inlet Pressure run (109.8°F). Although the flame temperature, as measured with a fixed thermocouple tip, fluctuated when different test gases were introduced. Some of the temperature fluctuations 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.

Changes in stack temperature were very small for both inlet pressures tests and remained stable throughout testing. Floor temperatures at both inlet pressures fell within the range of 80.0 ± 1.0°F. Ambient, inlet water and outlet water temperature remained within the parameters set in the test protocol.



Emissions

NO_X emissions did not exceed 94 ppm with the highest value being observed during the Low Inlet Pressure run (93.6 ppm). The lowest NO_X value was observed during the 2nd Normal Inlet Pressure run (88.2 ppm). CO and HC emissions values were neglegible at both Normal and Low Inlet Pressures.



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

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	Blue flame with continuous orange tipping
		2	Blue flame with continuous orange tipping
		3	Blue flame with continuous orange tipping
2	Normal and without delays	1	Blue flame with random orange tipping
		2	Blue flame with random orange tipping
		3	Blue flame with random orange tipping

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**
2	Normal and without delays	1	Blue flame with random orange tipping
		2	Blue flame with random orange tipping
		3	Blue flame with random orange tipping
3	Normal and without delays	1	Blue flame with continuous orange tipping
		2	Blue flame with continuous orange tipping
		3	Blue flame with continuous orange tipping

Appendix A: Test Protocol

1. Standards

- ANSI Z21.10.1-2001, Standard for Gas Water Heaters, Volume I
- South Coast Air Quality Management District Rule 1121, Control of NO_X Emission from Residential Type Natural Gas-Fired Water Heaters (last amended December 10, 1999)
- South Coast Air Quality Management District Protocol for Rule 1121 (last amended January 1998)

2. Equipment Specifications

- **Description:** 40 Gallon Residential Water Heater (Manufactured 1995)
- **Burner:** 4 ½ inch diameter atmospheric burner
- **Input rating:** 32,000 Btu/hr
- **Type of fuel:** Natural Gas
- **Required gas supply pressure:** 5 – 14” w.c.
- **Required gas manifold pressure:** 4” w.c.

3. Test Arrangement

3.1. Basic Set-up - The water heater will be operated in an open laboratory without closet or alcove, on a level stand and in accordance with manufacturer’s specifications. Underneath the water heater, a piece of ¾” thick plywood measuring 30” X 30” will be used for thermocouple placement to measure floor temperatures around the water heater. The surface of the plywood will be painted flat black.

3.2. Water Supply – Inlet water will be blended with a mixing valve as necessary to provide the required water temperatures and flow rates.

3.3. Internal Tank Temperature - A six-thermocouple assembly for internal tank temperature measurement is to be provided as required by section 7.1.5 of the AQMD Protocol.

3.4. Floor Temperature – One (1) thermocouple will be positioned at each corner of the plywood base around the water heater to measure radiant temperature.

3.5. Water Piping - Water piping and temperature measurement sites are to be per Figure 4 of the SCAQMD Protocol for Rule 1121 except that the horizontal portions of the water connections are not to be 24” above the heater as specified therein. Because much of the other testing is to be done per the ANSI standard (without a vent pipe) connections are to be made close to the top of the heater in a manner that will assure that combustion products do not contact the piping.

3.6. Draw Rate Control - Supply water pressure is to be regulated and a throttling valve and ball-type shutoff valve are to be provided in the outlet piping. The arrangement is to be such that water draw can be started or stopped without affecting a pre-set flow rate.

3.7. Vent Pipe - Per section 2.1.8 of Standard ANSI Z21.10.1, no vent pipe is to be provided for the performance test. Combustion product samples are to be taken with a single-point probe 3 inches inside the flue (of the water heater) just before the draft hood.

3.8. 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 if available, or at a tee in the gas piping at the heater connection.

3.9. Instrumentation - Instrumentation is to be per the SCAQMD Protocol for Rule 1121.

4. Basic Operating Condition

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

4.1. Ambient Temperature - Ambient temperature shall be maintained between 70 and 80°F. The thermocouple must be shielded from radiation and positioned at the approximate vertical midpoint of the water heater and 2 feet from the surface of the heater (Sections 4.1 & 7.1.6 of the SCAQMD Protocol for Rule 1121).

4.2. Inlet & Outlet Water Temperatures – Inlet water shall be supplied at 72 ± 4°F and outlet water is to be maintained at 130 ± 5°F (Section 4.2.1 of the SCAQMD Protocol for Rule 1121).

4.3. Inlet Water Pressure – The inlet water pressure must be adequate to maintain a steady inlet water flow rate and outlet water temperature throughout the entire test.

4.4. Normal Gas Supply Pressure - 7.0 ± 0.3” w.c.

4.5. Basic Firing Set-up - The basic firing setup is to be that combination of gas orifice size, supply pressure and water flow required to deliver rated input with Baseline Gas. Manifold pressure is to be within ± 10% of that specified on the rating plate.

5. 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 (1,303 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 (1,436 Btu/cf), highest-heat content gas (1,152 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 (1,373 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 (1,412 Btu/cf), high-heat content gas (1,107 Btu/cf)

6. Testing

6.1. Start-up Run

Operate water heater on Baseline Gas as received at normal gas supply pressure (7.0" w.c.) to verify that testing instrumentation (thermocouples, pressure transducers, data logger, etc.) is working properly and determine the approximate as received input rate after 15 minutes of operation. During this time, record temperature, pressure, gas flow and emissions data.

6.2. As Received

At normal inlet pressure (7.0" w.c.), operate the water heater with Baseline Gas and verify the input rate. Once steady-state conditions are achieved, begin testing and collection of temperature, pressure and emissions data. Unless otherwise specified, each run for Baseline and Substitute Gases will be 15 minutes. Also, manual switching between test gases should take approximately 14 seconds.

Continue steady-state water heater operation with Baseline Gas and then conduct a high-speed switch to Gas 2. Continue data acquisition (per above) while operating with Gas 2, observing changes in data before, during and after changeover.

Continue steady-state water heater operation with Gas 2 and then conduct a high-speed switch to Gas 3. Continue data acquisition (per above) while operating with Gas 3, observing changes in data before, during and after changeover.

Continue steady-state water heater operation with Gas 3 and then conduct a high-speed switch to re-establish Baseline Gas. If operational and/or safety problems were encountered while testing with Gases 2 & 3, all other Substitute Gases will be tested immediately after the 2nd Baseline Gas run in the following order:

- Gas 6 (High Wobbe: 1,412 Btu/cf)
- Re-establish Baseline Gas (Low Wobbe: 1,302 Btu/cf)
- Gas 5 (Medium Wobbe: 1,374 Btu/cf)
- Gas 5A (Medium Wobbe: 1,374 Btu/cf)
- Re-establish Baseline Gas (Low Wobbe: 1,302 Btu/cf)
- Gas 4 (Medium Wobbe: 1,370 Btu/cf)
- Gas 4A (Medium Wobbe: 1,371 Btu/cf)
- Conclude with Baseline Gas (Low Wobbe: 1,302 Btu/cf)

If no problems were encountered while testing with Gases 2 & 3, the test will conclude after the 2nd Baseline Gas run. At the conclusion of this test, shut down the water heater, remove the burner assembly and examine the combustion chamber for the presence of soot by means of the white cloth technique. If soot is found, clean the chamber and repeat testing with suspect gas blend(s); selected on the basis of yellow tipping observations during testing. Establish which gas(es) tends to burn with soot deposition.

6.3. Performance Test

Begin drawing water when the mean tank temperature reaches 130°F and adjust draw rate to maintain an outlet water temperature of 130 ± 5°F. At normal gas supply pressure (7.0” w.c.), operate the water heater with Baseline Gas and verify the input rate. (**Note:** *If necessary, the gas orifice may be changed to achieve the required input rate for this test*). Once steady-state conditions are achieved, begin testing and collection of temperature, pressure and emissions data. Unless otherwise specified, each run for Baseline and Substitute Gases will be 15 minutes. Also, switching between test gases should take approximately 14 seconds.

Continue steady-state water heater operation with Baseline Gas and then conduct a high-speed switch to Gas 2. Continue data acquisition (per above) while operating with Gas 2, observing changes in data before, during and after changeover.

Continue steady-state water heater operation with Gas 2 and then conduct a high-speed switch to Gas 3. Continue data acquisition (per above) while operating with Gas 3, observing changes in data before, during and after changeover.

Continue steady-state water 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 changeover.

The remaining Substitute Gases will be tested in the following order:

- Gas 6 (High Wobbe: 1,412 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 4 (Medium Wobbe: 1,370 Btu/cf)
- Gas 4A (Medium Wobbe: 1,371 Btu/cf)
- Conclude testing with Baseline Gas (Low Wobbe: 1,302 Btu/cf)

At the conclusion of this test, shut down the water heater, remove the burner assembly and examine the combustion chamber for the presence of soot by means of the white cloth technique. If soot is found, clean the chamber and repeat testing with suspect gas blend(s); selected on the basis of yellow tipping observations during testing. Establish which gas(es) tends to burn with soot deposition.

6.4. Input Pressure Test (Baseline Gas Only)

Adjust the water heater to normal inlet pressure (7.0” w.c.) while operating on Baseline Gas. Once steady-state conditions are obtained, begin testing and collection of temperature, pressure and emissions data. Unless otherwise specified, each Baseline Gas run will be 15 minutes and each adjustment period between inlet pressures will be 5 minutes. Also, switching between test gases should take approximately 14 seconds.

Continue steady-state water heater operation at normal inlet pressure, and then make a gradual adjustment to low inlet pressure (3.5” w.c.). Continue data acquisition (per above) during adjustment, observing changes in data before, during and after inlet pressure adjustment. Once steady-state conditions are met, the low inlet pressure test will begin.

Continue steady-state water heater operation at low inlet pressure, and then make a gradual adjustment to increased inlet pressure (10” w.c.). Continue data acquisition (per above) during adjustment, observing changes in data before, during and after inlet pressure adjustment. Once steady-state conditions are met, the increased inlet pressure test will begin.

Continue steady-state water heater operation at increased inlet pressure, and then make a gradual adjustment to reestablish normal gas supply pressure. Continue data acquisition (per above) during adjustment, observing changes in data before, during and after gas supply pressure adjustment. Once steady-state conditions are met, the normal gas supply pressure test will begin. The Input Pressure Test will conclude once the last run at normal inlet pressure is complete.

At the conclusion of this test, shut down the water heater, remove the burner assembly and examine the combustion chamber for the presence of soot by means of the white cloth technique. If soot is found, clean chamber and repeat testing with suspect gas blend(s); selected on the basis of yellow tipping observations during testing. Establish which gas(es) tends to burn with soot deposition.

(NOTE: Prior to beginning the Inlet Pressure Test, increase the inlet test pressure to 10” w.c. If the manifold pressure at the increased inlet test pressure is not greater than the manifold pressure at normal inlet test pressure, tests at the increased inlet test pressure need not be conducted per ANSI Z21.10.1-2001).

6.5. Ignitions Test

6.5.1. Cold Ignition

Using Baseline Gas, adjust the water heater to normal gas supply pressure (7.0” w.c.). Purge the gas delivery system of Baseline Gas with Gas 3. Using Gas 3, ignite the water heater from a cold start for one minute. Document visual observations of the flame, ignition delays and any other phenomena observed. Repeat this process 2 more times, allowing the water heater to re-establish cold start conditions in between each ignition.

Purge the gas delivery system of Gas 3 with Gas 2. Using Gas 2, ignite the water heater from a cold start for one minute. Document visual observations of the flame, ignition delays and any other phenomena observed. Repeat this process 2 more times, allowing the water heater to re-establish cold start conditions in between each ignition.

6.5.2. Hot Ignition

Using Baseline Gas, adjust the water heater to normal gas supply pressure (7.0” w.c.). Purge the gas delivery system of Baseline Gas with Gas 3. Using Gas 3, ignite the water heater for one minute. Document visual observations of the flame, ignition delays and any other phenomena observed. Repeat this process 2 more times.

Purge the gas delivery system of Gas 3 with Gas 2. Using Gas 2, ignite the water heater for one minute. Document visual observations of the flame, ignition delays and any other phenomena observed. Repeat this process 2 more times.

7. 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.

8. Calculations

CO, HC & NO_X emissions values (Corrected to 3% O_2) are to be calculated per the AQMD protocol for Rule 1121. Other calculations are to be per standard practice.

9. Measurement

The following test measurements will be taken:

- Gas Delivery System Parameters (Temperatures & Pressures)
- Supply & Manifold Pressure
- Fuel Gas Temperature
- Ambient Temperature
- Flame Temperature
- Stack Temperature
- Inlet Water and Outlet Water Temperatures
- Floor Temperatures
- Gas Flow Rate
- Inlet Water Flow Rate

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 “start-up run” during which the water heater will be operated “as received” on Baseline Gas. After testing under “as received” conditions, “performance” data is to be obtained with the water heater adjusted to its rated input. The gas orifice size and supply pressure required to achieve that condition with Baseline Gas are to be maintained during subsequent testing with other gas blends.

Allowing water heater operation to “float” with gas blend allows conclusion that a performance change is related only to the gas. The “as received” start-up data provides a basis for inference as to how factory de-rating practices might have affected performance.

Water piping connections:

The SCAQMD Protocol for Rule 1121 requires in Figure 4 that the horizontal portions of the water pipe connections be 24” above the heater. Adhering to that dimension creates problems (exhaust product impingement) during most other testing, which, per the ANSI Standard, is conducted without vent pipe. To save test setup time, lower pipe connections are to be used for all testing. The effect, if any, on NO_X emission is expected to be small. Since all tests will be conducted with the same arrangement, any differences can be attributed to gas blend changes, not the water piping.

Appendix B: Table of Averages

As Received Test

Table of Averages Residential Water Heater As Received Test November 2, 2004				
Gases	**Base**	**2**	**3**	**Base**
HHV (Btu/cf)	1,002	974	1,152	1,002
Wobbe (Btu/cf)	1,303	1,269	1,436	1,303
Input Rate (Btu/hr)	28,886	27,813	31,706	28,404
Corrected SCFH	28.8	28.5	27.5	28.2
Emissions (not from certified tests)				
Raw O_2 (%)	7.3	7.7	5.7	7.3
Raw CO_2 (%)	7.9	7.7	8.9	7.8
CO (ppm @ 3% O_2)	0.0	0.0	0.0	0.0
HC (ppm @ 3% O_2)	0.1	0.1	0.0	0.1
NO_X (ppm @ 3% O_2)	96.2	94.4	97.4	97.5
Ultimate CO_2 (%)	12.1	12.2	12.3	12.1
Equivalence Ratio (Φ)	0.68	0.66	0.75	0.67
Temperatures (°F)				
Ambient	75.0	74.8	74.7	74.2
Gas	75.1	75.2	75.2	75.0
Stack	391.7	393.4	397.5	392.6
Tank	111.9	126.5	101.1	110.1
Flame	1,685	1,665	1,735	1,720
Floor	78.7	78.6	78.6	78.7
Inlet Water	73.5	74.3	73.7	74.5
Outlet Water	129.0	129.8	133.2	130.8
Pressures				
Supply (in. w.c.)	7.1	7.1	6.9	6.9
Manifold (in. w.c.)	4.3	4.2	4.3	4.3

Performance Test

Table of Averages Residential Water Heater Performance Test November 3, 2004												
Gases	**Base**	**2**	**3**	**Base**	**6**	**Base**	**5**	**5A**	**Base**	**4**	**4A**	**Base**
HHV (Btu/cf)	1,002	974	1,152	1,002	1,107	1,002	1,099	1,100	1,002	1,145	1,148	1,002
Wobbe (Btu/cf)	1,303	1,269	1,436	1,303	1,412	1,303	1,373	1,374	1,303	1,370	1,371	1,303
Input Rate (Btu/hr)	30,742	30,019	34,550	30,454	33,430	30,464	32,739	32,515	30,208	33,167	32,559	29,931
Corrected SCFH	30.7	30.8	30.0	30.4	30.2	30.4	29.8	29.6	30.1	29.0	28.4	29.9
Emissions (not from certified tests)												
Raw O_2 (%)	6.0	6.3	4.2	6.0	4.5	6.0	4.9	5.0	5.9	4.8	4.8	5.9
Raw CO_2 (%)	8.7	8.6	9.8	8.6	9.6	8.6	9.5	9.4	8.7	9.7	9.7	8.7
CO (ppm @ 3% O_2)	0.0	0.1	5.7	0.1	3.9	0.4	1.2	1.0	0.1	1.2	1.4	0.1
HC (ppm @ 3% O_2)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NO_X (ppm @ 3% O_2)	88.7	86.5	89.0	89.1	88.4	90.8	88.1	88.9	90.6	87.9	89.4	89.2
Ultimate CO_2 (%)	12.1	12.2	12.3	12.1	12.2	12.1	12.3	12.3	12.1	12.6	12.7	12.1
Equivalence Ratio (Φ)	0.74	0.68	0.81	0.74	0.80	0.74	0.79	0.78	0.74	0.79	0.79	0.74
Temperatures (°F)												
Ambient	74.5	74.7	74.4	74.2	74.2	74.0	74.1	74.6	74.4	74.2	74.8	74.9
Gas	75.0	75.0	74.8	74.7	74.6	74.5	74.7	74.8	75.0	75.0	75.1	75.2
Stack	391.8	386.5	393.5	392.6	389.5	389.2	393.8	391.1	391.3	390.6	392.9	390.2
Tank	121.8	105.7	117.1	115.7	103.5	121.8	110.6	111.7	122.7	105.8	119.6	112.1
Flame	1,803	1,805	1,777	1,802	1,764	1,795	1,776	1,776	1,798	1,774	1,772	1,796
Floor	79.0	79.1	78.7	79.4	79.4	79.3	79.4	79.8	79.9	79.7	80.1	80.2
Inlet Water	74.0	72.7	73.7	73.1	73.9	76.3	73.4	74.4	74.6	73.8	74.7	73.7
Outlet Water	129.7	130.7	129.6	130.5	127.8	126.7	131.8	131.2	130.5	131.6	129.7	131.4
Pressures												
Supply (in. w.c.)	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
Manifold (in. w.c.)	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3

Inlet Pressure Test

Table of Averages Residential Water Heater Inlet Pressure Test November 3, 2004			
Gases	**Normal (7" w.c)**	**Low (3.5" w.c.)**	**Normal (7" w.c)**
HHV (Btu/cf)	1,002		
Wobbe (Btu/cf)	1,303		
Input Rate (Btu/hr)	31,003	26,313	31,125
Corrected SCFH	30.9	26.3	31.1
Emissions (not from certified tests)			
Raw O_2 (%)	5.8	8.3	5.8
Raw CO_2 (%)	8.7	7.3	8.8
CO (ppm @ 3% O_2)	0.0	0.3	0.0
HC (ppm @ 3% O_2)	0.0	0.0	0.0
NO_X (ppm @ 3% O_2)	90.0	93.6	88.2
Ultimate CO_2 (%)	12.1	12.2	12.1
Equivalence Ratio (Φ)	0.74	0.63	0.74
Temperatures (°F)			
Ambient	74.9	74.1	73.5
Gas	75.6	75.2	74.6
Stack	386.4	386.3	384.7
Tank	114.9	114.0	109.8
Flame	1,790	1,842	1,793
Floor	80.2	79.7	79.0
Inlet Water	74.9	73.5	73.5
Outlet Water	130.4	132.4	130.5
Pressures			
Supply (in. w.c.)	7.1	3.5	7.0
Manifold (in. w.c.)	4.3	3.2	4.3

Appendix C: Test Gases

Gas Analysis Sample Date	Baseline 10/22/04	2 8/5/04	3 7/27/04	4 8/5/04	4A 7/27/04	5 8/18/04	5A 7/19/04	6 8/7/04
COMPONENTS	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**
C6 + 57/28/14	0.0193	0.0307	0.0297	0.1858	0.0406	0.0737	0.0435	0.0000
NITROGEN	1.8773	1.0866	0.0609	1.0608	1.0782	0.8003	0.7777	0.0000
METHANE	94.5236	95.8713	86.7978	84.9713	84.3951	88.8139	90.8094	91.6800
CARBON DIOXIDE	1.3922	2.9973	0.0000	3.0005	3.0516	1.4074	1.4130	0.0000
ETHANE	1.4587	0.0000	9.3416	4.7846	0.0220	5.2987	0.0230	5.5300
PROPANE	0.2748	0.0141	2.7663	2.4015	11.3998	2.6048	6.9175	1.7500
i-BUTANE	0.0503	0.0000	1.0037	1.1936	0.0094	0.0022	0.0113	0.5200
n-BUTANE	0.0478	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	0.0152	0.0000	0.0000	0.5944	0.0000	0.1567	0.0000	0.0000
n-PENTANE	0.0102	0.0000	0.0000	0.6001	0.0000	0.0000	0.0000	0.0000
OXYGEN	0.3305	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
TOTAL	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**
Compressibility Factor	0.998	0.998	0.997	0.997	0.997	0.997	0.997	0.998
HHV (Btu/real cubic foot)	**1002.09**	**974.40**	**1151.62**	**1145.13**	**1148.33**	**1099.38**	**1099.82**	**1107.06**
LHV (Btu/real cubic foot)	902.92	877.27	1041.31	1035.92	1039.51	993.10	993.61	999.82
Specific Gravity	0.5911	0.5895	0.6434	0.6989	0.7018	0.6407	0.6410	0.6143
WOBBE Index	**1303.42**	**1269.12**	**1435.73**	**1369.72**	**1370.73**	**1373.49**	**1373.72**	**1412.47**

Appendix D: Zero, Span and Linearity Tables

November 2, 2004 (As Received Test)

	Zero, Span & Linearity Data As Received Test November 2, 2004	**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 - 7:44 AM	0.12	-0.02	-0.03	0.61	0.11
Zero	Zero Drift Check - 4:41 PM	0.03	0.04	-0.01	-0.85	-0.35
Zero	**Total Drift Over Test Period**	**0.09**	**0.06**	**0.02**	**1.46**	**0.46**
Zero	**Was the Zero Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Span	**Span Calibration Gas (High-Range Values)**	**20.90**	**12.00**	**182.40**	**443.00**	**84.37**
Span	**Allowable Span Drift (Less Than ± 3% of Range)**	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
Span	Span Calibration - 7:55 AM	20.90	12.05	182.29	443.56	84.38
Span	Span Drift Check - 4:21 PM	20.88	12.00	184.36	438.49	86.31
Span	**Total Drift Over Test Period**	**0.02**	**0.05**	**2.07**	**5.07**	**1.93**
Span	**Was the Span Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**9.03**	**8.00**	**81.60**	**443.00**	**17.80**
Linearity	**Allowable Linearity Drift (Less Than ±1% of Range)**	**0.25**	**0.20**	**2.00**	**10.00**	**1.00**
Linearity	Linearity Check - 7:59 AM	9.13	8.04	78.25	446.80	17.97
Linearity	**Difference From Mid-Range Values**	**0.10**	**0.04**	**3.35**	**3.80**	**0.17**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**Yes**	**No**	**Yes**	**Yes**
Linearity	Linearity Check - 4:28 PM	9.14	7.98	78.98	438.07	18.16
Linearity	**Difference From Mid-Range Values**	**0.11**	**0.02**	**2.62**	**4.93**	**0.36**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**Yes**	**No**	**Yes**	**Yes**

November 3, 2004 (Performance & Inlet Pressure Tests)

	Zero, Span & Linearity Data Performance & Inlet Pressure Test November 3, 2004	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 - 8:28 AM	0.14	0.06	0.16	-0.07	-0.03
Zero	Zero Drift Check - 4:14 PM	0.07	0.10	0.11	-0.55	-0.17
Zero	**Total Drift Over Test Period**	**0.07**	**0.04**	**0.05**	**0.48**	**0.14**
Zero	**Was the Zero Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Span	**Span Calibration Gas (High-Range Values)**	**20.90**	**12.00**	**182.40**	**443.00**	**84.37**
Span	**Allowable Span Drift (Less Than ± 3% of Range)**	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
Span	Span Calibration - 8:36 AM	20.92	12.06	182.34	442.99	84.42
Span	Span Drift Check - 4:07 PM	20.83	12.02	181.93	434.35	85.46
Span	**Total Drift Over Test Period**	**0.09**	**0.04**	**0.41**	**8.64**	**1.04**
Span	**Was the Span Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**9.03**	**8.00**	**81.60**	**443.00**	**17.80**
Linearity	**Allowable Linearity Drift (Less Than ±1% of Range)**	**0.25**	**0.20**	**2.00**	**10.00**	**1.00**
Linearity	Linearity Check - 8:39 AM	9.18	8.04	78.86	443.46	17.91
Linearity	**Difference From Mid-Range Values**	**0.15**	**0.04**	**2.74**	**0.46**	**0.11**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**Yes**	**No**	**Yes**	**Yes**
Linearity	Linearity Check - 4:10 PM	9.12	8.00	78.66	433.94	17.99
Linearity	**Difference From Mid-Range Values**	**0.09**	**0.00**	**2.94**	**9.06**	**0.19**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**Yes**	**No**	**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

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

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)	$CH_4 + 2O_2 + 2(3.78)N_2 \Rightarrow 1CO_2 + 2H_2O + 2(3.78)N_2$	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

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 (Table 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**

SCFH (Uncorrected)

$$SCFH = ACFH \times \left[\frac{P_{Fuel}\,(psig) + P_1\,(psia)}{P_{standard}} \right] \times \left[\frac{T_{standard}}{T_{Fuel}\,(^{o}F) + 459.67} \right]$$

Where

SCFH = Standard Cubic Feet per Hour

ACFH = Actual Cubic Feet per Hour

P_{Fuel} = Gas Supply Pressure (psig)

P_1 = Average Pressure in Los Angeles @ average elevation of 257 ft (psia)

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

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

T_{Fuel} = Fuel Temperature (°F)

SCFH (Corrected)

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

Input Rate (Btu/cf)

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

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

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
Water Temperature Mixing Valve	Powers	434	n/a

Appendix G: Test Set-Up/Schematic

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