LNG Research Study

Gravity Vented Wall Furnace (Legacy)

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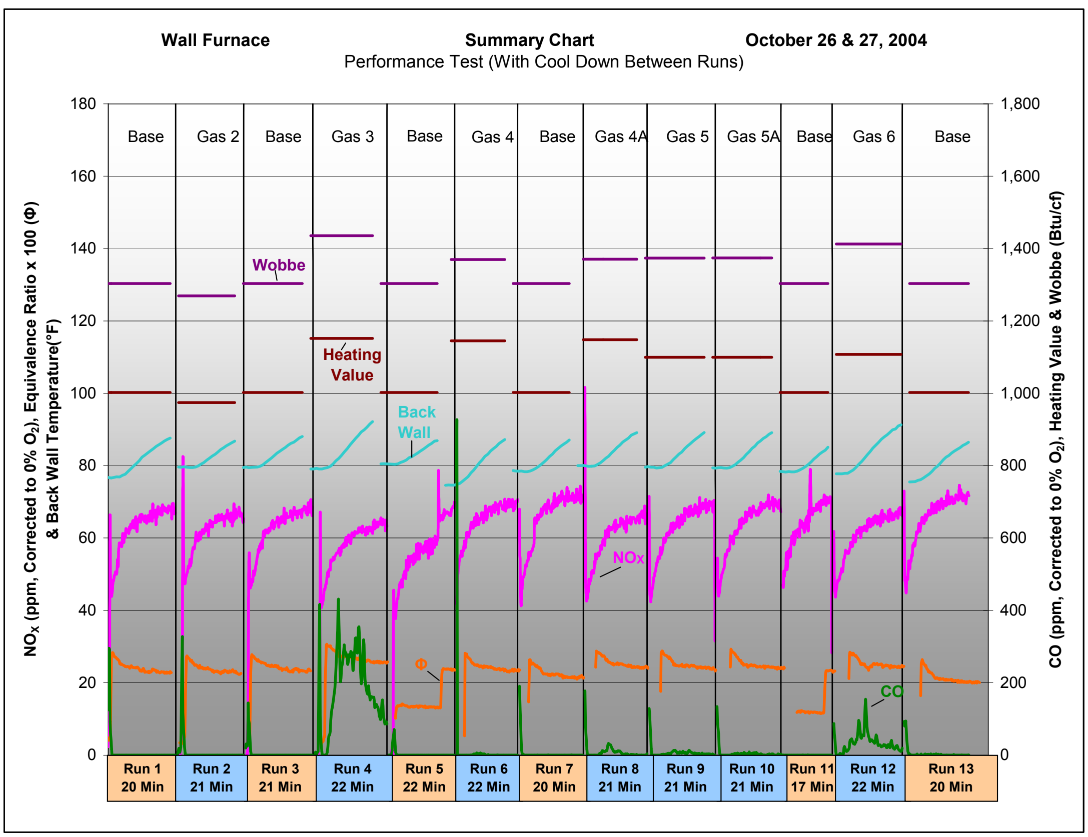
Results Summary

Results obtained from all tests conducted reveal (a) there were no operational, ignition, flame stability, or safety problems; (b) none of the temperatures monitored had critical changes; (c) the highest average CO emissions were recorded while running on Gas 3 (184 ppm, Corrected to 0% O_2 - Air Free); and (d) the lowest average NO_X emissions were recorded while running on Gas 3 (59 ppm, Corrected to 0% O_2 - Air Free).

Performance Test (with Cool Down Between Runs)

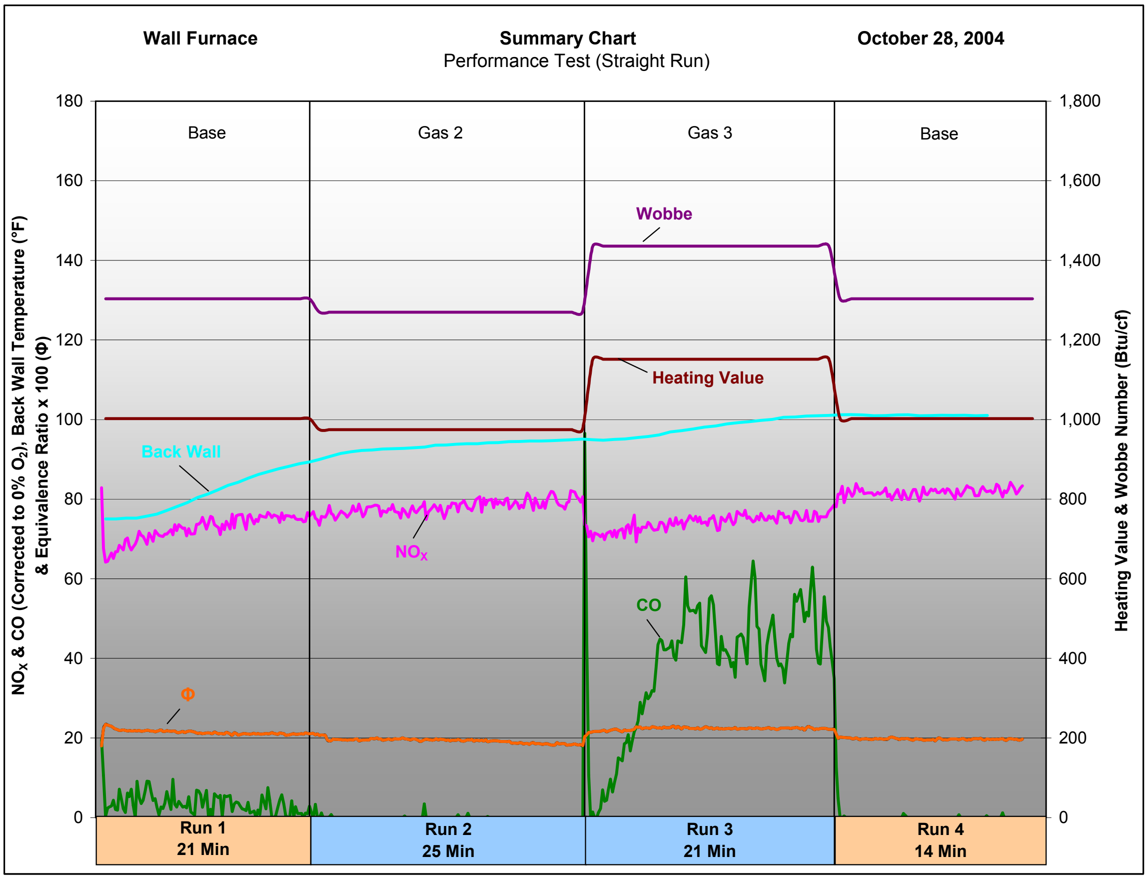
The gravity vented wall furnace (wall furnace) average input rate for the 1st Baseline Gas run was 35,740 Btu/hr. Average CO emissions values were highest with Gas 3 (183 ppm, Corrected to 0% O_2) and Gas 6 (34 ppm, Corrected to 0% O_2) but below 8 ppm with the remaining high Wobbe Number/high heat content gases (Gases 4, 4A, 5 and 5A). Unexpected combustion characteristics changes were experienced with Runs 5 and 11 (Baseline Gas runs) that could not be explained. Omitting runs 5 and 11, NO_X emissions were lowest with Gases 3, 4A and 6.



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

Performance Test (Straight Run)

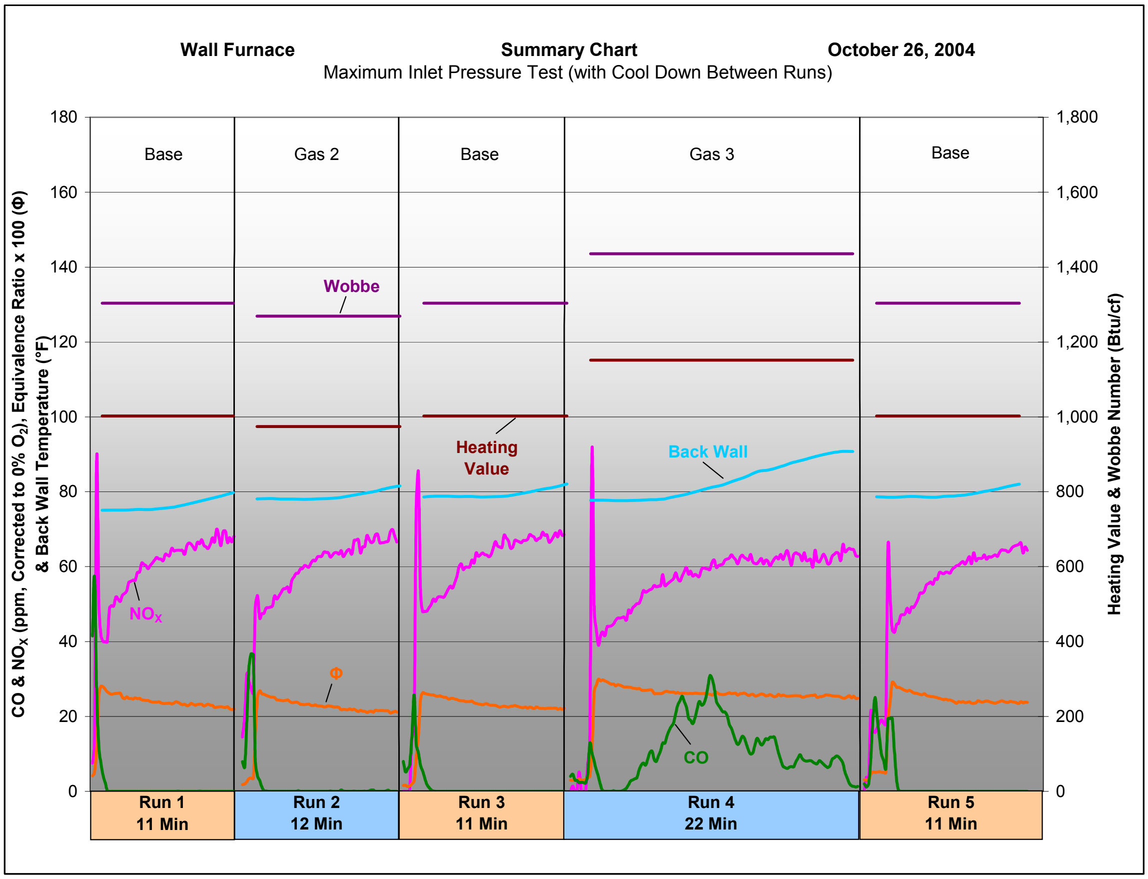
The wall furnace input rate for the 1st Baseline Gas run was 33,370 Btu/hr, 4.6% below rated input. An average CO emissions value of 38 ppm (Corrected to 0% O_2) was observed for Gas 3 while average CO emissions values for Gas 2 and the 2nd Baseline Gas runs were insignificant. Average NO_X emissions values for the first three runs (Baseline Gas, Gas 2 & Gas 3) were between 72 and 78 ppm (Corrected to 0% O_2) but increased above 80 ppm (Corrected to 0% O_2) for the 4th run (Baseline Gas).



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

Maximum Inlet Pressure Test

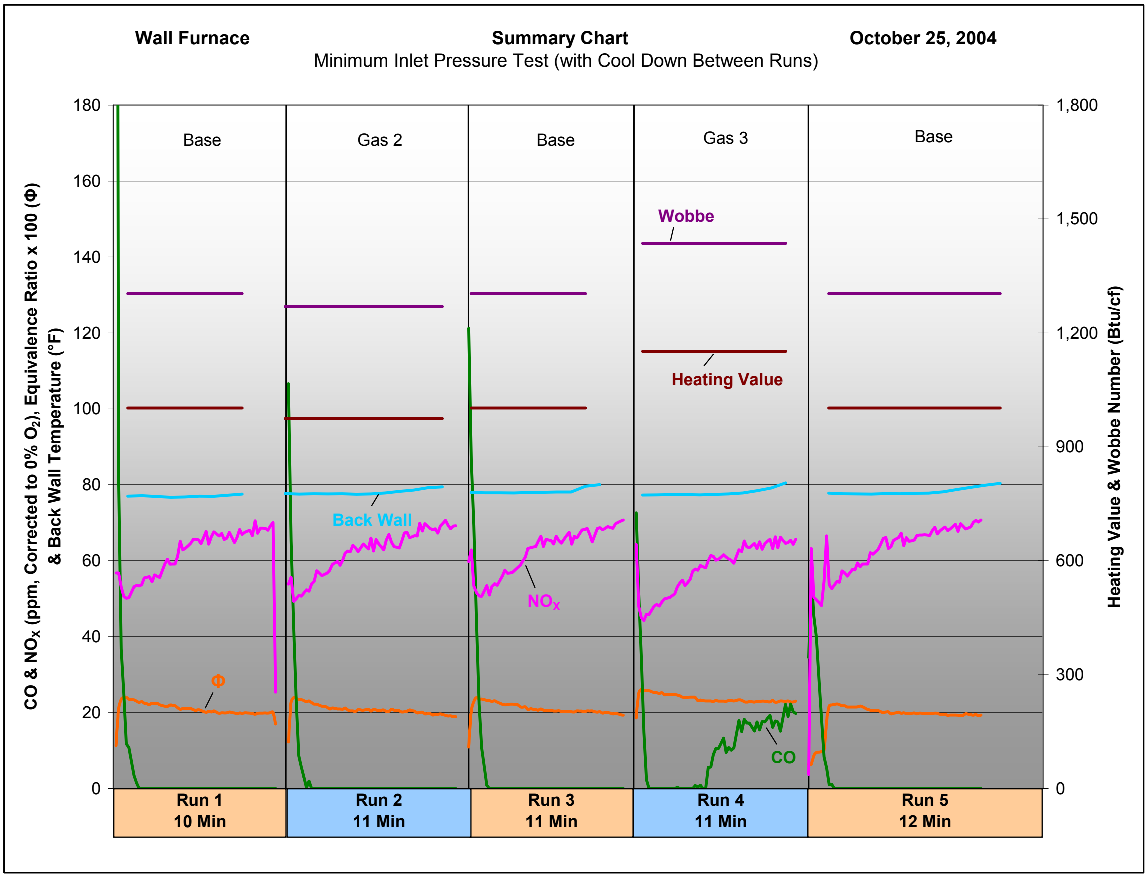
Results revealed an average CO emissions value of 110 ppm (Corrected to 0% O_2) for Gas 3 while average CO emissions values for Gas 2 and Baseline Gas were below 11 ppm (Corrected to 0% O_2). Average NO_X emissions values for the first three runs (Baseline Gas & Gas 2) were above 60 ppm (Corrected to 0% O2) but decreased for the last 2 runs (Gas 3 & Baseline Gas).



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

Minimum Inlet Pressure Test

Average CO emissions values were below 10 ppm (corrected to 0% O_2) and average NO_X emissions values ranged between 58 ppm and 65 ppm (Corrected to 0% O_2) for all gases tested.



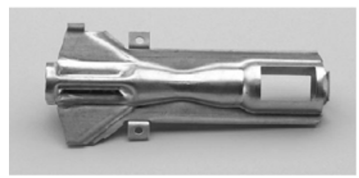
NOTE: Emission test results are for information purposes, they were not the result of certified tests.

Equipment Selection Criteria

A gravity vented wall furnace (legacy) was selected because of the large number of these units in the Southern California Gas Company territory, their long life expectancy, and the potential for the heat exchangers to crack due to over firing. Due to the mild winters in Southern California these units can last for many years and the potential of the heat exchanger to crack could increase when they are over fired. In addition, we wanted to corroborate previous studies done in 1995 by the Southern California Gas Company that showed these types of atmospheric units could handle a wide range of gases.

Equipment Specification

- **Description:** Gravity Vented Wall Furnace (Legacy) with a stamped steel heat exchanger vertically oriented with a draft diverter on top.
- **Burner:** 4 in-shot atmospheric burners firing vertically into heat exchanger (see image on the right)



- **Maximum input rating:** ~35,000 Btu/hr
- **Type of fuel:** Natural Gas
- **Required gas supply pressure:** 4.5 - 10.5" w.c.

Standards

A detailed description of the protocol used to develop the test procedures is included in appendix A. The test protocol was developed based on the following test standards.

- ANSI Z21.86 2004
- South Coast Air Quality Management District – Instrumental analyzer procedure for continuous gaseous emissions - District Method 100.1

Installation

Instrumentation was installed following the above test standards and input from manufacturers and consultants. The gravity vented wall furnace (Legacy) was installed in a wall stud space. Thermocouples were installed to measure flame, inlet air, heated air, flue gas, ambient and gas temperatures of the furnace. Also, pressure transducers were installed to measure manifold and skid pressures. A gas meter was set to measure the gas flow and an emissions probe was built and placed in the flue vent (Type B round) of the furnace.

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 (1,436 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 (1,374 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)

Test Procedure

Test procedures were developed based on the above test standards. However, due to differences between the test standards, the time limitations, and restrictions of the facilities, the test procedures were simplified with input from the manufacturers and consultants directed to develop a sound test procedure.

Before every test the following steps were performed:

- All emissions analyzers were calibrated and checked for linearity.
- Data logger was enabled to verify temperature, pressure and gas flow readings.

During every test, the following steps were performed:

- Baseline and Substitute Gases were run continuously with switching between gases taking less than 30 seconds.
- Emissions, pressure and temperature data was observed before, during and after changeover.

After every test the following steps were performed:

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

Performance Test (with Cool Down Between Runs)

Using Baseline, manifold pressure was adjusted to obtain a rated input of 35,000 Btu/hr ± 2%. Once the rated input was established, the unit was cooled down to room temperature in order to commence testing*.

- Begin testing with Baseline gas for 20 minutes, then turn the burner off.
- Cool down the unit, using an air blower, to room temperature ± 5°F.
- Switch to Gas 2 and run unit for 20 minutes, then turn the burner off.
- Cool down the unit, using an air blower, to room temperature ± 5°F.
- Switch to Baseline Gas and run unit for 20 minutes, then turn the burner off.
- Cool down the unit, using an air blower, to room temperature ± 5°F.
- Switch to Gas 3 and run unit for 20 minutes, then turn the burner off.
- Cool down the unit, using an air blower, to room temperature ± 5°F.
- Switch to Baseline Gas and run unit for 20 minutes, then turn the burner off.
- Cool down the unit, using an air blower, to room temperature ± 5°F.
- Switch to Gas 4 and run unit for 20 minutes, then turn the burner off.
- Cool down the unit, using an air blower, to room temperature ± 5°F.
- Switch to Baseline Gas and run unit for 20 minutes, then turn the burner off.
- Cool down the unit, using an air blower, to room temperature ± 5°F.
- Switch to Gas 4A and run unit for 20 minutes, then turn the burner off.
- Cool down the unit, using an air blower, to room temperature ± 5°F.
- Switch to Gas 5 and run unit for 20 minutes, then turn the burner off.
- Cool down the unit, using an air blower, to room temperature ± 5°F.
- Switch to Gas 5A and run unit for 20 minutes, then turn the burner off.
- Cool down the unit, using an air blower, to room temperature ± 5°F.
- Switch to Baseline Gas and run unit for 20 minutes, then turn the burner off.
- Cool down the unit, using an air blower, to room temperature ± 5°F.
- Switch to Gas 6 and run unit for 20 minutes, then turn the burner off.
- Cool down the unit, using an air blower, to room temperature ± 5°F.
- Switch to Baseline Gas and run unit for 20 minutes, then turn the burner off.

*Purge unit with the next gas blend while cooling down.

Performance Test (Straight Run)

- Begin testing with Baseline gas for 20 minutes.
- Switch to Gas 2 for 20 minutes.
- Switch to Gas 3 for 20 minutes.
- Switch to Baseline Gas for 15 minutes and then turn the burner off.

Maximum/Minimum Inlet Pressure Tests

- Set inlet pressure to maximum (10.5” w.c.).
- Begin testing with Baseline gas for 10 minutes, then turn the burner off.
- Cool down the unit, using an air blower, to room temperature ± 5°F.
- Switch to Gas 2 and run unit for 10 minutes, then turn the burner off.
- Cool down the unit, using an air blower, to room temperature ± 5°F.
- Switch to Gas 3 and run unit for 10 minutes, then turn the burner off.
- Cool down the unit, using an air blower, to room temperature ± 5°F.
- Switch to Baseline Gas and run unit for 10 minutes, then turn the burner off.
- Cool down the unit, using an air blower, to room temperature ± 5°F.
- Set inlet pressure to minimum (4.5” w.c) and repeat the same test sequence with Gas 2 & Gas 3.

Burner Operating Characteristics

At normal input rate and normal inlet pressure, turn the furnace on and off manually 10 consecutive times; allowing a 5 sec run before shutting off the burner. Observe any flame flash outside the appliance and report any undue noise when burner ignites, operates and extinguishes. Burners and ignition devices shall effectively ignite without delayed ignition or flashback.

Pilot Burners and Safety Shutoff Devices

Using an On/Off switch, conduct at least 25 successive ignition test cycles with Gas 2. Each cycle consists of maintaining burner operation for 30 seconds and burner shut off for 30 seconds. Repeat with Gas 3 immediately using the same test sequence. If burner failed to ignite at any instance or continued extinction of the pilot, repeat procedure with Gas 4A & Gas 6

Results[1,2]

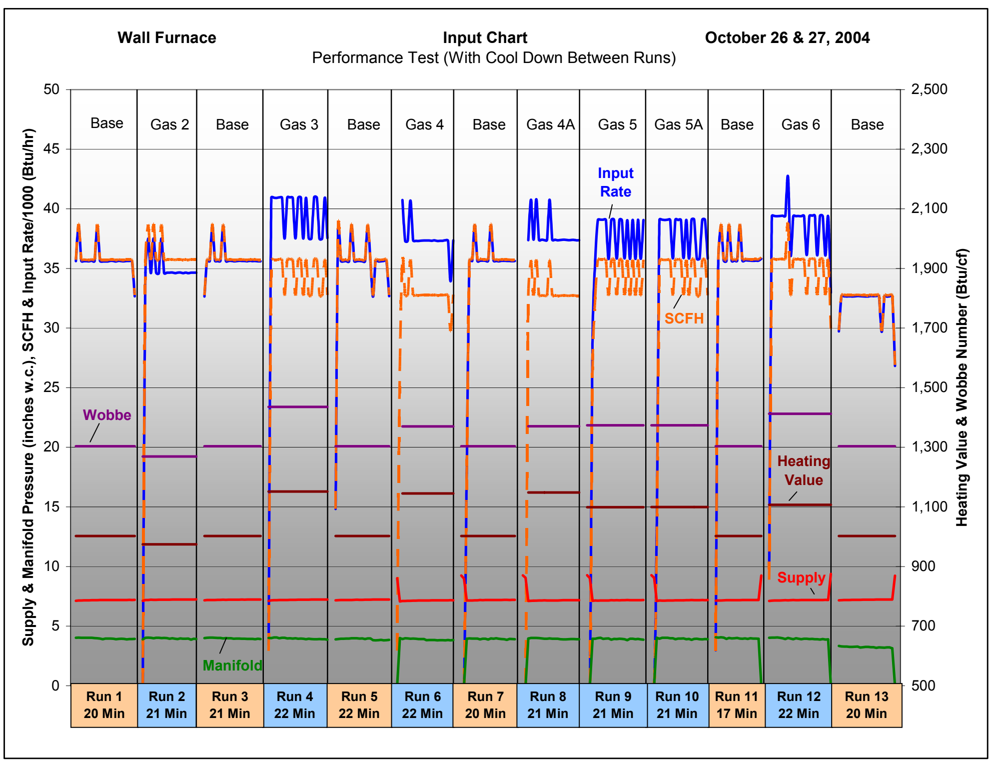
Performance Test (with Cool Down Between Runs)

Input

The input rate observed with the 1st Baseline Gas run was 35,739 Btu/hr, 2.1% above the rated input. The highest input rate was observed with Gas 3 (39,692 Btu/hr – Run 4) while the lowest occurred with Baseline Gas (32,128 Btu/hr – Run 13).

Although the supply pressure remained unchanged throughout the test, it was unclear why the manifold pressure dropped during the 13th Run (Baseline Gas). This drop in manifold pressure caused the wall furnace input rate to drop 8% below rated input. Gas flow rate ranged between 32 and 37 scfh.

Supply pressure remained stable at 7.2" w.c. for all test runs. However, the manifold pressure fluctuated slightly but, for the most part, it remained within the limits set by the test protocol (3.5" w.c ± 10%) except for the last Baseline Gas (Run 13) where the manifold pressure dropped to 3.1" w.c.



[1] All emissions, temperature and input values mentioned throughout the results section are average values.
[2] Emissions values are corrected to 0% O_2.

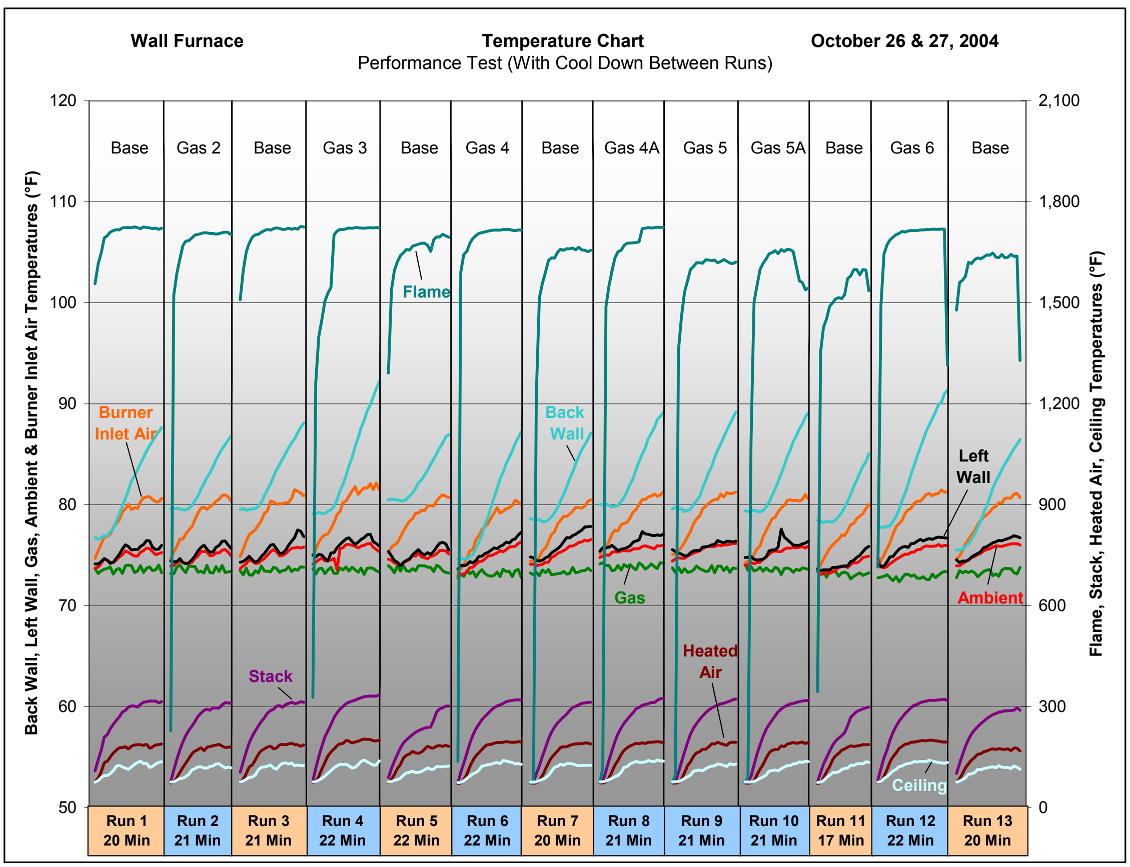
Temperatures

The highest flame temperature was obtained with Gas 4 (1,704°F) whereas Baseline Gas (run 11 - 1,527°F) held the lowest flame temperature. 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 (280°F), followed by Gas 6 (273°F) and Gas 4 (271°F). The lowest stack temperature was recorded with Baseline Gas (Run 11 - 225°F). The rapid stack temperature increase with Baseline Gas (Runs 5 and 11) was caused by unexpected changes in the combustion characteristics.

Left wall, back wall and ceiling temperatures behaved similarly with all gases tested and did not exceed the temperature limit set by the protocol (90°F in excess of room temperature).

Both ambient and gas temperatures were steady in each of the test runs and averaged 74.9 ± 1°F and 73 ± °F.

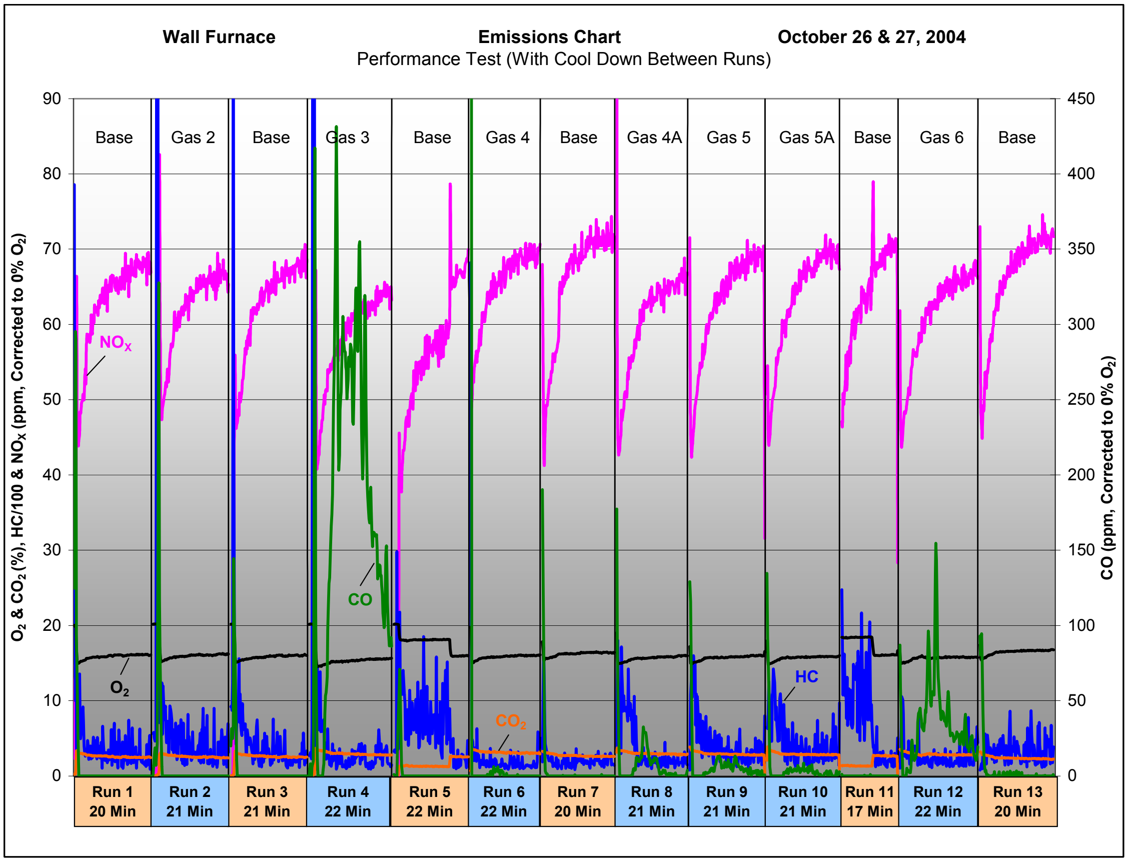


Emissions

The highest CO emissions values were observed with Gas 3 (184 ppm) and Gas 6 (35 ppm). CO emissions values for Gases 2, 4, 4A, 5 and 5A ranged between 1 and 7 ppm. CO emissions values with Baseline Gas runs remained below 5 ppm throughout the entire test.

NO_X emissions values ranged between 57 ppm and 66 ppm for all gases tested. Unexpected changes in O_2 values during Runs 5 & 11 (Baseline Gas runs) caused spikes in NO_X emissions values and increases in CO_2 values.

An unexpected decrease in O_2 values during Runs 5 & 11 (Baseline Gas runs) caused spikes in NO_X emissions values and increases in CO_2 values.



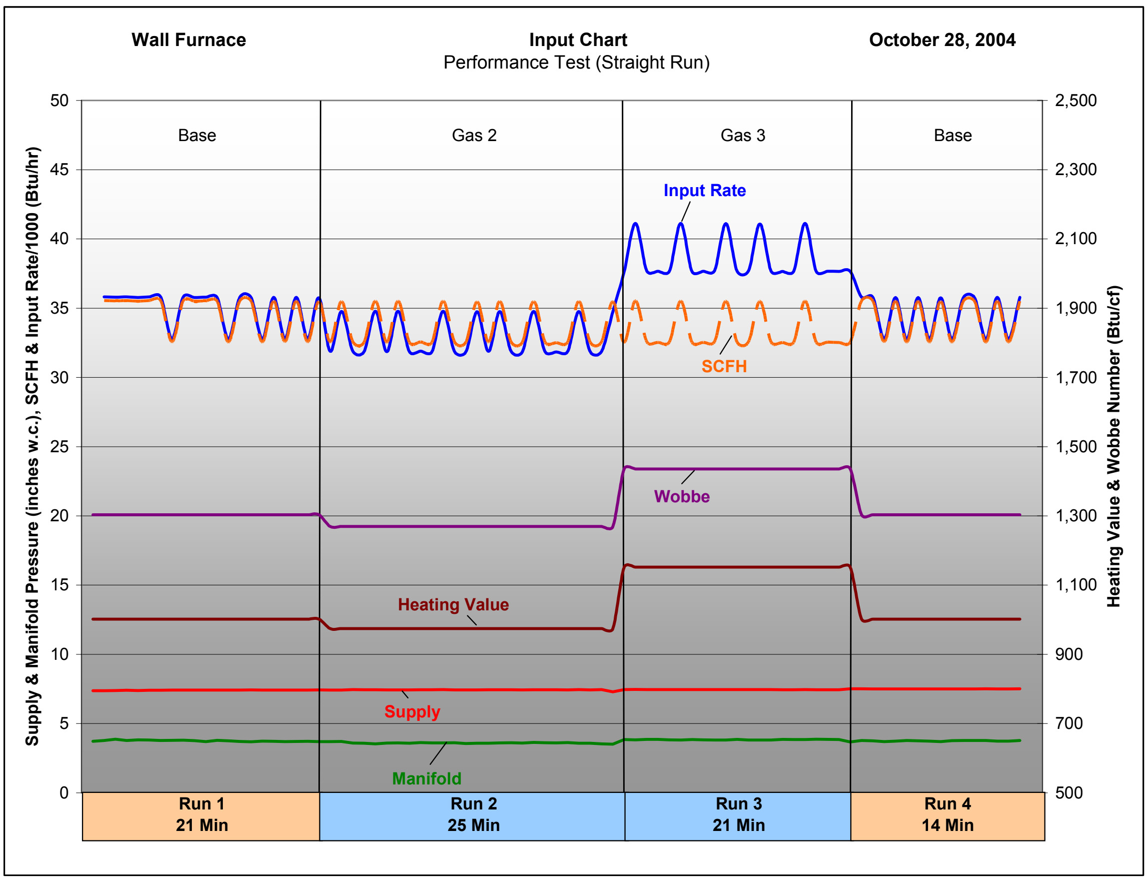
NOTE: Emission test results are for information purposes, they were not the result of certified tests.

Performance Test (Straight Run)

Input

During this test, the gravity vented wall furnace (wall furnace) ran continuously without cooling the unit between runs. The input rate for the 1st Baseline Gas run was 33,933 Btu/hr, which is 3% below rated input. The highest input rate was observed with Gas 3 (38,566 Btu/hr) while the lowest occurred with Gas 2 (32,868 Btu/hr). Baseline Gas (Run 1) experienced the highest flow rate (35 scfh) while the lowest was observed with Gas 3 (33 scfh).

Supply and manifold pressure remained stable for the entire test duration and averaged 7.4" w.c. and 3.6" w.c., respectively.



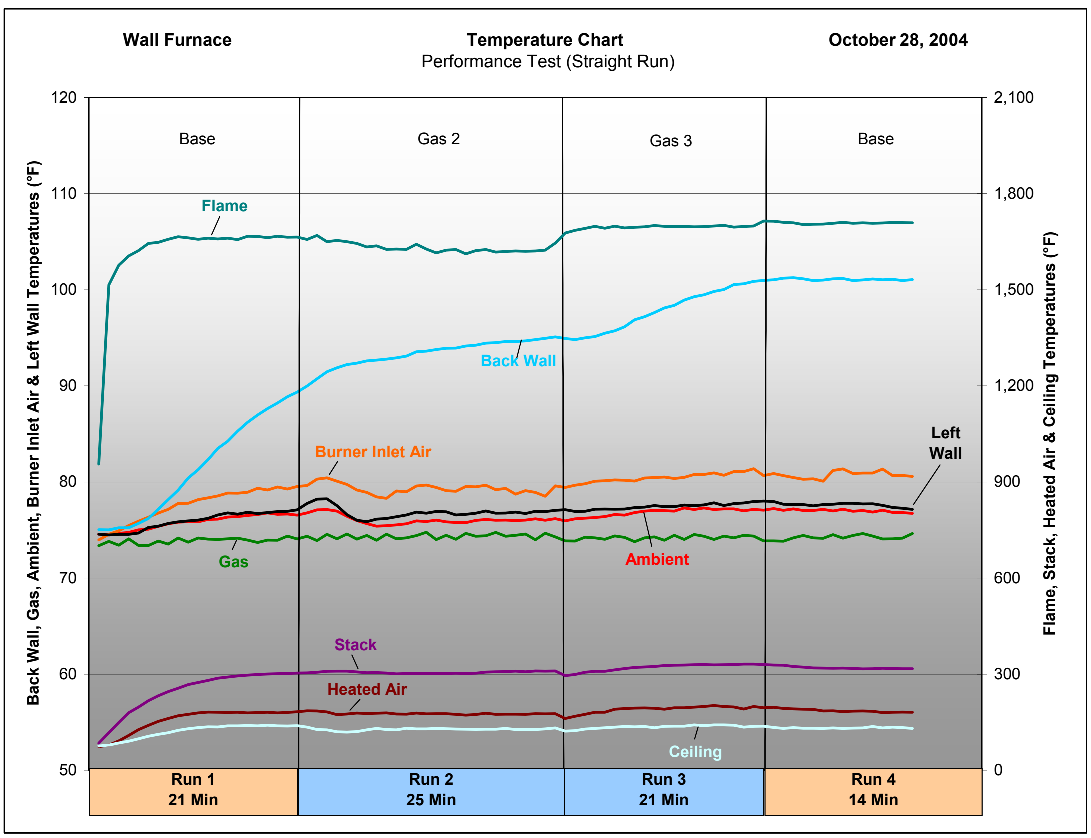
Temperatures

The flame temperature observed for Run 1 (Baseline Gas) was 1,644°F and gradually decreased with Gas 2 (1,632°F). An increase in flame temperature was observed with Gas 3 (1,697°F), which carried its increasing effect over to Run 4 (1,708°F - Baseline Gas). 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..

Back wall temperature increased gradually with each of the gases tested and stabilized with the Baseline Gas last run at 101°F. Back wall temperature did not exceed the temperature limit set by the protocol.

Both gas and ambient temperatures remained stable during the testing period and averaged 74°F and 76°F.

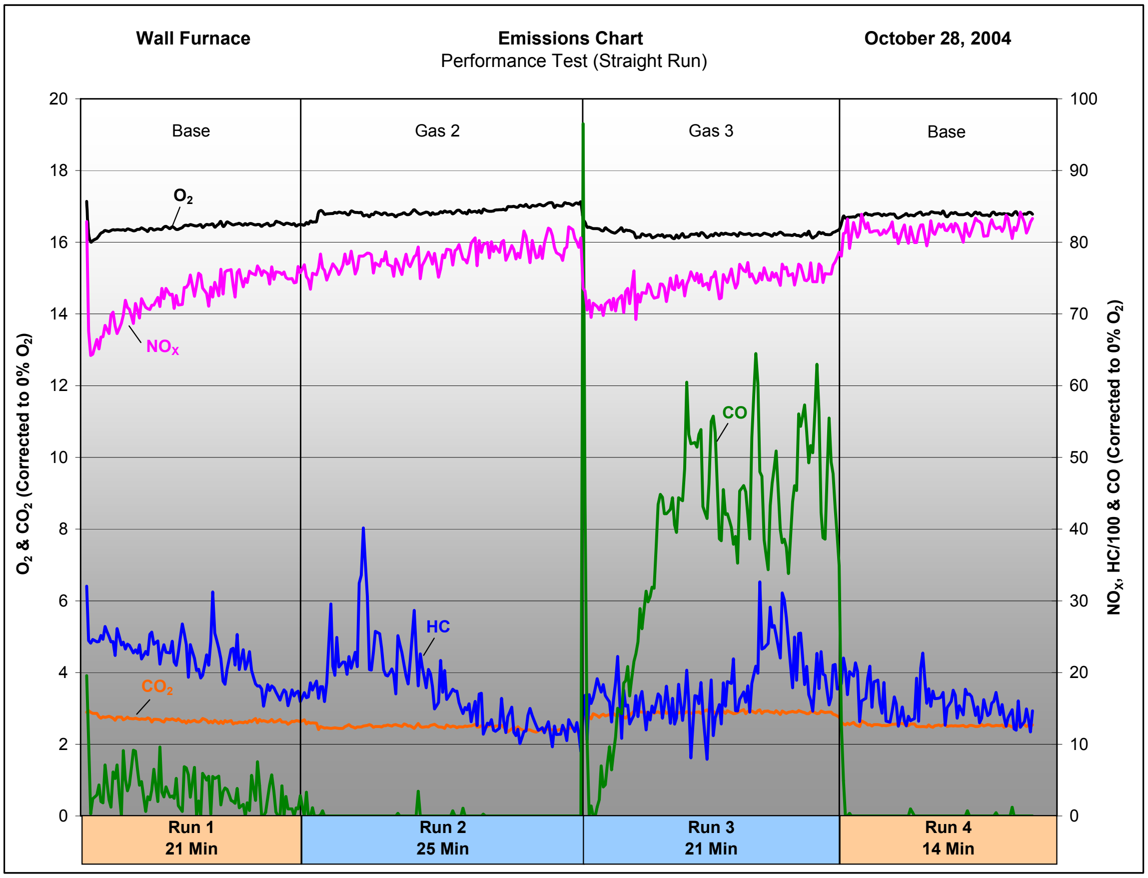
Stack and ceiling temperatures gradually changed with each of the gases tested. The highest stack and ceiling temperatures were observed with Gas 3 at 321°F and 135°F, respectively.



Emissions

NO_x emissions values exceeded 72 ppm for all gases tested. NO_x emissions values for Gases 2 and 3 were 78 ppm and 74 ppm. Baseline Gas NO_x emissions values were 73 ppm (Run 1) and 82 ppm (Run 4).

The highest CO emission value was observed with Gas 3 (38 ppm); however, CO emissions values were less than 4 ppm with Gas 2 and Baseline Gas runs



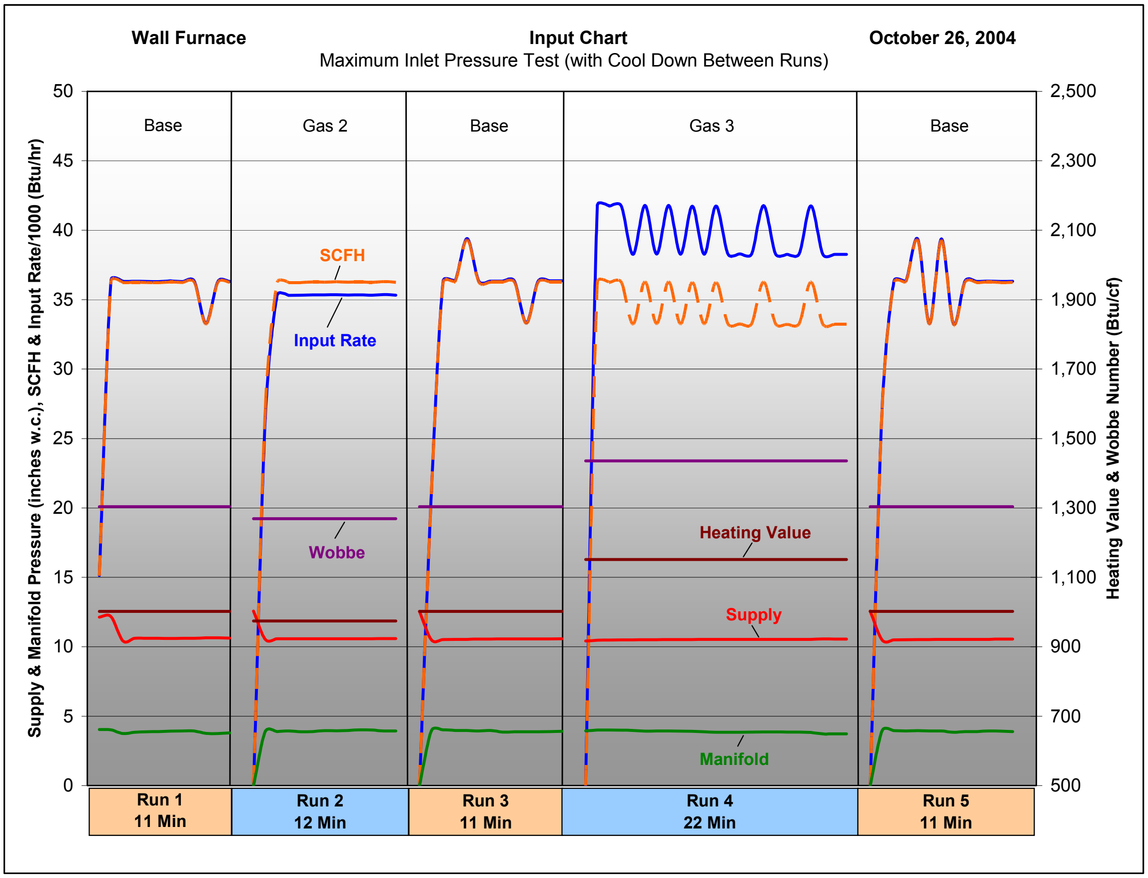
NOTE: Emission test results are for information purposes, they were not the result of certified tests.

Maximum Inlet Pressure Test (10.5” w.c.)

Input

The wall furnace operated at 3% above rated input when supply pressure was adjusted to 10” w.c. Both manifold and supply pressure remained steady throughout the test run, averaging 3.9” w.c. and 10.6” w.c., respectively.

The gas flow rate depended directly on the gas compositions and the presence of heavier components in some of the gases tested. Both Gas 2 and Baseline Gas (36 scfh) achieved the highest flow rate, whereas Gas 3 experienced the lowest flow rate (34 scfh). In contrast, the highest input rate was observed with Gas 3 (39,702 Btu/hr) while the lowest input rate occurred with Gas 2 (35,332 Btu/hr).

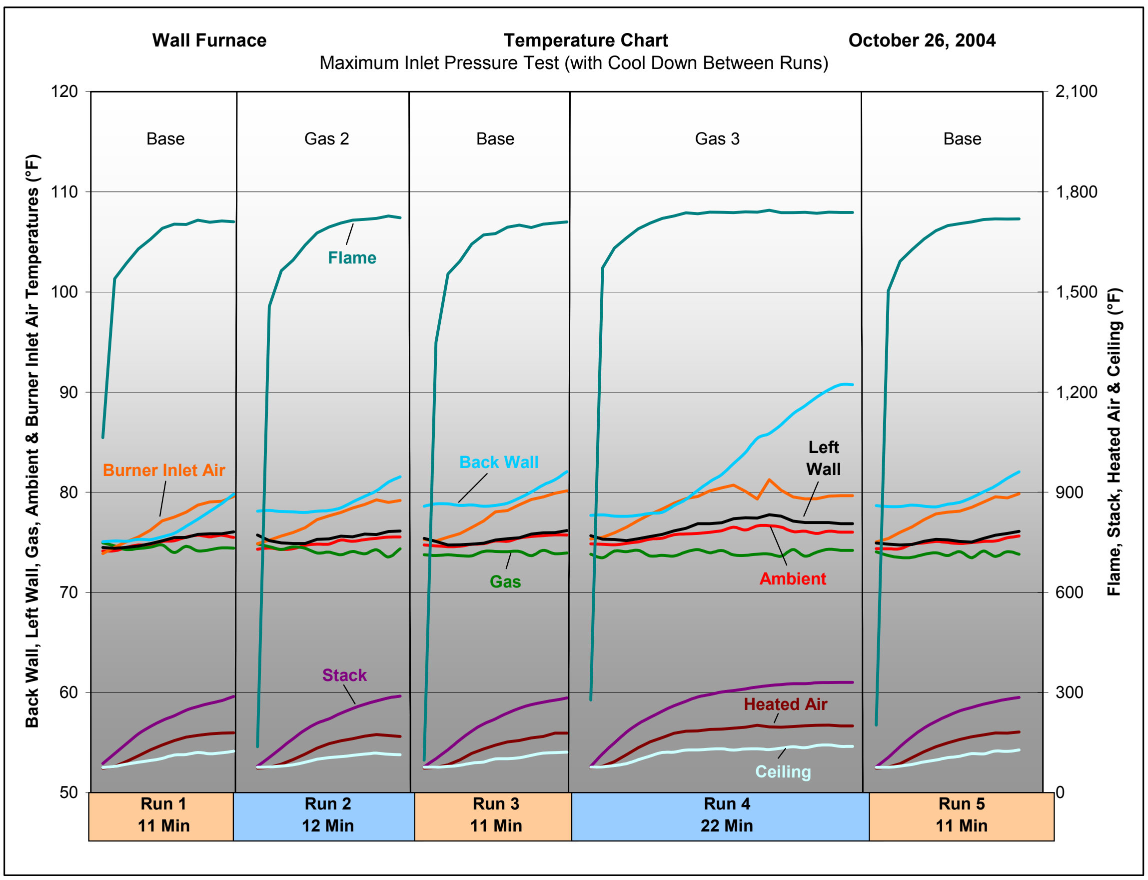


Temperatures

Flame temperature was highest with Gas 3 (1,718°F), followed by Baseline Gas (1,686°F – Run 5). Although the flame temperature reacted to the different gases tested, these temperature measurements were relative and depended on the variation of the flame shape and size since the location of the thermocouple tip was fixed throughout all the test runs. 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, heated air, ceiling and left wall temperatures were highest with Gas 3. Both ambient and gas temperatures remained stable at 75°F and 74°F for the entire test period.

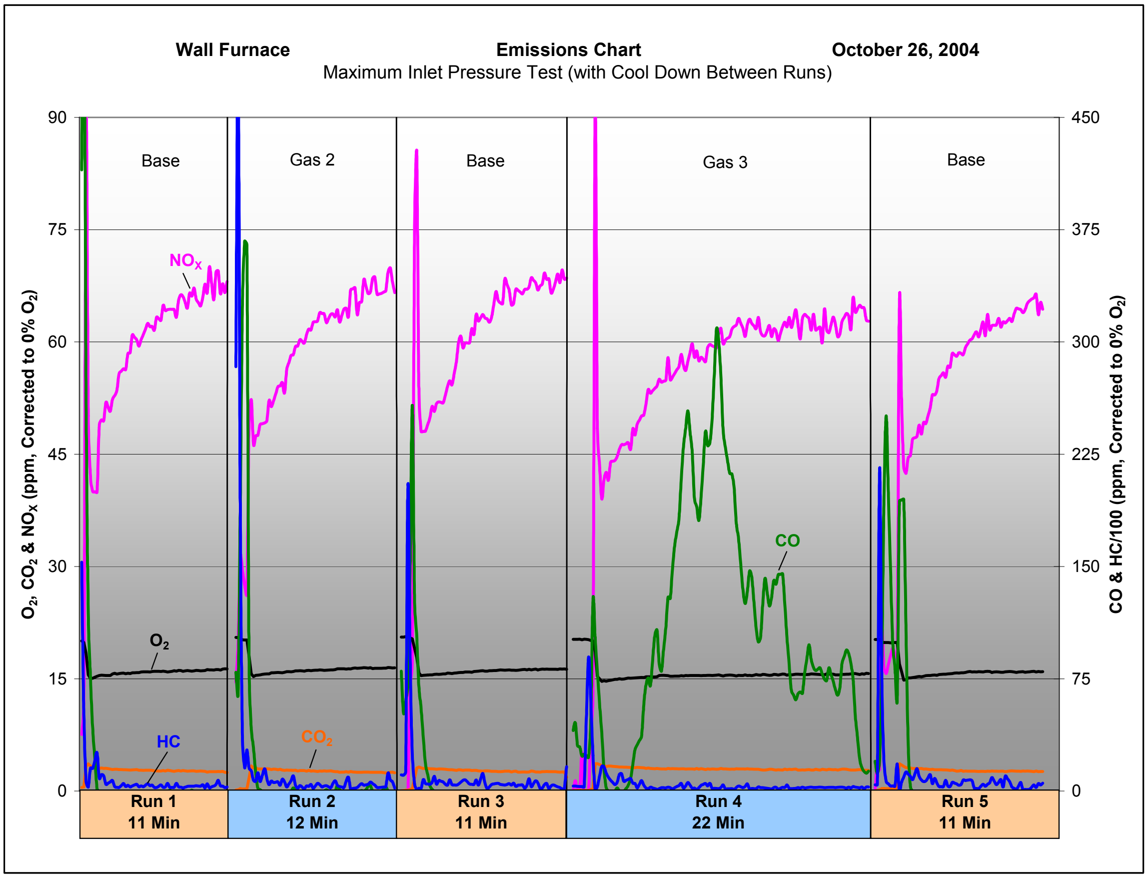
Gas 3 test duration was extended to 22 minutes to monitor any significant temperature increase while operating with a higher heating value. No considerable changes were observed and all temperatures remained within the limits set by the protocol.



Emissions

NO_X emissions values ranged between 57 and 63 ppm. The highest NO_X emissions value was observed with Baseline Gas (62 ppm – Run 3) and the lowest with Gas 3 (58 ppm). In contrast, the highest CO emissions value was observed with Gas 3 (111 ppm) while Gas 2 and all Baseline Gas runs were below 12 ppm.

The highest HC emissions value was observed with Baseline Gas (550 ppm – Run 5), followed by Gas 2 (512 ppm). Gas 3 (334 ppm) held the lowest HC emissions value.



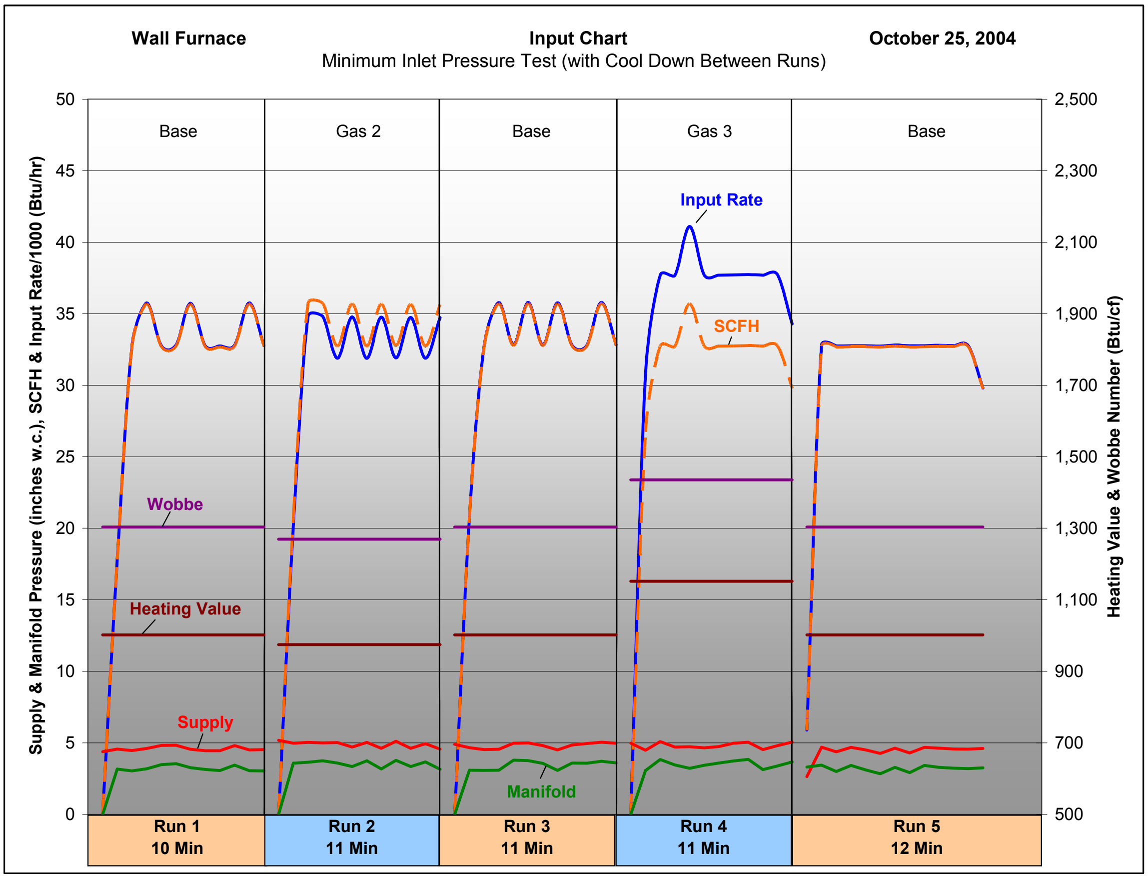
NOTE: Emission test results are for information purposes, they were not the result of certified tests.

Minimum Inlet Pressure Test (4.5" w.c.)

Input

The wall furnace operated at 4.3% below its rated input when the supply pressure was adjusted to 4.5" w.c. Manifold pressure ranged between 3.2" w.c. and 3.5" w.c. whereas supply pressure ranged between 4.5" w.c. (Run 5) and 4.9" w.c. (Run 2).

The highest input rate was observed with Gas 3 (37,698 Btu/hr) and the lowest occurred with Baseline Gas (32,522 Btu/hr – Run 5). Gas 2 held the highest gas flow rate (34 scfh) whereas the lowest rate was observed with Baseline Gas (32 scfh - Run 5).

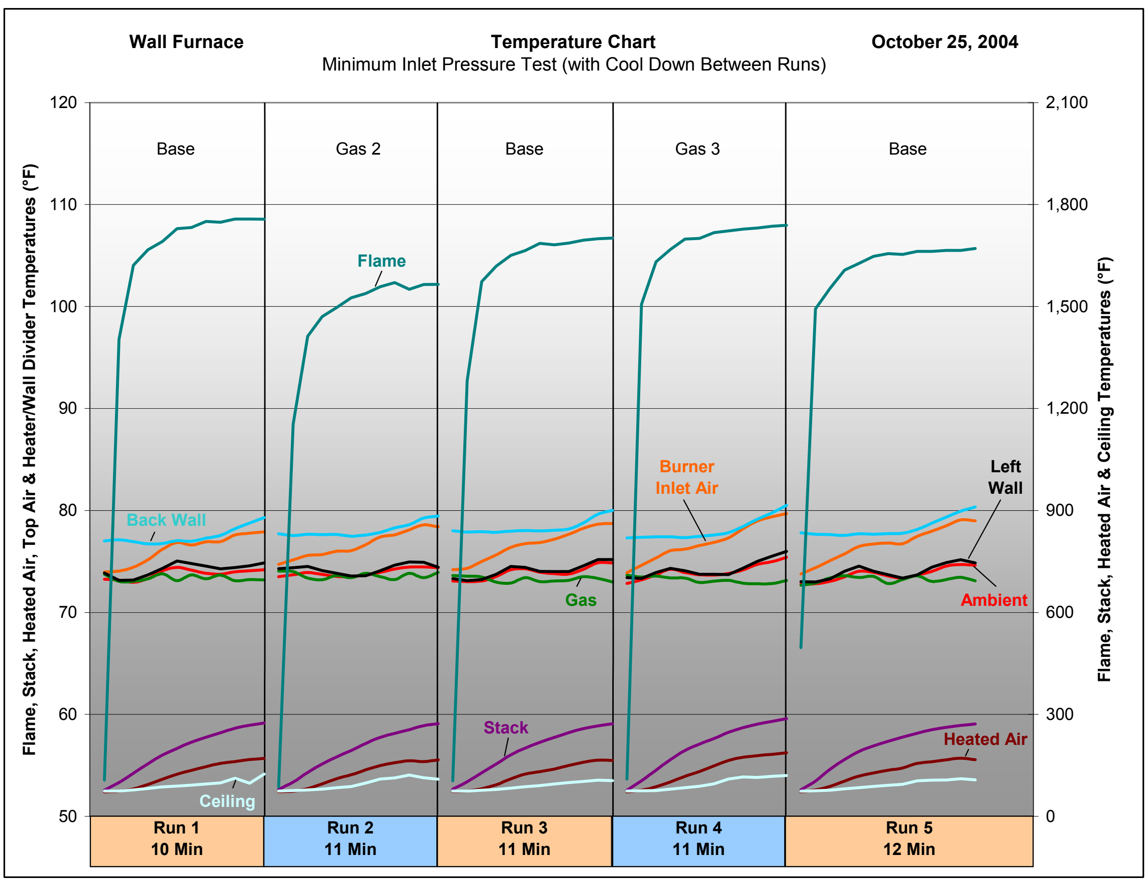


Temperatures

Flame temperature was highest with Baseline Gas (1,721°F – Run 1), followed by Gas 3 (1,707°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.

Left wall, back wall and ceiling temperatures behaved similarly with all gases tested and did not exceed the temperature limits set by the protocol (90°F in excess of room temperature).

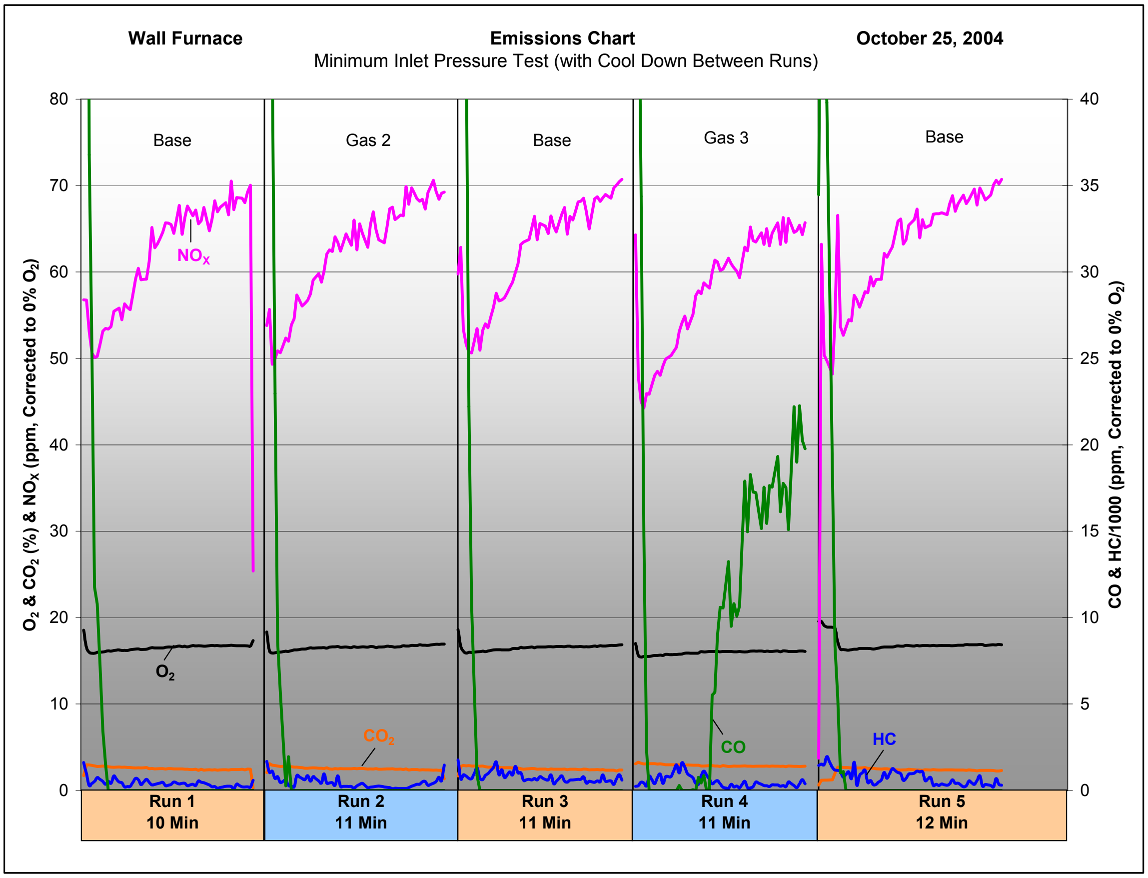
Stack temperature was highest with Gas 3 (239°F) whereas Gas 2 held the lowest stack temperature at 223°F. Both ambient and gas temperatures remained stable at 74°F and 73°F for the entire test period.



Emissions

Baseline Gas had the highest NO_X emissions value (64 ppm – Run 5) while the lowest was observed with Gas 3 (58 ppm). The remaining runs had NO_X emissions values ranging 62 ± 1 ppm. CO emissions values were below 11 ppm for all gases.

The highest HC emissions values were observed with Baseline Gas run 3 (756 ppm) and Run 5 (659 ppm). Gas 3 and Gas 2 HC emissions values were 756 ppm and 433 ppm.



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Ignition Reliability Test

The wall furnace burner passed the ignition reliability test with Gases 2 and 3. These gases were chosen because they have the lowest and highest heating value and Wobbe Number among all gases tested. No delayed ignition or flash back was observed during this test. Ignition took effect immediately for all 30 ignition consecutive tests performed with each of the gases tested.

Appendix A: Test Protocol

1. **Standards**
   - ANSI Z21. 86 - 2004.
   - South Coast Air Quality Management District – Instrumental analyzer procedure for continuous gaseous emissions - District Method 100.1
2. **Wall Furnace Description**
   - **Description:** Gravity Vented Wall Furnace (Legacy)
   - **Burner:** 4 in-shot atmospheric burners firing vertically into heat exchanger
   - **Maximum input rating:** ~35,000 Btu/hr
   - **Type of fuel:** Natural Gas
   - **Required gas supply pressure:** 4.5 – 10.5" w.c.
3. **Test Arrangement**

3.1. Basic Setup

The gravity vented wall furnace (legacy) shall be connected to a vent extending to a height 12 feet above the test floor. The appliance shall be installed with the minimum clearances specified by the manufacturer in a test wall as shown in Figure 7 (Test structure for vented wall furnaces for installation between studs 16 inches or less on center), Z21.86 – 2004. The portions of the appliance normally located in a wall shall be enclosed on top, bottom and sides by wood framing of 2 inches nominal thickness and a width appropriate for the wall thickness specified for installation by the manufacturer. When the manufacturer specifies nominal 2 by 4 stud walls, the width of the studs in the test wall shall be 3 ½ inches. The studs at the sides of the appliance shall extend to a height of 8 feet, including the floor and ceiling plates. In the case of appliances having top vertical flue outlets, such top framing shall be omitted from the stud spacing enclosing the flue outlet when the manufacturer's instructions do not specify such framing. Additional studs of appropriate width and extending from the floor plate to the ceiling plate shall be placed at 16 inches on center outside the studs framing the space in which the appliance is installed.

The ceiling plate adjacent to the vent shall maintain the specified clearance from the vent pipe, and a flat sheet metal collar of suitable shape to fit closely about the periphery of the vent shall be placed over this clearance space and secured to the ceiling plate, or if a plate spacer is supplied by the manufacturer, that spacer will be used. Both sides of this frame shall be enclosed with nominal ¾ inch plywood panels with both sides painted dull black. A side wall and ceiling shall be provided as shown in Figure 7.

3.2. Draft Hoods

Draft hoods shall be in place during all performance tests.

3.3. 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 wall furnace gas control.

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 (1,436 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 (1,374 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

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

5.2. Test Pressures and Burner Adjustments

Unless otherwise stated, all tests will be conducted at normal inlet test pressure and normal input rate. When operated for 15 minutes, starting with all parts of the appliance at room temperature, the burner adjustments shall be within +/- 2% of the manufacturer's specified hourly Btu input rating. Primary air shall be set to give a good flame at this adjustment and neither burner ratings nor primary air adjustments shall be changed during a series of tests with any one test gas. Any adjustments resulting in an appreciable deposit of carbon during any of the tests specified shall not be acceptable.

5.3. Burner Operating Characteristics

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

5.4. Pilot Burners and Safety Shutoff Devices

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

Gas shall be admitted to the main burner(s) by turning on fully in a continuous movement any manual means provided for controlling main burner gas flow. At least 25 successive ignition tests shall be conducted with the main burner gas flow maintained for 30 seconds and interrupted for 30 seconds for each cycle. Failure to effect ignition immediately after gas reaches the main burner port(s) in any one instance, or continued extinction of the pilot, shall be considered as noncompliance with this provision (Note: Test the unit with Gases 2 and 3 first. If it failed, retest with Gases 4A and 6).

Any type of pilot equipped with an automatic igniter shall not cause excessive flame flash out or damage to the appliance.

5.5. Wall, Floor and Ceiling Temperatures

The temperatures on the surface of any exterior portion of the test wall in contact with the wall furnace shall not be more than 117^{o}F in excess of room temperature when the appliance is operated as required in the following method of test. The temperatures within the stud space enclosing any portion of the appliance and the test vent, and on the floor under the appliance and for a distance of 18 inches in front of and to the sides of the appliance shall not be more than 90^{o}F in excess of room temperature when the appliance is operated as required in the following method of test.

5.6. Flue Gas temperature

Under normal operating conditions, the average temperature of the flue gases of a wall furnace shall not exceed 380°F above room temperature. The flue gas temperature shall be determined by a grid of parallel-connected No. 24 AWG thermocouples, located in a horizontal plane 3 feet 6 inches above the plane of the flue outlet and connected to an indicating or recording potentiometer.

5.7. Temperature at Discharge Air Opening and Surface Temperature

This test shall be conducted as specified in section 8.7.1 of ANSI Z21.86 2004.

5.8. Evaluation of Clothing Ignition Potential

This test shall be conducted as specified in section 8.8 of ANSI Z21-86 2004.

5.9. Draft Hoods

Flue gases shall not issue from the relief openings of a draft hood when the wall furnace is connected to a vent terminating 12 feet above the floor.

6. Testing

6.1. Startup Run

Operate wall furnace on baseline gas for one hour as-received – i.e. with gas orifices received in the wall furnace and inlet test pressure at the rating plate value ± 0.2" w.c. Fifteen minutes after starting, record firing rate data, CO_2 and carbon monoxide emission. Also record room ambient temperature and stack temperature.

6.2. Base Case at Rated Input

Operate wall furnace on baseline gas for 15 minutes. While operating the appliance, clock the gas meter every 5 minutes to examine firing rate and collect emissions data continuously. If necessary adjust furnace to operate at the rating plate input, holding inlet test pressure within 10% of that specified on the rating plate. This establishes and defines the "basic firing setup".

6.3. Steady Operation Testing with Baseline and Substitute gases

Operate the wall furnace at normal input rate and normal inlet test pressure with baseline gas and conduct a high-speed switch to the substitute gas 2 then gas 3. Perform a 20 minutes run for each of the two substitute gases. Record data continuously and observe transient phenomena. Note that the firing rate is not to be adjusted. Possible phenomena include flame color change, flame lifting, flashback or rollout, pilot burner instability or outage, etc.

With the furnace continuing to operate at steady state on the substitute gas, conduct a high-speed switch to the baseline gas and record observations. Turn off unit and allow it to cool down.

6.4. Cycling Operation Testing with Baseline and Substitute gases

While conducting this test, all parts of the appliance shall be cooled to room temperature ± 10^{o}F after each cycle. When cooling temperature is reached, start up the appliance with Baseline Gas and run it for 10 minutes. Turn the appliance off and cool it down. While the appliance is cooling, purge gas line hose with the first substitute gas to be tested. When cooling temperature is reached start the appliance up with the first substitute gas and run it for 10 minutes then turn the unit off. Repeat sequence with the remaining substitute gases.

When testing has been conducted with all gases, shut down furnace and examine heat exchangers for presence of soot. If soot is found, clean and repeat testing with suspect gas blend(s), selected on the basis of earlier yellow tipping observations. Establish which gas(es) tends to burn with soot deposition.

6.5. Hot operation

Repeat the testing of section 6.4 at supply pressure 4.5” w.c. and 10.5” w.c. conditions, using only Gases 2 and 3. Observe and record the same phenomena.

7. Special tests

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

8. Additional Testing

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

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

Appendix B: Tables of Averages

Performance Test (with Cool Down Between Runs)

Table of Averages Wall Furnace Performance Test (with Cool Down Between Runs) October 26 & October 27, 2004													
Gases	**Base**	**2**	**Base**	**3**	**Base**	**4**	**Base**	**4A**	**5**	**5A**	**Base**	**6**	**Base**
HHV (Btu/cf)	1,002	974	1,002	1,152	1,002	1,145	1,002	1,148	1,099	1,100	1,002	1,107	1,002
Wobbe (Btu/cf)	1,303	1,269	1,303	1,436	1,303	1,370	1,303	1,371	1,374	1,374	1,303	1,413	1,303
Input Rate (Btu/hr)	35,739	35,066	35,754	39,692	35,758	37,495	35,957	37,893	37,868	38,054	36,173	38,687	32,128
Corrected SCFH	35.9	36.2	35.9	34.6	35.9	32.9	36.1	33.2	34.6	34.8	36.3	35.1	32.2
Emissions (not from certified tests)													
Raw O_2 (%)	15.9	16.0	15.8	15.3	17.5	15.8	16.2	15.7	15.7	15.7	17.4	15.7	16.5
Raw CO_2 (%)	2.6	2.6	2.6	3.0	1.6	3.1	2.7	15.7	2.9	2.9	1.9	2.9	2.4
CO (ppm @ 0% O_2)	1.6	2.3	2.3	183.5	1.9	0.7	3.8	7.1	6.3	4.2	0.0	34.5	4.5
HC (ppm @ 0% O_2)	364.2	451.3	400.6	301.1	681.2	192.6	229.2	379.0	439.4	453.5	748.3	271.8	330.4
NO_X (ppm @ 0% O_2)	63.0	62.3	62.7	58.6	56.9	65.3	65.7	60.5	62.6	63.6	63.7	61.2	65.9
Ultimate CO_2 (%)	11.0	11.0	10.9	11.1	10.1	13.0	12.3	12.0	11.8	11.7	11.4	11.6	11.5
Equivalence Ratio (Φ)	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.3	0.2
Temperatures (°F)													
Ambient	74.9	74.8	74.9	75.3	74.8	74.9	75.4	75.6	75.6	75.3	73.9	75.2	75.3
Flame	1,704	1,682	1,696	1,646	1,661	1,704	1,636	1,671	1,604	1,610	1,526	1,681	1,605
Gas	73.6	73.6	73.5	73.5	73.6	73.2	73.3	73.9	73.6	73.6	73.2	72.9	73.3
Stack	267.1	255.7	261.4	280.6	227.3	270.7	256.9	262.2	268.4	267.2	225.3	273.1	244.2
Burner Inlet	78.8	78.9	79.1	79.7	78.9	78.1	78.3	79.1	79.4	78.9	77.2	79.2	78.7
Heated Air	164.0	157.8	161.5	175.6	158.7	171.9	164.1	167.4	167.1	165.8	157.0	175.3	152.9
Left Wall	75.3	75.3	75.5	75.9	75.1	75.5	76.3	76.4	75.8	75.7	74.3	75.9	75.7
Back Wall	81.5	82.3	82.9	84.2	82.8	80.3	81.9	83.6	83.5	83.5	80.6	83.9	80.5
Ceiling	116.2	110.8	113.9	118.6	106.4	120.9	116.7	121.0	114.4	114.0	112.8	123.9	109.5
Pressures													
Supply (in. w.c.)	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.3	7.3	7.3
Manifold (in. w.c.)	4.0	4.0	4.0	4.0	3.9	3.9	3.9	3.9	3.9	3.9	3.7	3.8	3.1

Note: The furnace was cooled down in between test runs.

Performance Test (Straight Run)

Table of Averages Wall Furnace Performance Test (Straight Run) October 28, 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)	33,370	32,872	38,488	34,576
Corrected SCFH	35.0	33.7	33.4	34.5
Emissions (not from certified tests)				
Raw O_2 (%)	16.4	16.9	16.2	16.8
Raw CO_2 (%)	2.7	2.5	2.9	2.5
CO (ppm @ 0% O_2)	3.6	0.1	38.3	0.2
HC (ppm @ 0% O_2)	438.3	349.5	355.8	315.9
NO_X (ppm @ 0% O_2)	72.7	78.0	74.2	81.8
Ultimate CO_2 (%)	12.5	12.8	12.9	12.8
Equivalence Ratio (Φ)	0.2	0.2	0.2	0.2
Temperatures (°F)				
Ambient	75.8	76.1	76.8	77.0
Flame	1,644	1,632	1,697	1,708
Gas	73.9	74.3	74.2	74.2
Stack	246.4	305.6	320.9	319.9
Burner Inlet	77.6	79.3	80.4	80.7
Heated Air	155.4	176.9	190.2	186.1
Wall (Left)	75.9	76.8	77.4	77.6
Back Wall	81.5	93.4	97.9	101.1
Heater/Wall	110.8	144.6	153.9	158.9
Ceiling	120.7	127.7	135.3	132.1
Pressures				
Supply (in. w.c.)	7.4	7.4	7.5	7.5
Manifold (in. w.c.)	3.8	3.6	3.8	3.7

Maximum Inlet Pressure

Table of Averages Wall Furnace Maximum Inlet Pressure Test (10.5" w.c.) October 26, 2004					
Gases	**Base**	**2**	**Base**	**3**	**Base**
HHV (Btu/cf)	1,002	974	1,002	1,152	1,002
Wobbe (Btu/cf)	1,303	1,269	1,303	1,436	1,303
Input Rate (Btu/hr)	36,052	35,332	36,344	39,702	36,328
Corrected SCFH	36.0	36.3	36.3	34.5	36.3
Emissions (not from certified tests)					
Raw O_2 (%)	15.9	16.1	16.0	15.4	15.7
Raw CO_2 (%)	2.8	2.7	2.7	3.0	2.8
CO (ppm @ 0% O_2)	8.1	2.8	4.3	110.9	11.0
HC (ppm @ 0% O_2)	479.2	511.6	476.9	334.4	550.2
NO_X (ppm @ 0% O_2)	60.8	60.7	62.2	57.8	58.2
Ultimate CO_2 (%)	11.8	11.7	11.7	11.3	11.3
Equivalence Ratio (Φ)	0.2	0.2	0.2	0.3	0.2
Temperatures (°F)					
Ambient	75.1	75.0	75.2	75.9	75.0
Flame	1,669	1,680	1,667	1,718	1,686
Gas	74.4	74.1	73.9	73.9	73.8
Stack	220.3	228.9	226.0	276.9	231.8
Burner Inlet	77.3	77.8	78.1	79.0	78.2
Heated Air	144.0	143.9	143.0	175.2	149.3
Wall (Left)	75.3	75.5	75.4	76.6	75.3
Back Wall	76.6	79.1	79.6	83.2	79.6
Ceiling	105.8	104.0	102.0	122.9	107.3
Pressures					
Supply (in. w.c.)	10.7	10.6	10.6	10.5	10.5
Manifold (in. w.c.)	3.9	3.9	3.9	3.9	3.9

Note: The furnace was cooled down in between test runs.

Minimum Inlet Pressure

Table of Averages Wall Furnace Minimum Inlet Pressure Test (4.5" w.c.) October 25, 2004					
Gases	**Base**	**2**	**Base**	**3**	**Base**
HHV (Btu/cf)	1,002	974	1,002	1,152	1,002
Wobbe (Btu/cf)	1,303	1,269	1,303	1,436	1,303
Input Rate (Btu/hr)	33,668	33,618	33,994	37,698	32,522
Corrected SCFH	33.6	34.5	33.9	32.7	32.5
Emissions (not from certified tests)					
Raw O_2 (%)	16.5	16.5	16.5	15.9	16.7
Raw CO_2 (%)	2.5	2.5	2.5	2.9	2.4
CO (ppm @ 0% O_2)	2.9	2.3	4.0	10.3	0.1
HC (ppm @ 0% O_2)	394.3	432.9	756.1	522.0	659.6
NO_X (ppm @ 0% O_2)	61.6	62.5	62.6	58.1	64.2
Ultimate CO_2 (%)	11.9	12.1	12.0	12.2	12.0
Equivalence Ratio (Φ)	0.2	0.2	0.2	0.2	0.2
Temperatures (°F)					
Ambient	73.9	74.0	74.1	74.2	73.8
Flame	1,721	1,525	1,666	1,707	1,630
Gas	73.3	73.5	73.2	73.1	73.3
Stack	225.9	223.1	225.4	238.7	223.6
Burner Inlet	76.6	77.0	77.1	77.5	77.0
Heated Air	134.4	134.7	131.9	147.4	134.7
Left Wall	74.4	74.3	74.3	74.4	74.1
Back Wall	77.6	78.1	78.4	78.3	78.4
Ceiling	95.6	99.6	92.5	100.4	94.0
Pressures					
Supply (in. w.c.)	4.6	4.9	4.8	4.8	4.5
Manifold (in. w.c.)	3.2	3.5	3.5	3.5	3.2

Note: The furnace was cooled down in between test runs.

Appendix C: Test Gases

Gas Sample Date	Baseline 9/14/04	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	0.0237	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	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**
Compressibility Factor	0.9970	0.9980	0.9972	0.9969	0.9969	0.9974	0.9974	0.9975
HHV (Btu/real cubic foot)	**1002.1**	**974.4**	**1151.6**	**1145.1**	**1148.3**	**1099.4**	**1099.8**	**1107.1**
LHV (Btu/real cubic foot)	902.9	877.3	1041.3	1035.9	1039.5	993.1	993.6	999.8
Specific Gravity	0.5911	0.5895	0.6434	0.6989	0.7018	0.6407	0.6410	0.6143
Wobbe Index	**1303.4**	**1269.1**	**1435.7**	**1369.7**	**1370.7**	**1373.5**	**1373.7**	**1412.5**

Appendix D: Zero, Span and Linearity Tables

Performance Test (with Cool Down Between Runs)

Zero, Span & Linearity Data
Performance Test (with Cool Down Between Runs)
October 26, 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 - 9:56 AM	0.20	0.00	0.77	-0.23	0.09
Zero	Zero Drift Check - 3:35 PM	0.20	-0.01	-0.38	-0.74	0.02
Zero	**Total Drift Over Test Period**	**0.00**	**0.01**	**1.15**	**0.51**	**0.07**
Zero	**Was the Zero Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Span	**Span Calibration Gas (High-Range Values)**	**20.90**	**12.20**	**182.40**	**434.00**	**42.86**
Span	**Allowable Span Drift (Less Than ± 3% of Range)**	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
Span	Span Calibration - 10:00 AM	20.87	12.01	182.62	435.87	84.45
Span	Span Drift Check - 3:28 PM	20.78	11.94	182.42	433.31	85.18
Span	**Total Drift Over Test Period**	**0.09**	**0.07**	**0.20**	**2.56**	**0.73**
Span	**Was the Span Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**9.03**	**8.00**	**79.50**	**217.00**	**17.80**
Linearity	**Allowable Linearity Drift (Less Than ±1% of Range)**	**0.25**	**0.20**	**2.00**	**10.00**	**1.00**
Linearity	Linearity Check - 3:31 PM	8.93	7.87	77.47	444.70	18.05
Linearity	**Difference From Mid-Range Values**	**0.10**	**0.13**	**2.03**	**227.70**	**0.25**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**Yes**	**No**	**No**	**Yes**

Zero, Span & Linearity Data
Performance Test (with Cool Down Between Runs)
October 27, 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 - 7:53 AM	0.19	-0.01	0.04	-0.31	0.04
Zero	Zero Drift Check - 2:35 PM	0.20	0.03	0.52	-0.10	0.18
Zero	**Total Drift Over Test Period**	**0.01**	**0.04**	**0.48**	**0.21**	**0.14**
Zero	**Was the Zero Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Span	**Span Calibration Gas (High-Range Values)**	**20.90**	**12.20**	**182.40**	**434.00**	**42.86**
Span	**Allowable Span Drift (Less Than ± 3% of Range)**	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
Span	Span Calibration - 8:23 AM	20.92	12.03	182.87	445.15	84.33
Span	Span Drift Check - 2:38 PM	20.48	11.82	183.75	430.10	85.05
Span	**Total Drift Over Test Period**	**0.44**	**0.21**	**0.88**	**15.05**	**0.72**
Span	**Was the Span Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**9.03**	**8.00**	**79.50**	**217.00**	**17.80**
Linearity	**Allowable Linearity Drift (Less Than ±1% of Range)**	**0.25**	**0.20**	**2.00**	**10.00**	**1.00**
Linearity	Linearity Check - 8:27 AM	9.18	8.02	77.91	447.64	18.33
Linearity	**Difference From Mid-Range Values**	**0.15**	**0.02**	**1.59**	**230.64**	**0.53**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**No**	**Yes**
Linearity	Linearity Check - 2:43 PM	9.03	7.91	78.75	432.71	18.24
Linearity	**Difference From Mid-Range Values**	**0.00**	**0.09**	**0.75**	**215.71**	**0.44**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

Performance Test (Straight Run)

	Zero, Span & Linearity Data Performance Test (Straight Run) October 28, 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 - 9:20 AM	0.22	0.05	0.1	0.32	0.43
Zero	Zero Drift Check - 11:39 AM	0.20	0.01	-0.09	-0.66	0.73
Zero	**Total Drift Over Test Period**	**0.02**	**0.04**	**0.19**	**0.98**	**0.30**
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 - 9:31 AM	20.97	12.02	397.92	441.65	83.87
Span	Span Drift Check - 11:45 AM	21.18	11.89	397.86	443.62	84.08
Span	**Total Drift Over Test Period**	**0.21**	**0.13**	**0.06**	**1.97**	**0.21**
Span	**Was the Span Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**9.03**	**8.00**	**182.40**	**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 - 9:37 AM	9.23	7.94	179.53	441.43	18.33
Linearity	**Difference From Mid-Range Values**	**0.20**	**0.06**	**2.87**	**1.57**	**0.53**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**Yes**	**No**	**Yes**	**Yes**
Linearity	Linearity Check - 11:52 AM	9.33	7.89	179.48	443.17	18.36
Linearity	**Difference From Mid-Range Values**	**0.30**	**0.11**	**2.92**	**0.17**	**0.56**
Linearity	**Was the Linearity Within Allowable Deviation?**	**No**	**Yes**	**No**	**Yes**	**Yes**

Maximum Inlet Pressure Test

Zero, Span & Linearity Data
Maximum Inlet Pressure Test
October 26, 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 - 9:56 AM	0.20	0.00	0.77	-0.23	0.09
Zero	Zero Drift Check - 3:35 PM	0.20	-0.01	-0.38	-0.74	0.02
Zero	**Total Drift Over Test Period**	**0.00**	**0.01**	**1.15**	**0.51**	**0.07**
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 - 10:00 AM	20.87	12.01	182.62	435.87	84.45
Span	Span Drift Check - 3:28 PM	20.78	11.94	182.42	433.31	85.18
Span	**Total Drift Over Test Period**	**0.09**	**0.07**	**0.20**	**2.56**	**0.73**
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 - 3:31 PM	8.93	7.87	77.47	444.70	18.05
Linearity	**Difference From Mid-Range Values**	**0.10**	**0.13**	**4.13**	**1.70**	**0.25**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**Yes**	**No**	**Yes**	**Yes**

Minimum Inlet Pressure Test

	Zero, Span & Linearity Data Minimum Inlet Pressure Test October 25, 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**
	Allowable Zero Drift (Less Than ± 3% of Range)	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
	Zero Calibration - 11:23 AM	0.21	0.04	0.48	0.22	0.05
	Zero Drift Check - 5:11 PM	0.23	0.03	-0.69	-0.54	-0.09
	Total Drift Over Test Period	**0.02**	**0.01**	**1.17**	**0.76**	**0.14**
	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**
	Allowable Span Drift (Less Than ± 3% of Range)	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
	Span Calibration - 11:33 AM	20.91	12.04	182.51	444.96	84.38
	Span Drift Check - 5:08 PM	19.94	11.81	181.65	448.27	85.79
	Total Drift Over Test Period	**0.97**	**0.23**	**0.86**	**3.31**	**1.41**
	Was the Span Drift Within Allowable Deviation?	**No**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**9.03**	**8.00**	**81.60**	**443.00**	**17.80**
	Allowable Linearity Drift (Less Than ±1% of Range)	**0.25**	**0.20**	**2.00**	**10.00**	**1.00**
	Linearity Check - 11:37 AM	9.19	8.00	78.11	444.38	18.60
	Difference From Mid-Range Values	**0.16**	**0.00**	**3.49**	**1.38**	**0.80**
	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)

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

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 analyzers (meet CARB and SCAQMD standards), Analyzer Calibration Gases, and Instrumentation.

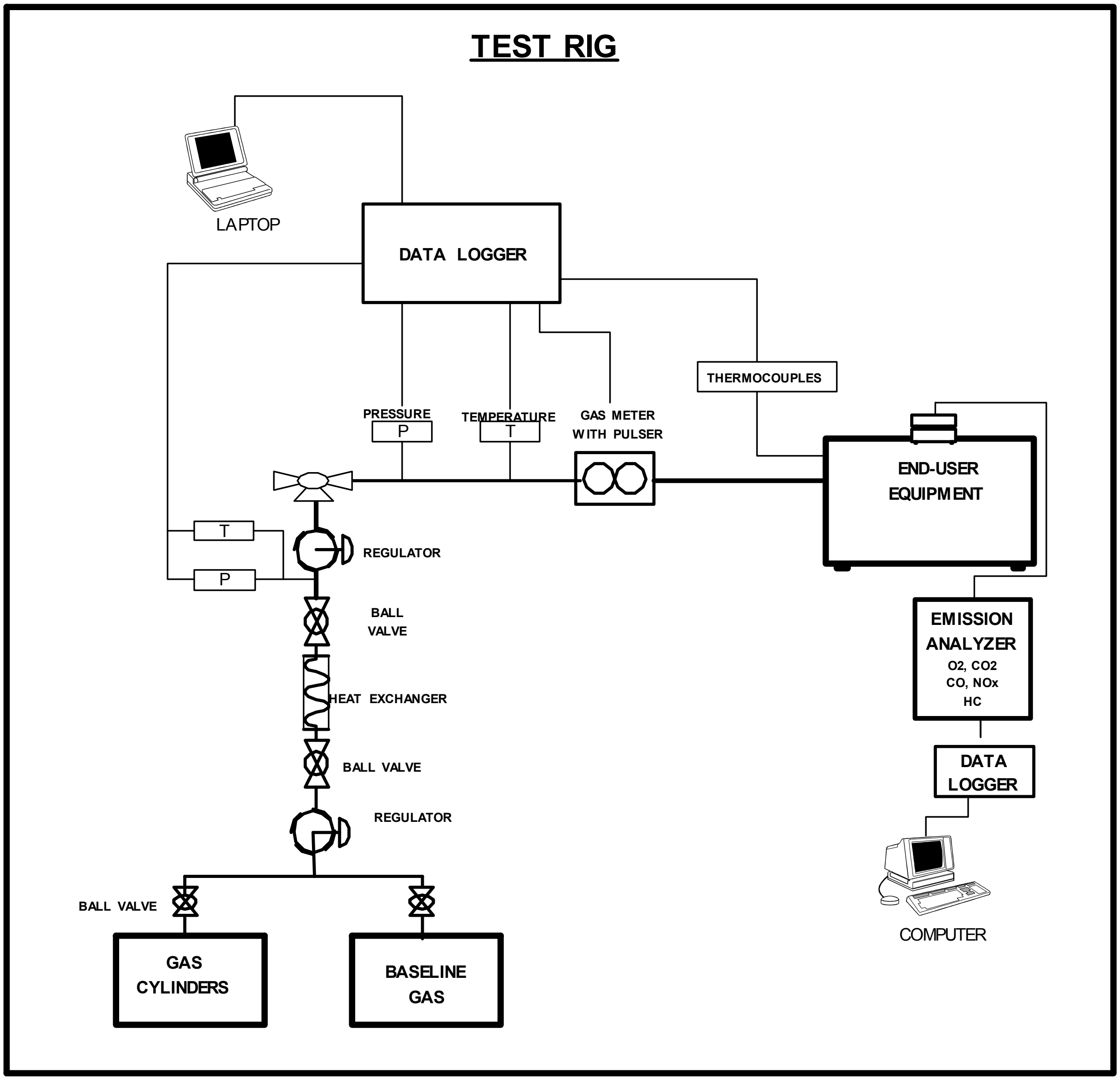
Emissions Analyzer				
Analyzer	Manufacturer	Model	Type	Accuracy
NO/NO_X	Thermo Environmental Instruments Inc.	10AR	Chemiluminescent	± 1% of full scale
CO	Thermo Environmental Instruments Inc.	48	Nondispersive infrared (NDIR) gas analyzer	± 1% of full scale
CO_2	Fuji	ZRH	Nondispersive infrared (NDIR) 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	Omega Engineering Co.	KMQSS	2.2°C or 0.75%
J	Omega Engineering Co.	JMQSS	2.2°C or 0.75%
R	Omega Engineering Co.	RMQSS	2.2°C or 0.75%
T	Omega Engineering Co.	TMQSS	2.2°C or 0.75%
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



Appendix H: Gravity Vented Wall Furnace Set-Up