# LNG Research Study

## FVIR Water Heater

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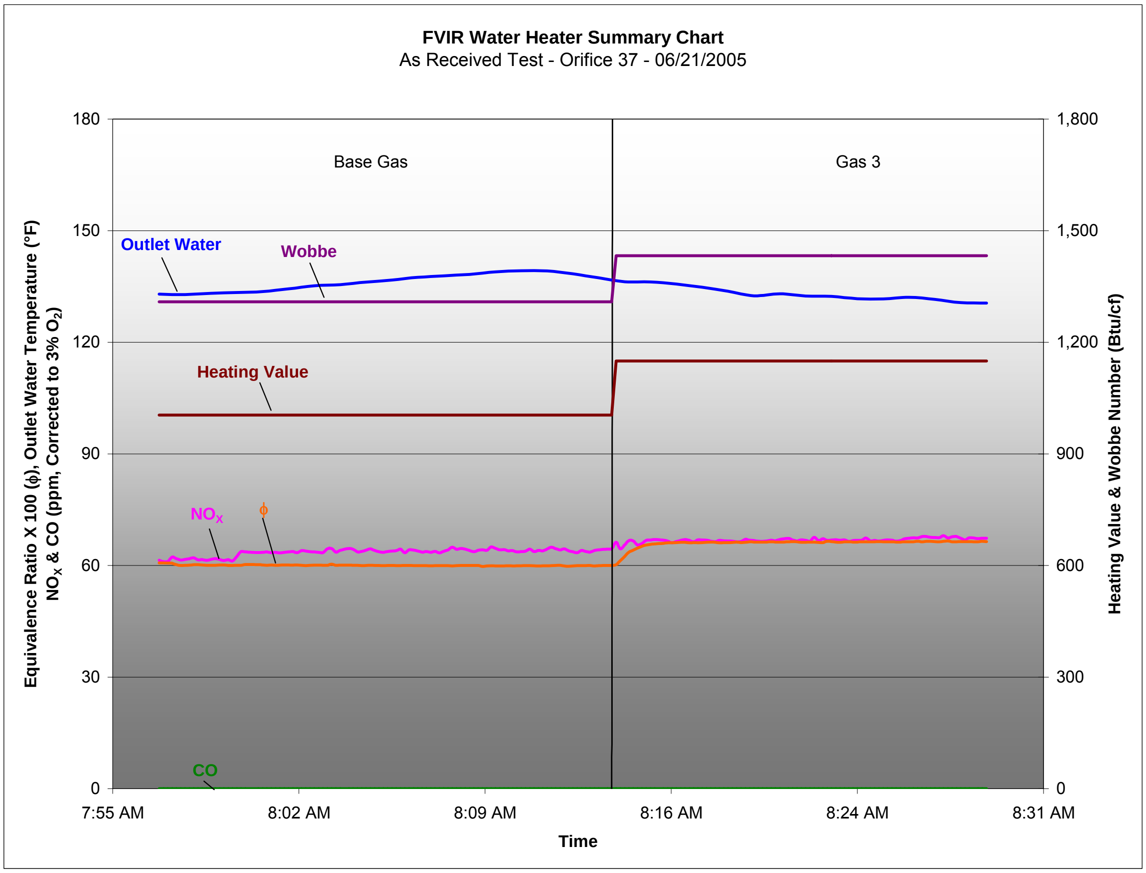
## Results Summary

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

Results while the water heater was tuned with Base Gas corroborate with results from testing conducted in June 2004 on a water heater with similar flammable vapor ignition resistance (FVIR) and burner technologies but made by a different manufacturer. Also, there were no notable differences in emissions when the test was conducted with or without the vent stack.

### As Received Test - Orifice 37

There was a slight increase in $NO_X$ emissions (corrected to 3% $O_2$) as the test transitioned from Base Gas (63.5 ppm) to Gas 3 (66.8 ppm). CO emissions (corrected to 3% $O_2$) remained negligibly low throughout the course of the test. Outlet water temperature was 135.9°F for Base Gas and 133.6°F for Gas 3.

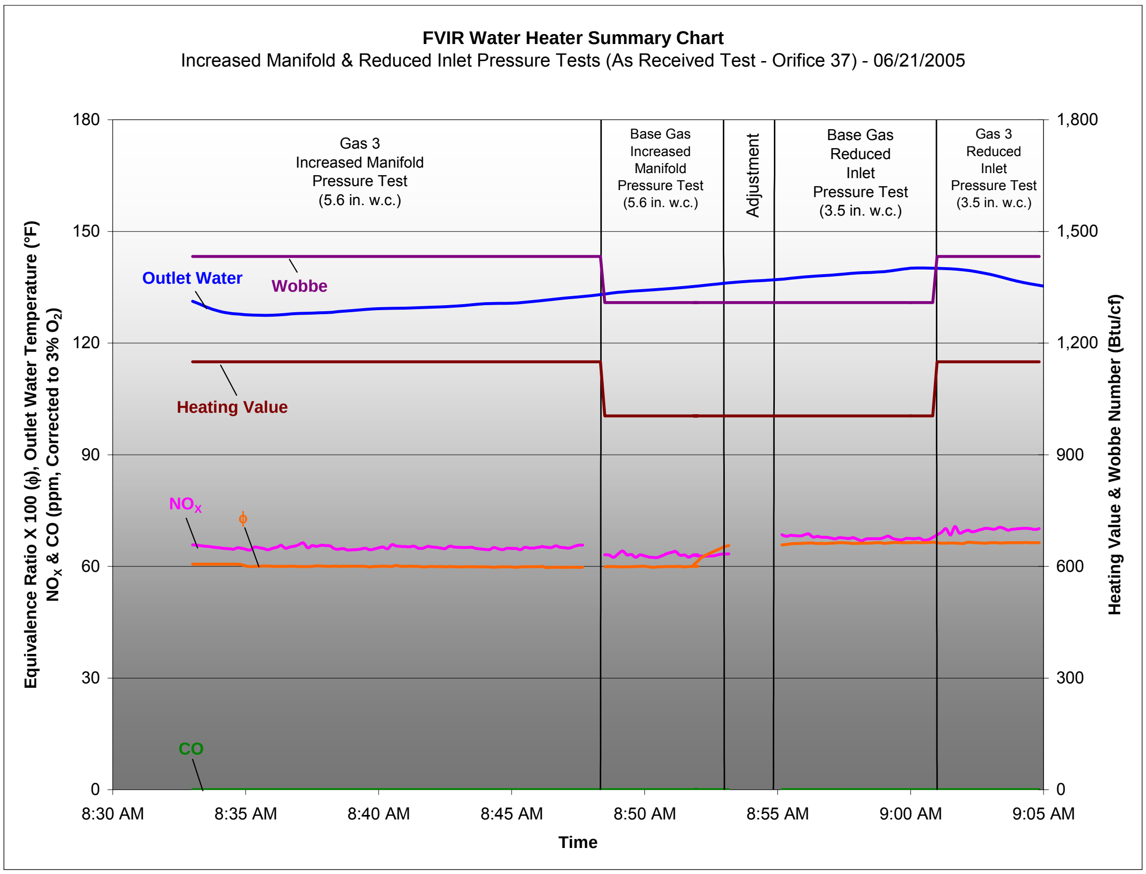



**NOTE:** Emission test results are for information purposes, they were not the result of certified tests.

## Increased Manifold & Reduced Inlet Pressure Tests (As Received Test - Orifice 37)

$NO_X$ emissions (corrected to 3% $O_2$) at increased manifold pressure for both Base Gas and Gas 3 were 63.0 ppm and 65.1 ppm, respectively. $NO_X$ emissions (corrected to 3% $O_2$) at reduced inlet pressure were 69.8 ppm for Gas 3 and 67.7 ppm for Base Gas. CO emissions (corrected to 3% $O_2$) were negligible throughout the length of the test.

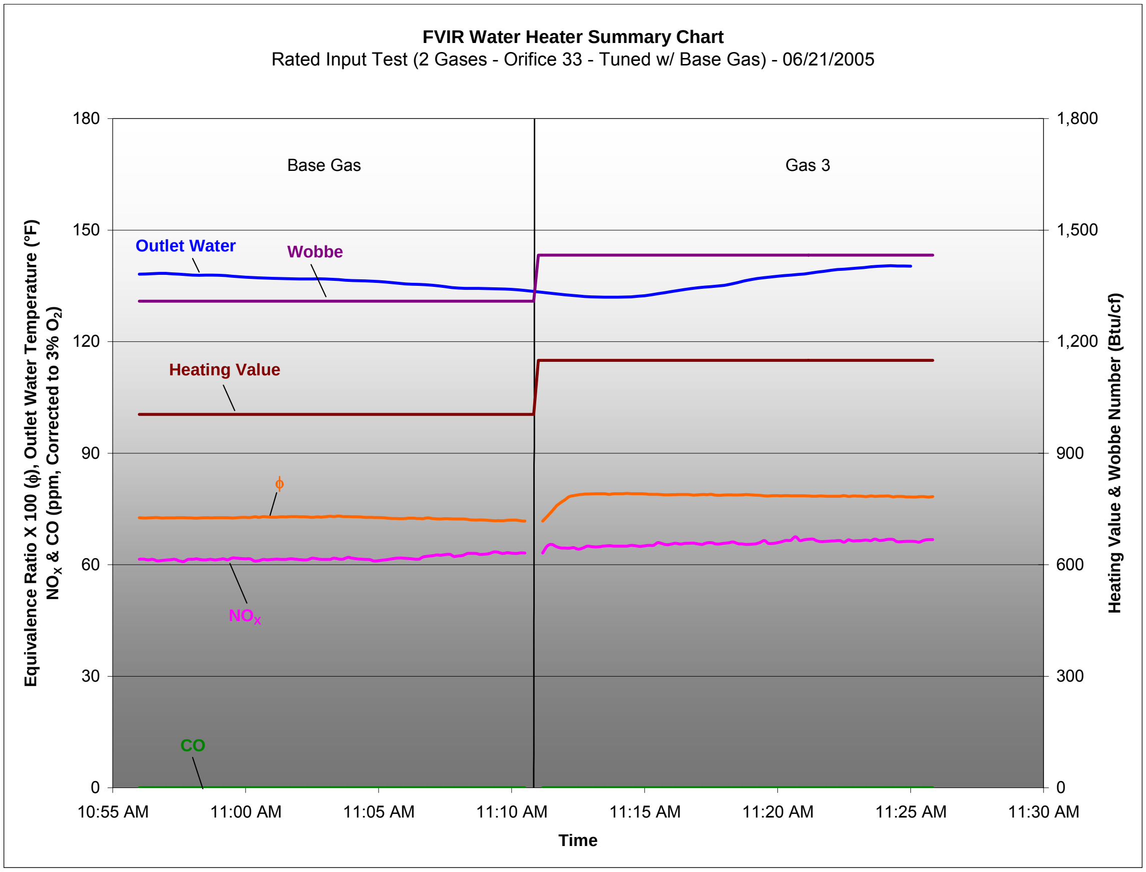
Outlet water temperature at increased manifold pressure was 129.5°F for Base Gas and increased to 134.1°F with Gas 3. Outlet water temperature increased for both gases at reduced inlet pressure with 138.6°F for Base Gas and 138.0°F for Gas 3.




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

## Rated Input Test (2 Gases - Orifice 33 - Tuned w/ Base Gas)

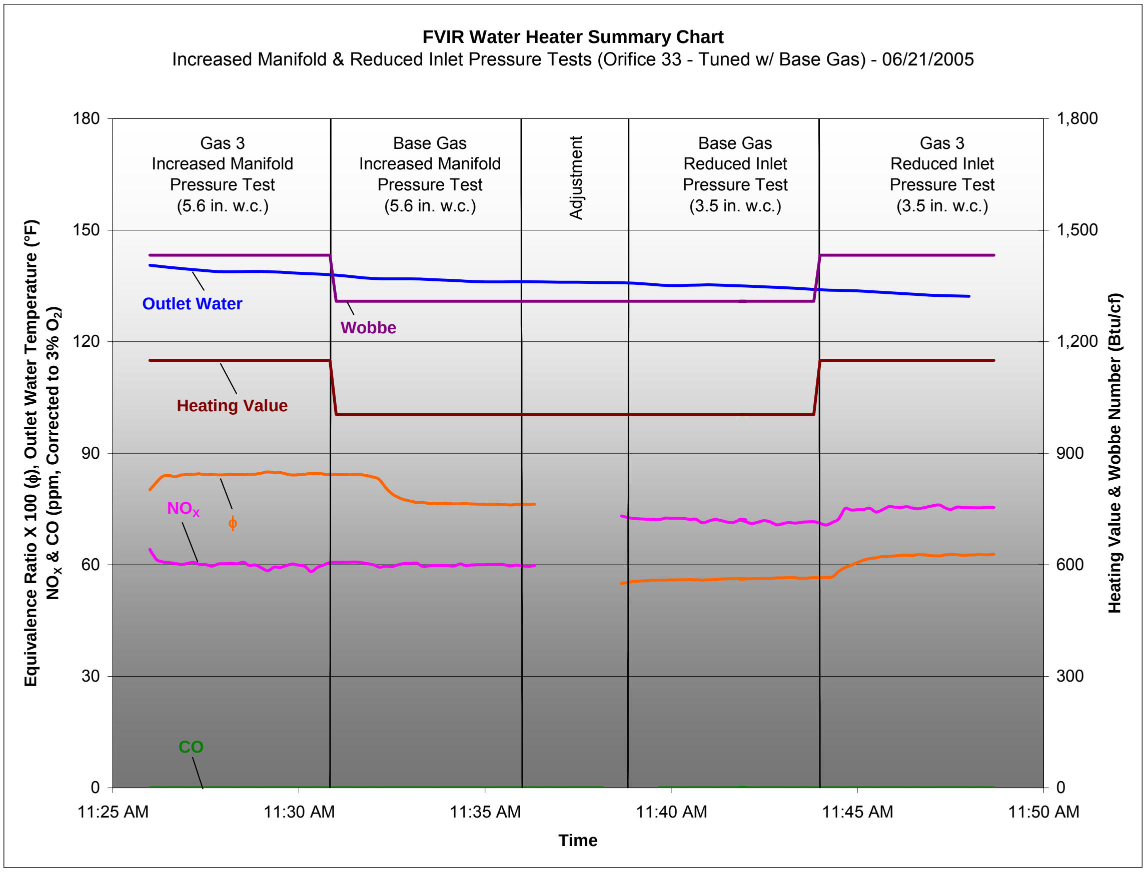
$NO_X$ emissions (corrected to 3% $O_2$) for Gas 3 were 65.8 ppm and 61.8 ppm for Base Gas. CO emissions (corrected to 3% $O_2$) remained negligibly low throughout the length of the test. Outlet water temperature was 136.2 ± 3°F for both gases.




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

## Increased Manifold & Reduced Inlet Pressure Test (Orifice 33 - Tuned w/ Base Gas)

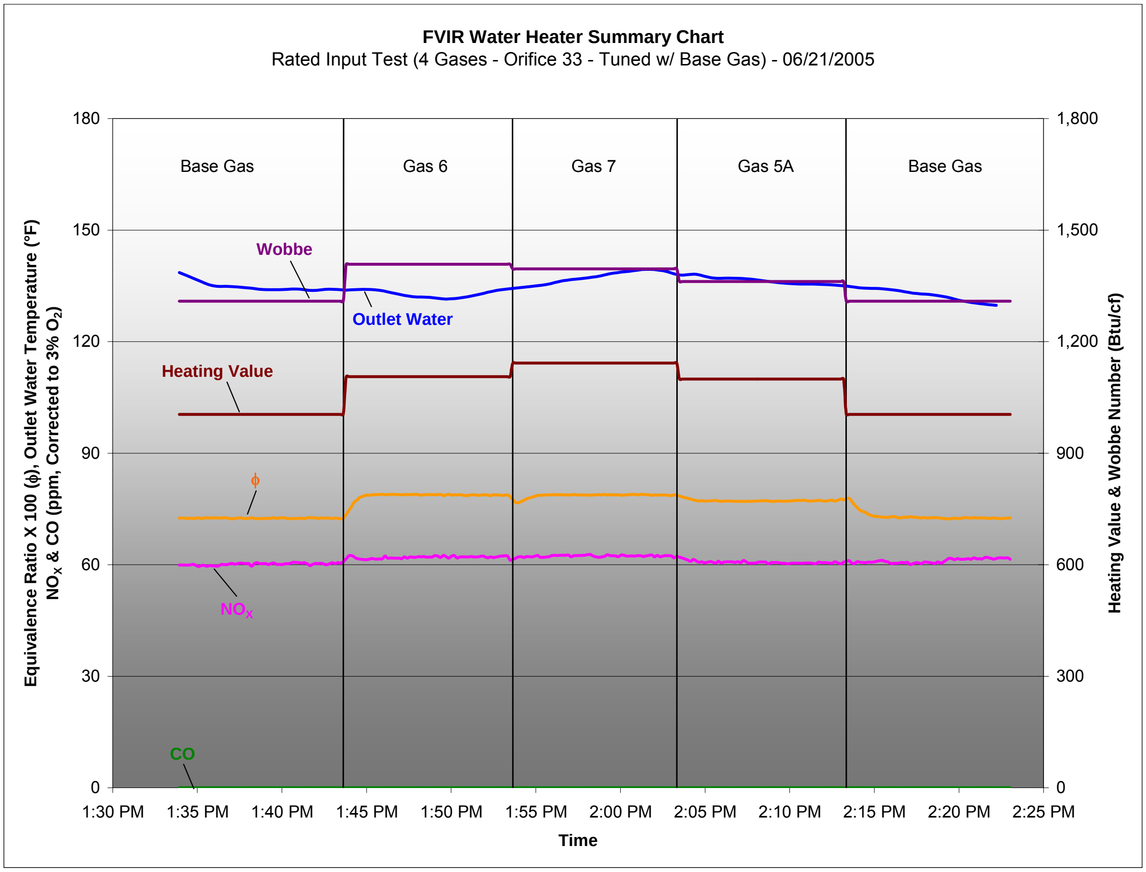
$NO_X$ emissions (corrected to 3% $O_2$) were 60.0 ± 0.1 ppm for both Base Gas and Gas 3 at increased manifold pressure. $NO_X$ emissions (corrected to 3% $O_2$) increased to 74.7 ppm for Gas 3 and 71.8 ppm for Base Gas at reduced inlet pressure. CO emissions (corrected to 3% $O_2$) remained negligibly low throughout the length of the test. Outlet water temperature gradually decreased throughout the test from 139.2°F (Base Gas at increased manifold pressure) to 133.1°F (Gas 3 at reduced inlet pressure).




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

### Rated Input Test (4 Gases - Orifice 33 - Tuned w/ Base Gas)

$NO_X$ emissions (corrected to 3% $O_2$) were between 60.0 ppm and 62.5 ppm and CO emissions (corrected to 3% $O_2$) were negligible for all gases tested. Outlet water temperatures ranged from 132.9°F to 137.1°F.

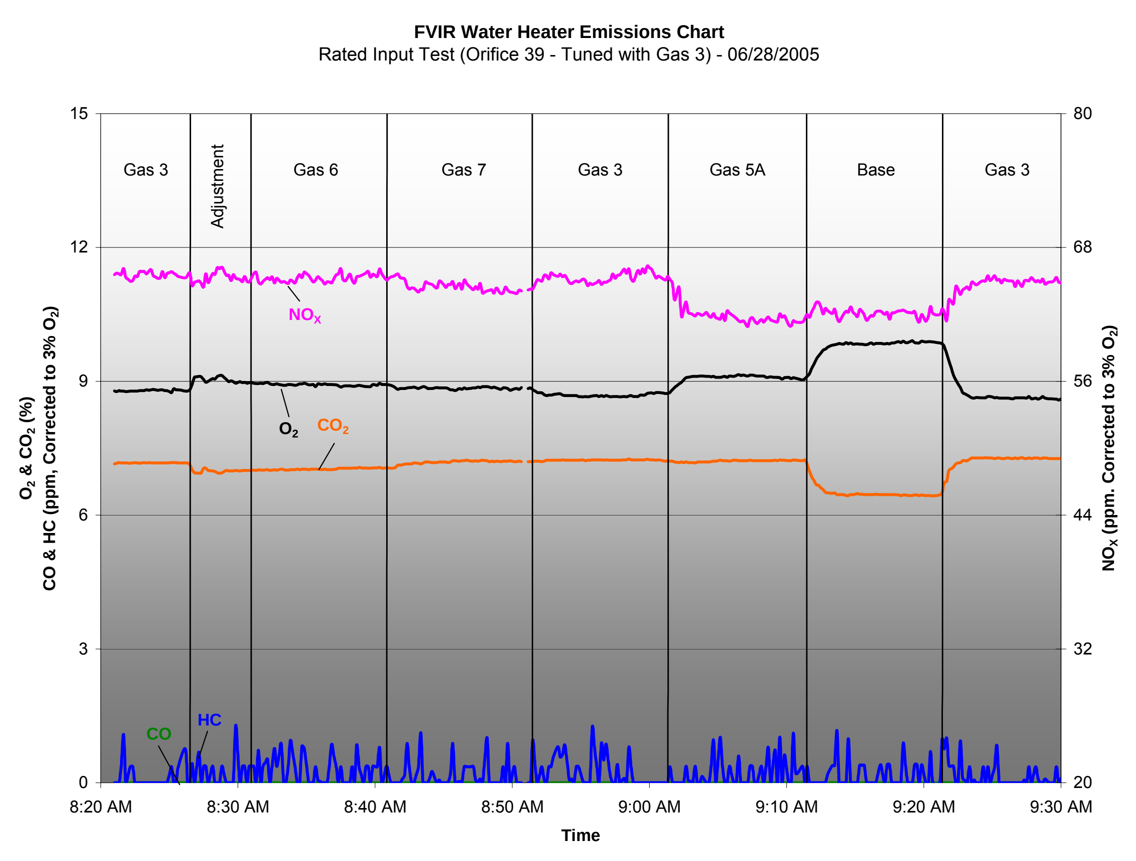



**NOTE:** Emission test results are for information purposes, they were not the result of certified tests.

## Rated Input Test (All Gases - Orifice 39 - Tuned w/ Gas 3)

$NO_X$ emissions (corrected to 3% $O_2$) was lowest with Gas 5A (61.9 ppm) and highest with Gas 6 (65.3 ppm). Also, all gases produced negligibly low CO and HC emissions values (corrected to 3% $O_2$) and $O_2$ percentages ranged from 8% to 10% throughout the length of the test.

Due to technical difficulties, the input and temperature data was not collected.

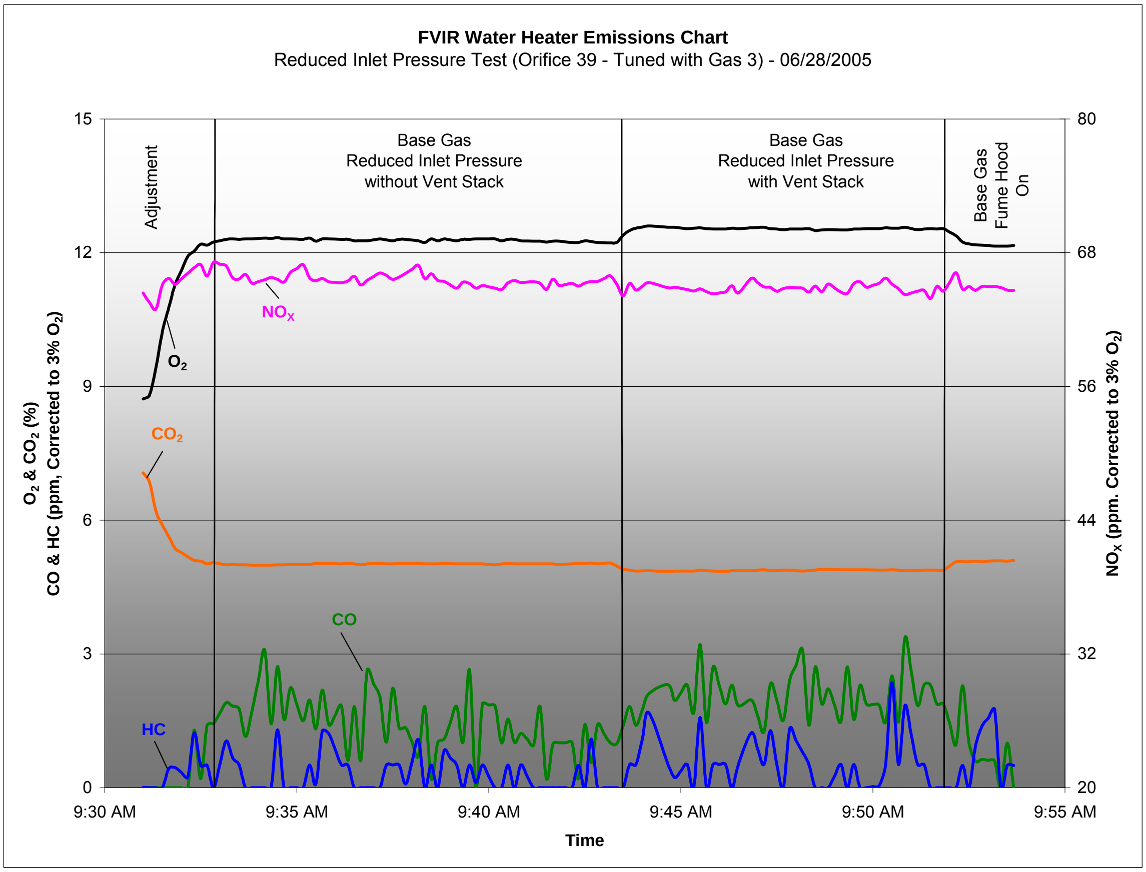



**NOTE:** Emission test results are for information purposes, they were not the result of certified tests.

**Reduced Inlet Pressure Test - Base Gas Only (Orifice 39 - Tuned w/ Gas 3)**

$NO_X$ emissions (corrected to 3% $O_2$) without the vent stack was 65.6 ppm and 64.8 ppm with the vent stack. HC and CO emissions (corrected to 3% $O_2$) remained negligibly low throughout the test.

Due to technical difficulties, the input and temperature data was not collected.




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

## Equipment Selection Criteria

This type of residential water heater was selected for a second test to (a) verify the results obtained in the first phase of testing (June 2004) on a water heater with similar flammable vapor ignition resistance (FVIR) burner technologies but made by a different manufacturer, (b) evaluate how it will react to the test gases after tuning it with the highest heating value and Wobbe Number gas (Gas 3) and (c) determine if there was a difference in the emissions when testing with and without a vent stack installed on the water heater.

The Flammable Vapor Ignition Resistant (FVIR) Water Heater represents modern technology that is required in all new residential water heaters. This technology limits flammable vapor fires from water heaters. The FVIR system incorporates a mechanism that prevents flames from propagating outside the water heater in the event of vapor ignition. On these units the openings for combustion air are smaller than found on previous water heaters. This led to a concern that there could be air/fuel ratio problems when rich Natural Gas fuel is supplied.

## Equipment Specifications

| | |
|---|---|
| **Description** | 40 Gallon Residential FVIR Water Heater (Manufactured 1995) |
| **Burner** | 4½ inch diameter atmospheric burner |
| **Maximum rated input** | 40,000 Btu/hr |
| **Type of fuel** | Natural Gas |
| **Required gas inlet pressure** | 5 – 14 in. w.c. |
| **Required manifold pressure** | 5 in. w.c. |

## Standards

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

| | |
|---|---|
| **ANSI Z21.10.1-2001** | Standard for Gas Water Heaters, Volume 1 |
| **SCAQMD Rule 1121** | Control of $NO_X$ Emission from Residential Type Natural Gas -Fired Water Heaters (last amended December 10,1999) |
| **SCAQMD 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" x 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 135 ± 5°F by continuously monitoring and manually adjusting outlet water flow. The water heater 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 Base Gas and Test Gases to the water heater. A 3 - way valve was used to connect both systems, allowing for interchangeability 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 inlet 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 performance testing 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 instrumentation 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 Base Gas to verify the water heater 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.

| **Gas** | **Wobbe Number** (Btu/cf) | **Heating Value** (Btu/cf) |
|---|---|---|
| Base | 1,303 (Low Wobbe) | 1,002 (Low heat content) |
| 3 | 1,436 (Highest Wobbe) | 1,152 (Highest heat content) |
| 5A | 1,362 (Medium Wobbe) | 1,099 (High heat content) |
| 6 | 1,412 (High Wobbe) | 1,107 (High heat content) |
| 7 | 1,395 (High Wobbe) | 1,142 (Highest heat content) |

## 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:

- Base Gas and Test 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:

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

### As Received Test - Orifice 37

At normal inlet pressure (6.9 ± 0.3 in. w.c.), operate the water heater with Base 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 Base Gas for 15 minutes
- Conclude testing with Gas 3 for 15 minutes

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

### Increased Manifold & Reduced Inlet Pressure Tests (As Received Test - Orifice 37)

For the Increased Manifold Pressure test, the manifold pressure was increased from normal pressure (5.0 in. w.c.) to 5.6 in. w.c. without adjusting inlet pressure (7.0 in. w.c.) while the water heater operated with Gas 3. Once steady-state conditions were achieved, testing and collection of temperature, pressure and emissions data began and gases were run in the following order:

- Gas 3 for 5 minutes at increased manifold pressure.
- Base Gas for 5 minutes at increased manifold pressure.

After the Base Gas run at increased manifold pressure, the manifold pressure was adjusted back to normal pressure and the inlet pressure was decreased to 3.5 in. w.c. for the Reduced Inlet Pressure test. Once steady-state conditions were achieved, testing continued in the following order:

- Base Gas for 5 minutes at reduced inlet pressure.
- Conclude testing with Gas 3 for 5 minutes at reduced inlet pressure.

### Rated Input Test (2 Gases - Orifice 33 - Tuned w/ Base Gas)

Prior to the start of the test, the atmospheric burner was removed and a new gas orifice was made using a #33 drill to achieve the rated input. The size of the orifice was determined using an Orifice Drill Size Chart from Southern California Gas Company established procedures.

The water heater was adjusted back to normal inlet pressure (7.0 in. w.c.) while operating on Base Gas to obtain a rated input of 40,000 Btu/hr ± 2%. 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 Base Gas for 15 minutes
- Conclude testing with Gas 3 for 15 minutes

**Increased Manifold & Reduced Inlet Pressure Tests (Orifice 33 - Tuned w/ Base Gas)**

The same procedure and settings were used in this test as mentioned above in the Increased Manifold & Reduced Inlet Pressure Tests (As Received Test – Orifice 37) but with Orifice #33 instead of #37.

For the Increased Manifold Pressure test, the manifold pressure was increased from normal pressure (5.0 in. w.c.) to 5.6 in. w.c. without adjusting inlet pressure (7.0 in. w.c.) while the water heater operated with Gas 3. Once steady-state conditions were achieved, testing and collection of temperature, pressure and emissions data began and gases were run in the following order:

- Gas 3 for 5 minutes at increased manifold pressure.
- Base Gas for 5 minutes at increased manifold pressure.

After the Base Gas run at increased manifold pressure, the manifold pressure was adjusted back to normal pressure and the inlet pressure was decreased to 3.5 in. w.c. for the Reduced Inlet Pressure test. Once steady-state conditions were achieved, testing continued in the following order:

- Base Gas for 5 minutes at reduced inlet pressure.
- Conclude testing with Gas 3 for 5 minutes at reduced inlet pressure.

**Rated Input Test (4 Gases - Orifice 33 - Tuned w/ Base Gas)**

This test was a continuation of the Rated Input Test (2 gases – Orifice 33 – Tuned w/ Base Gas) described above and the same procedure and settings were utilized. The only difference is that during this test three more test gases were introduced. The test gases were introduced in the following order:

- Begin testing on Base Gas for 10 minutes
- Gas 6 for 10 minutes
- Gas 7 for 10 minutes
- Gas 5A for 10 minutes
- Conclude testing with Base Gas for 10 minutes

### Rated Input Test (All Gases - Orifice 39 - Tuned w/ Gas 3)♦

Prior to the start of the test, the atmospheric burner was removed and a new gas orifice was made using a #39 drill to achieve the rated input with Gas 3. The size of the orifice was determined using an Orifice Drill Size Chart from Southern California Gas Company established procedures.

The water heater was adjusted to normal inlet pressure (7.0 in. w.c.) while operating on Gas 3 to obtain a rated input of 40,000 Btu/hr ± 2%. 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 Gas 3 for 10 minutes
- Gas 6 for 10 minutes
- Gas 7 for 10 minutes
- Gas 3 for 10 minutes
- Gas 5A for 10 minutes
- Base Gas for 10 minutes
- Conclude testing with Gas 3 for 10 minutes

### Reduced Inlet Pressure Test (Orifice 39 - Tuned w/ Gas 3)♦

At normal manifold pressure, the inlet pressure was decreased to 3.5 in. w.c. while operating on Gas 3. 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 Gas 3 for 5 minutes and make adjustments to reduced inlet pressure
- Base Gas for 10 minutes without Vent Stack
- Base Gas for 10 minutes with Vent Stack
- Conclude testing with Base Gas for 5 minutes with the Fume Hood "on"

### Cold Ignition Test

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

### Hot Ignition Test

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

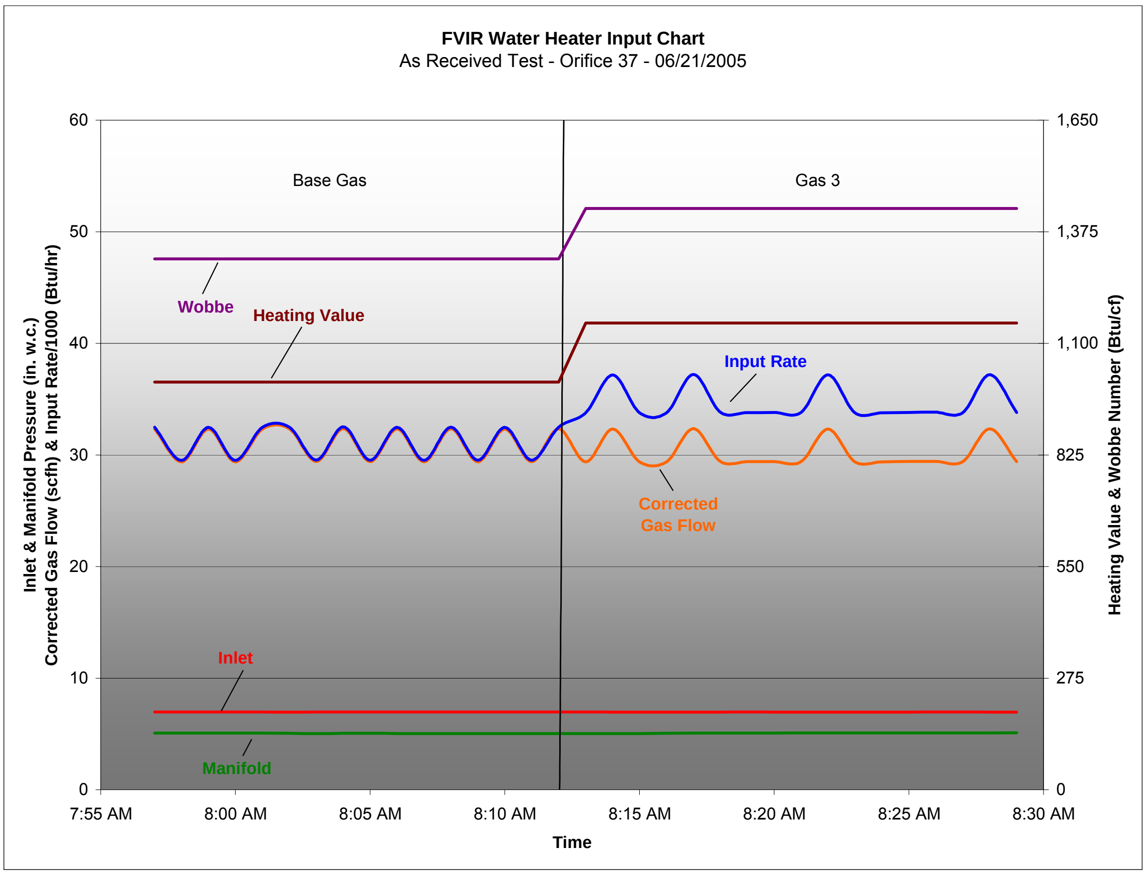
♦ The temperature, input, and pressure data was lost for this test.

## Results[1,2,3]

### As Received Test - Orifice 37

*Input*

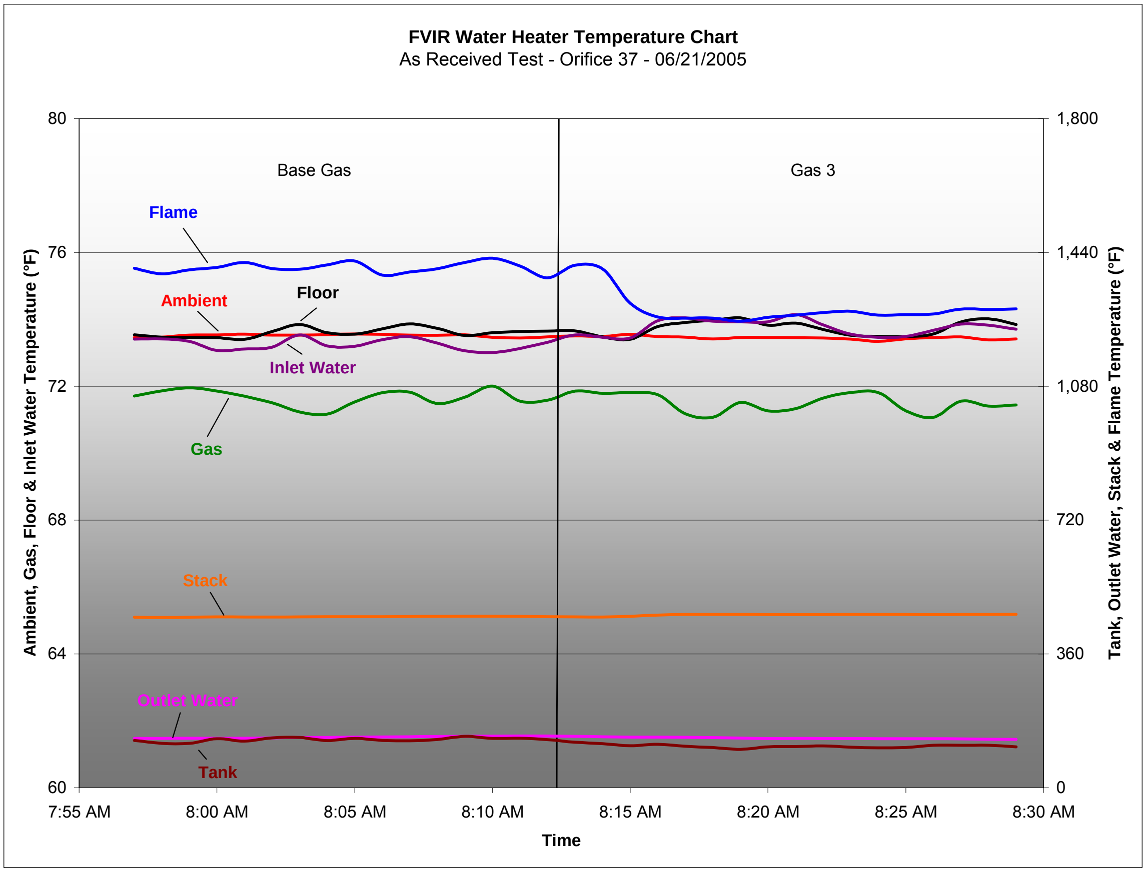
The input rate for Base Gas was 31,289 Btu/hr and 34,713 Btu/hr with Gas 3. The corrected gas flow rate with Base Gas was 31.1 scfh and decreased slightly to 30.2 scfh with Gas 3. Inlet and manifold pressure remained stable throughout the course of the test and within the parameters specified in the test protocol.




[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% $O_2$.
[3] When either Base Gas or Gas 3 is used as the set-up gas, the values reported for the set-up gas are the average values of all runs for that gas during each test.

*Temperature*

The flame and tank temperatures were higher with Base Gas (1,399°F and 129.5°F) than with Gas 3 (1,290°F and 112.1°F). Outlet water (134.0 ± 2.0°F), inlet water (73.5 ± 0.3°F), floor (73.6 ± 0.1°F), and stack (462.0 ± 3.0°F) temperatures remained steady throughout the test. Ambient and gas temperatures remained constant throughout the course of the test



*Emissions*

$NO_X$ emissions increased from 63.5 ppm (Base Gas) to 65.8 ppm (Gas 3). HC emissions ranged from 1.0 ppm to 1.3 ppm while CO emissions were negligibly low. $O_2$ percentage decreased from 9% to 8% when Gas 3 was introduced.

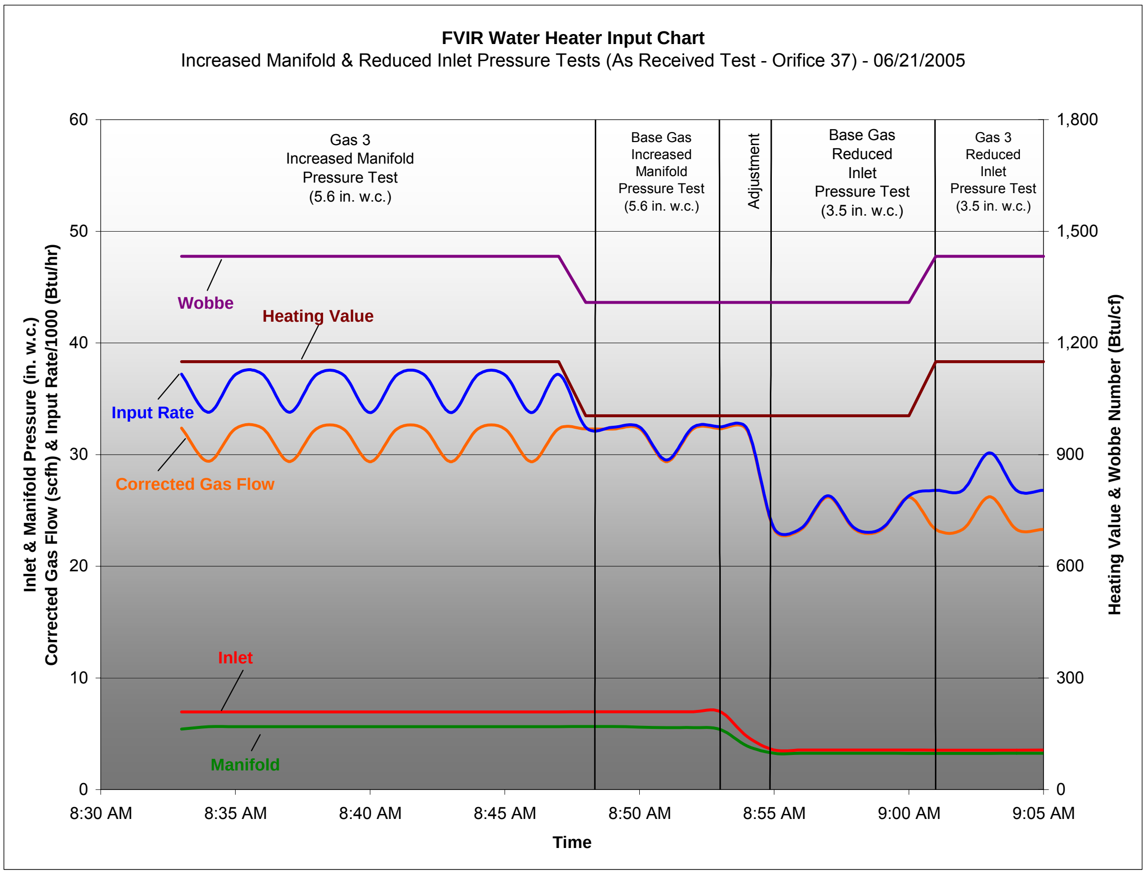

**NOTE:** Emission test results are for information purposes, they were not the result of certified tests.

**Increased Manifold & Reduced Inlet Pressure Tests (As Received Test - Orifice 37)**

*Input*

The input rates for Gas 3 and Base Gas were lower at reduced inlet pressure (3.5 in. w.c.) then at increased manifold pressure (7.0 in. w.c.). For Gas 3, the input rate was 27,547 Btu/hr at reduced inlet pressure and 36,146 Btu/hr at increased manifold pressure. For Base Gas, the input rate was 24,442 Btu/hr at reduced inlet pressure and 32,117 Btu/hr at increased manifold pressure.

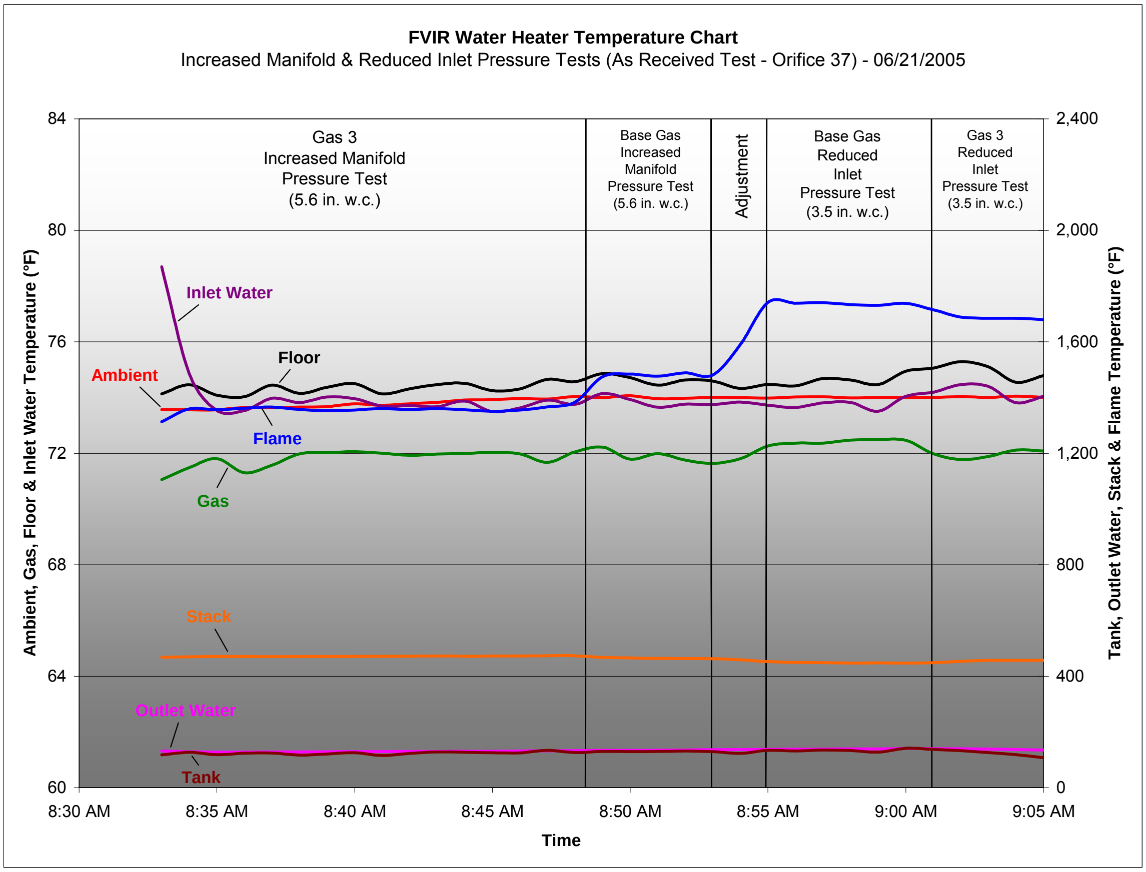
The corrected gas flow was 24.2 ± 0.2 at reduced inlet pressure and 31.7 ± 0.3 scfh at increased manifold pressure. With the exception of the adjustment period, both inlet and manifold pressure remained stable throughout the course of the test.



*Temperature*

The flame temperature ranged from 1,355°F to 1,461°F at increased manifold pressure, and 1,690°F to 1,737°F at reduced inlet pressure. This increase in temperature was due to a change in flame shape and length when the inlet pressure was reduced, thus exposing a hotter section of the flame to the fixed thermocouple.

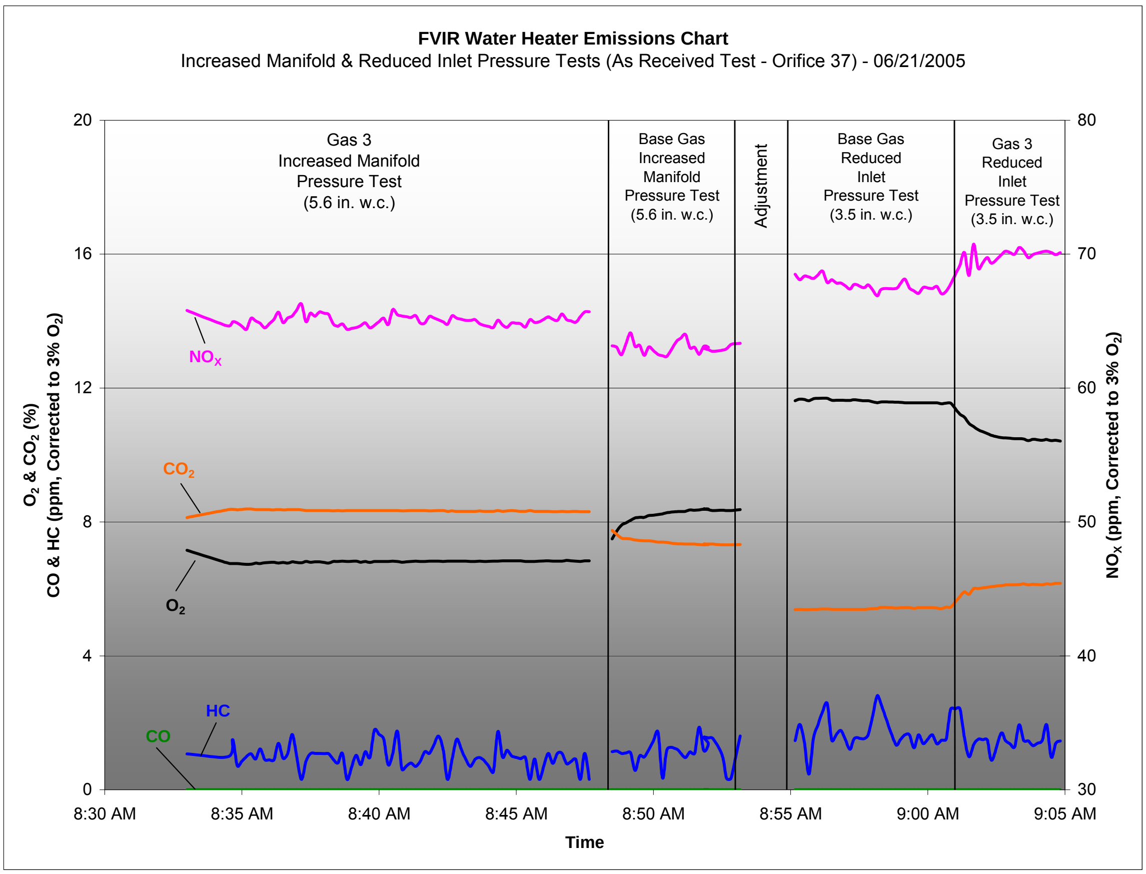
Tank temperature ranged from 123.2°F to 133.6°F and stack temperature ranged from 448.7°F to 471.1°F. Ambient (73.9 ± 0.2°F), gas (72.0 ± 0.4°F), inlet water (74.0 ± 0.2°F) and floor (74.5 ± 0.5°F) temperatures remained stable throughout the course of the test.



*Emissions*

$O_2$ percentage, $NO_X$ and HC emissions were higher at reduced inlet pressure than at increased manifold pressure for both Base Gas and Gas 3. For Base Gas, $NO_X$ emissions at increased manifold pressure were 63.0 ppm and 67.7 ppm at reduced inlet pressure. For Gas 3, $NO_X$ emissions at increased manifold pressure were 65.1 ppm and 69.8 ppm at reduced inlet pressure.

HC emissions at increased manifold were 1.1 ± 0.1 ppm and 1.6 ± 0.1 ppm at reduced inlet pressure. $O_2$ percentage for both gases was higher at reduced inlet pressure (11.0 ± 1.0%) then at increased manifold pressure (7.5 ± 0.7%). CO emissions values were negligible throughout the course of the test.



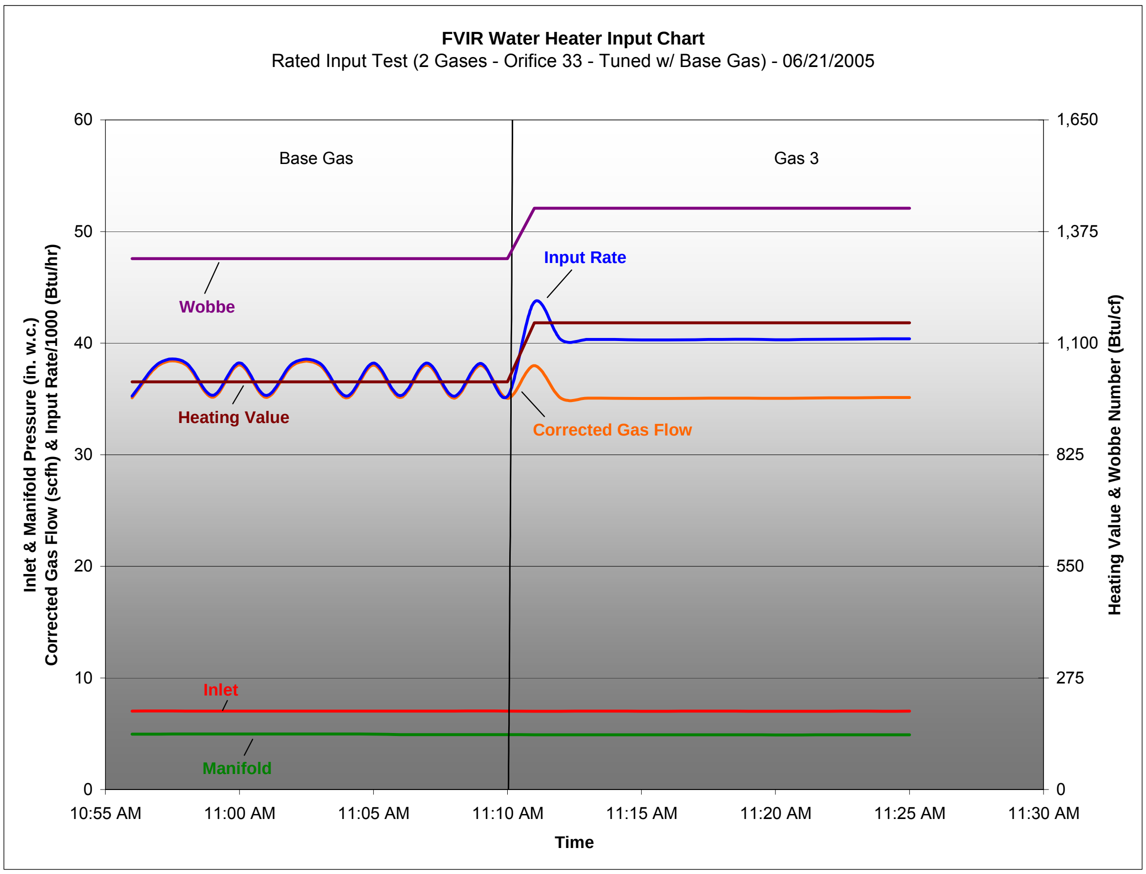

**NOTE:** Emission test results are for information purposes, they were not the result of certified tests.

## Rated Input Test (2 Gases – Orifice 33 – Tuned w/ Base Gas)

*Input*

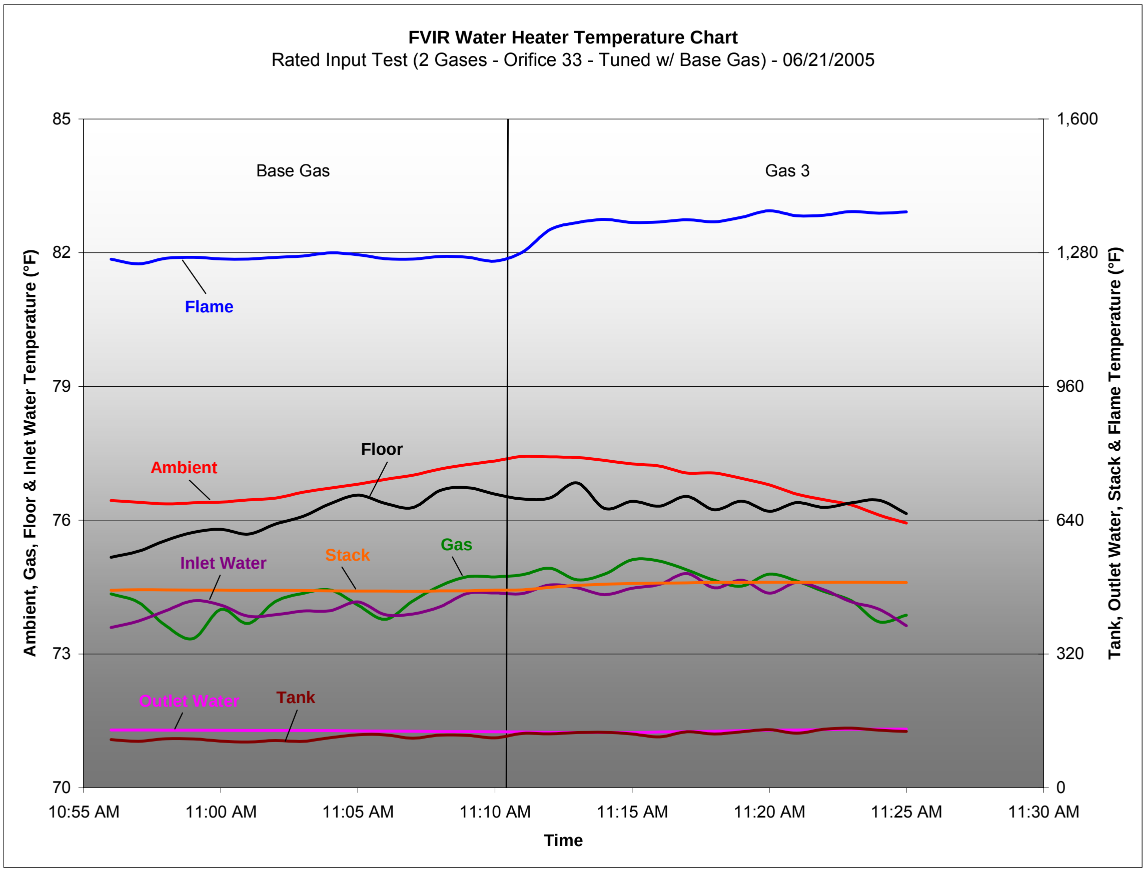
The input rate for Gas 3 was 40,665 Btu/hr and 36,932 Btu/hr for Base Gas. During this test, Base Gas was 7.67% below rated input – outside the limits specified in the protocol.

The corrected gas flow remained at 36.8 scfh with Base Gas and 35.4 scfh with Gas 3. Inlet and manifold pressure remained stable throughout the course of the test and within the parameters specified in the test protocol.



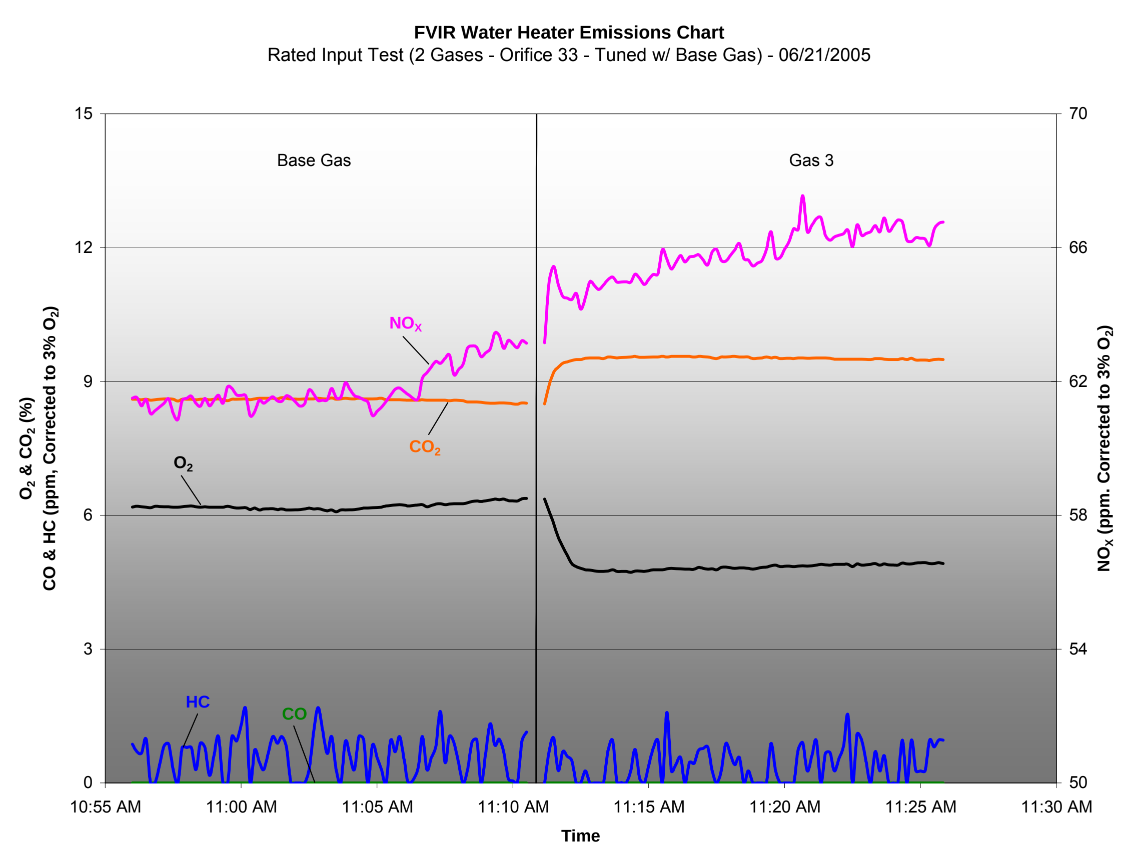
*Temperature*

Flame, stack and tank temperatures were highest with Gas 3 (1,358°F, 488.3°F and 133.0°F) compared to Base Gas (1,267°F, 472.0°F and 117.9°F). Ambient (76.8 ± 0.1°F), gas (74.3 ± 0.3°F), inlet water (74.2 ± 0.2°F), outlet water (136.1 ± 0.3°F) and floor (76.2 ± 0.2°F) temperatures remained stable throughout the course of the test.



*Emissions*

$NO_X$ emissions with Base Gas were 61.8 ppm and 65.8 ppm with Gas 3. CO and HC emission values remained negligible throughout the length of the test. $O_2$ percentage was at 6.2% with Base Gas and 4.9% with Gas 3.



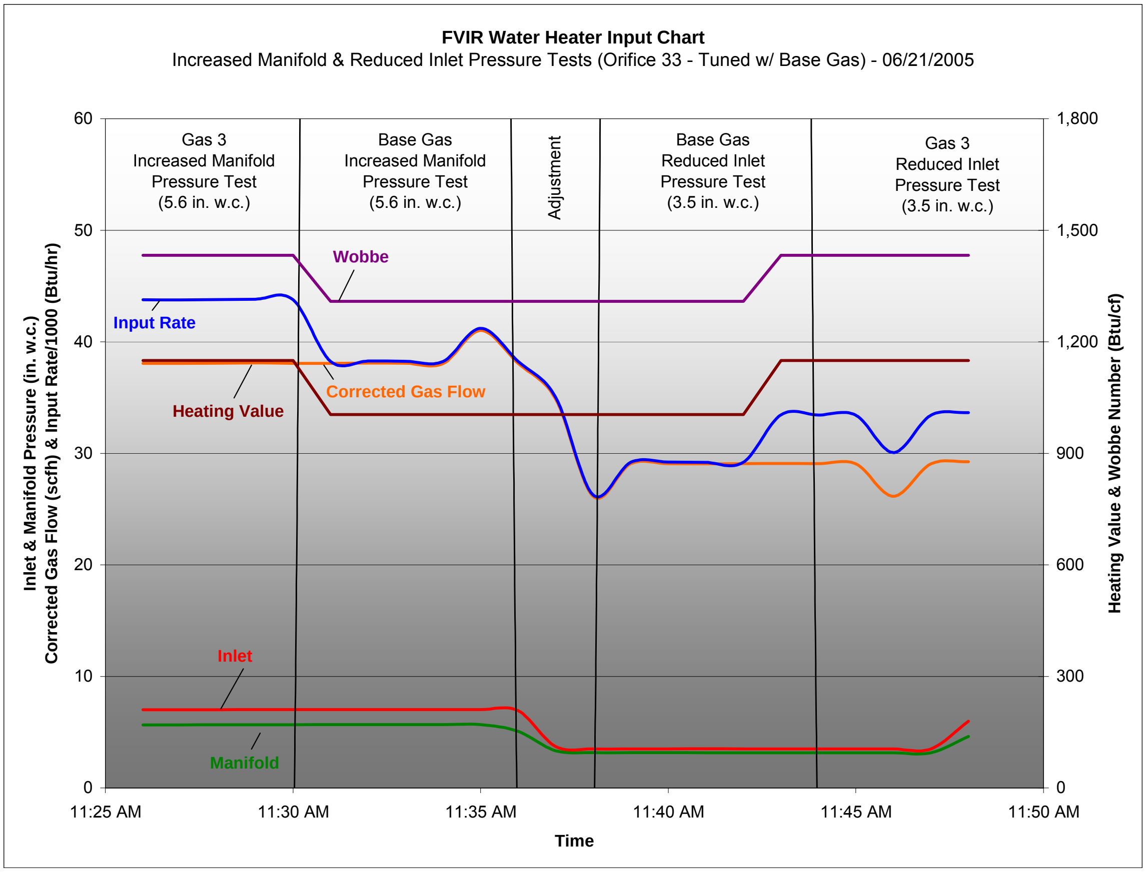

**NOTE:** Emission test results are for information purposes, they were not the result of certified tests.

## Increased Manifold & Reduced Inlet Pressure Tests (Orifice 33 – Tuned w/ Base Gas)

*Input*

The input rates for Gas 3 and Base Gas were lower at reduced inlet pressure (3.5 in. w.c.) than at increased manifold pressure (7.0 in. w.c.). For Gas 3, the input rate was 32,913 Btu/hr at reduced inlet pressure and 43,883 Btu/hr at increased manifold pressure. For Base Gas, the input rate was 30,158 Btu/hr at reduced inlet pressure and 38,932 Btu/hr at increased manifold pressure.

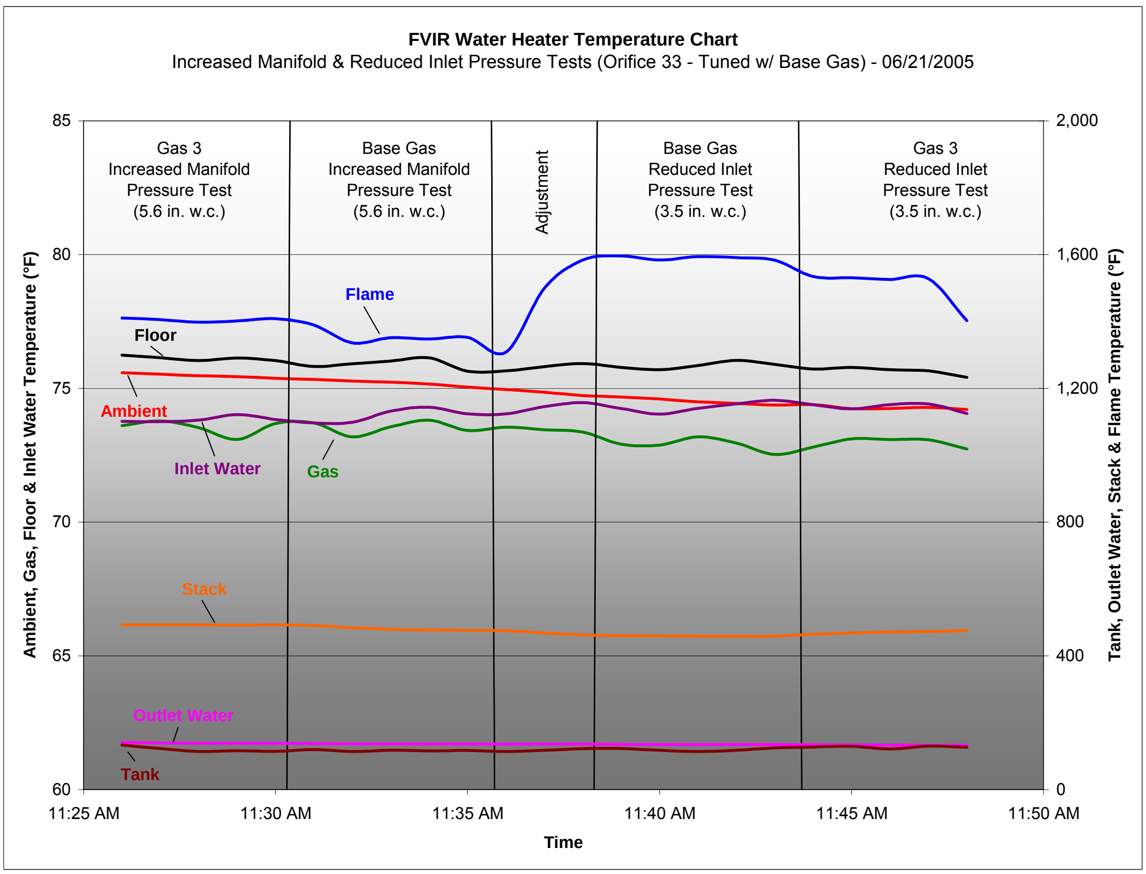
The corrected gas flow was 28.9 ± 0.3 at reduced inlet pressure and 38.5 ± 0.3 scfh at increased manifold pressure. With the exception of the adjustment period, both inlet and manifold pressure remained stable throughout the course of the test.



*Temperature*

The flame temperature ranged from 1,355°F to 1,405°F at increased manifold pressure, and 1,505°F to 1,590°F at reduced inlet pressure. This increase in temperature was due to a change in flame shape and length when the inlet pressure was reduced, thus exposing a hotter section of the flame to the fixed thermocouple.

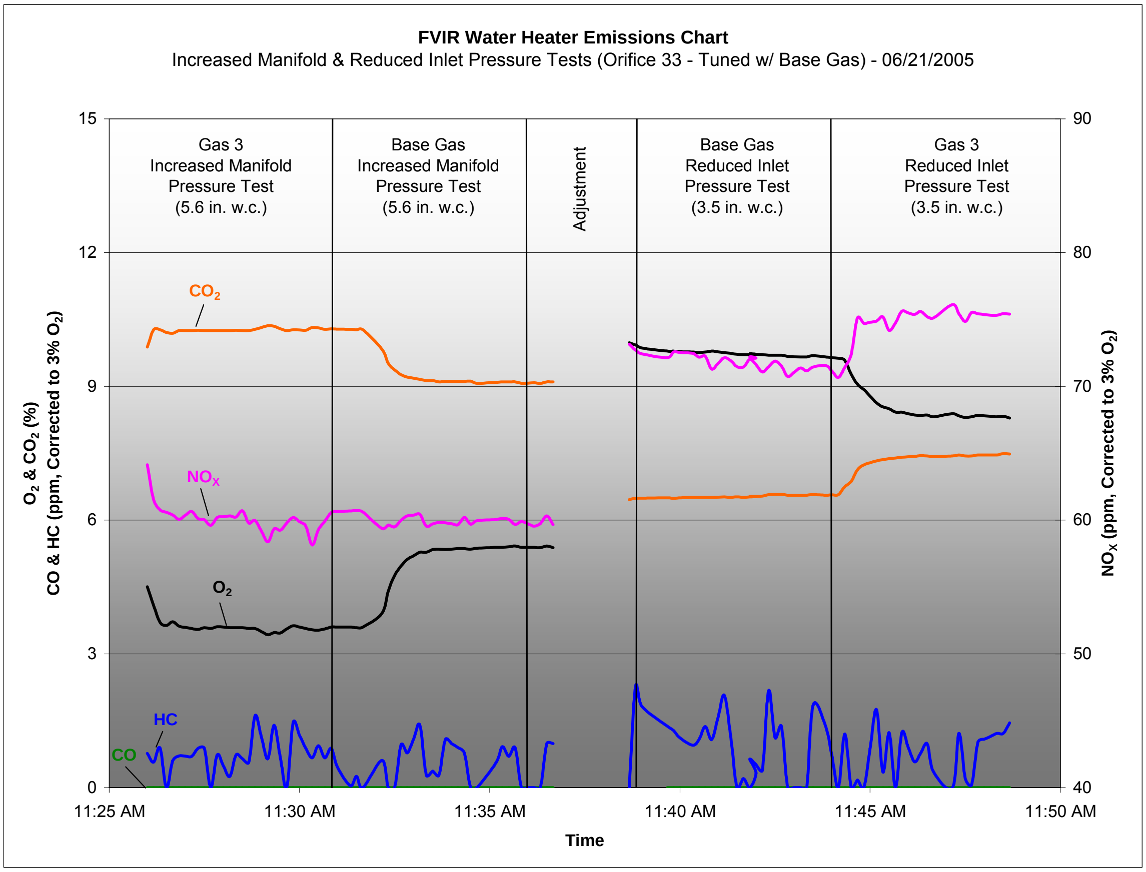
Tank temperature ranged from 116.7°F to 127.2°F and stack temperature ranged from 459.3°F to 492.4°F. Ambient (75.0 ± 0.5°F), gas (73.2 ± 0.3°F), inlet water (74.0 ± 0.3°F) and floor (75.9 ± 0.2°F) temperatures remained stable throughout the course of the test.



*Emissions*

$NO_X$ emissions were higher at reduced inlet pressure than at increased manifold pressure for both Base Gas and Gas 3. For Base Gas, $NO_X$ emissions at increased manifold pressure were 60.0 ppm and 71.8 ppm at reduced inlet pressure. For Gas 3, $NO_X$ emissions at increased manifold pressure were 60.1 ppm and 74.7 ppm at reduced inlet pressure.

$O_2$ percentage for both gases was higher at reduced inlet pressure (9.0 ± 0.7%) than at increased manifold pressure (4.2 ± 0.7%). CO emissions values were negligible and HC emissions were 0.7 ± 0.5 ppm throughout the course of the test.

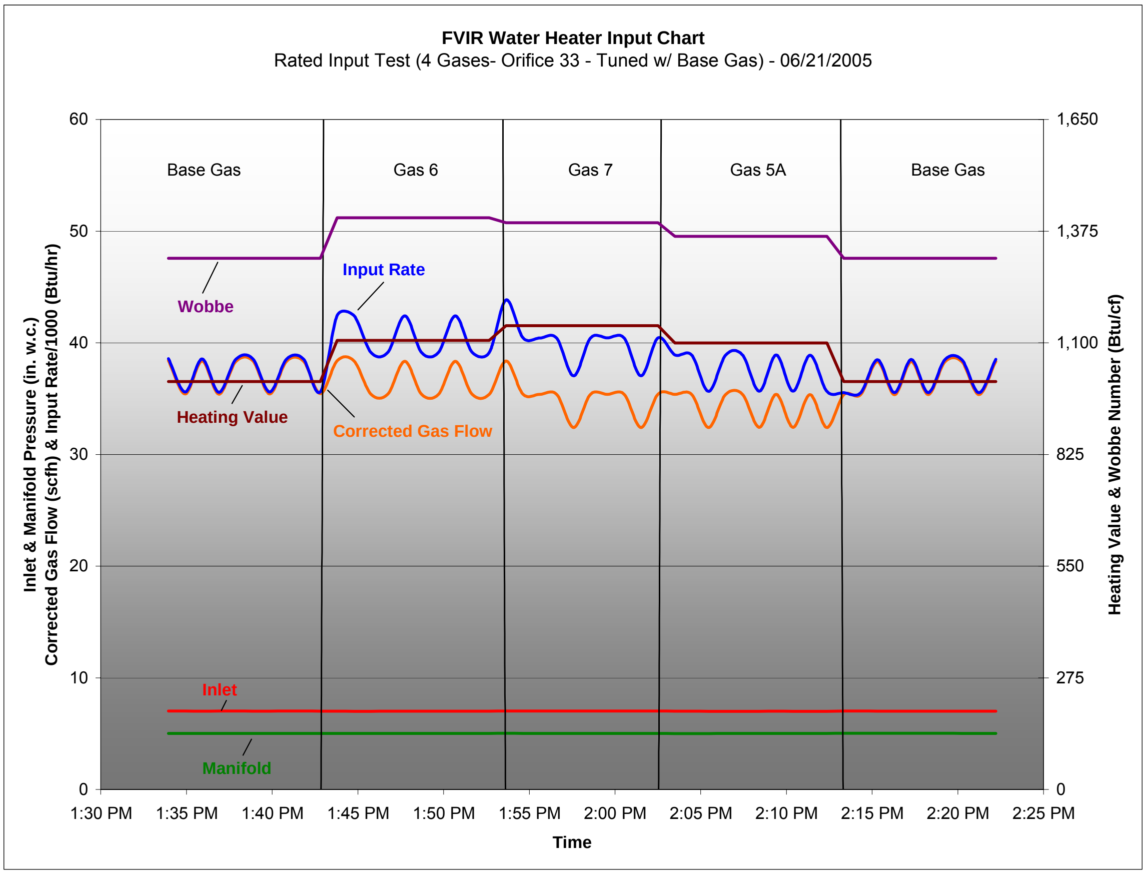



**NOTE:** Emission test results are for information purposes, they were not the result of certified tests.

## Rated Input Test (4 Gases – Orifice 33 – Tuned w/ Base Gas)

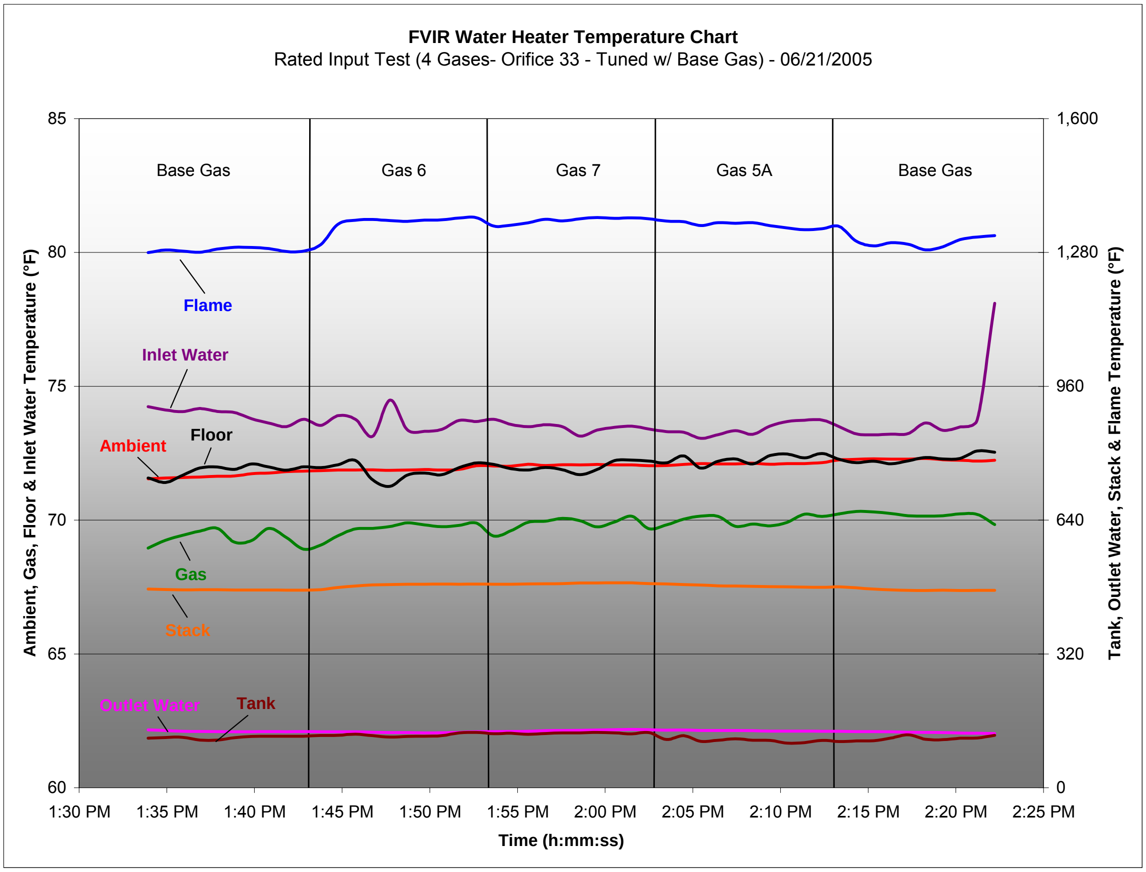
*Input*

The highest input rate occurred with Gas 6 (40,558 Btu/hr), followed by Gas 7 (40,208 Btu/hr) with the lowest input rate occurring with Base Gas (37,287 Btu/hr). The corrected gas flow was lowest with Gas 5A (34.3 scfh) and highest with Base Gas (37.1 scfh). Both inlet and manifold pressures remained constant throughout the course of the test.



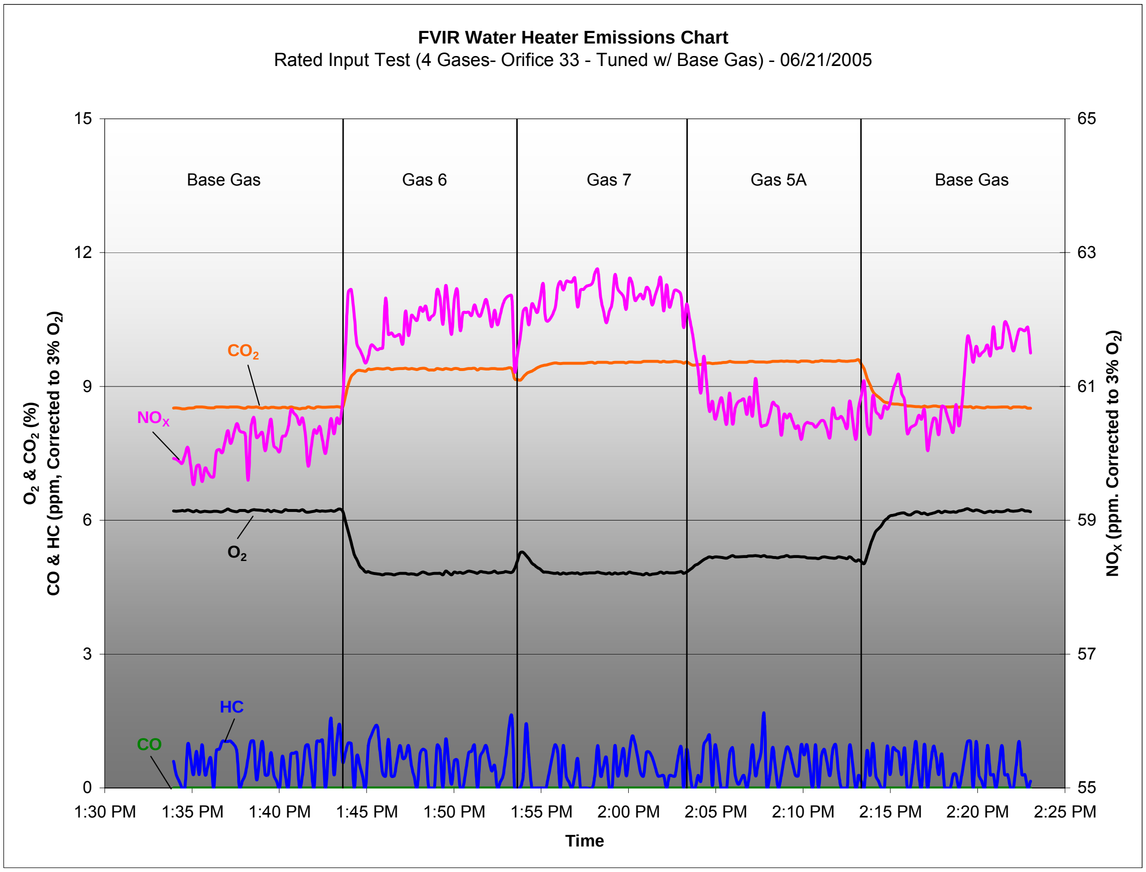
*Temperature*

Flame temperature ranged from 1,352°F to 1,346°F for all gases except Base Gas, which was lowest (1,297°F). Stack temperature ranged from 473.7°F to 488.4°F and tank temperature ranged from 113.7°F to 130.5°F. Ambient (72.0 ± 0.3°F), gas (69.8 ± 0.5°F), inlet water (73.6 ± 0.3°F) and floor (72.0 ± 0.3°F) temperatures remained steady throughout the duration of the test.



*Emissions*

The $NO_X$ emissions were highest with Gas 6 and Gas 7 (62.0 and 62.3 ppm) while CO and HC emissions were negligible throughout the course of the test. $O_2$ percentage ranged from 4.9% (Gas 6 and Gas 7) to 6.1% (Base Gas).




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

**Cold Ignition Test**

For each setup gas (Base Gas and Gas 3), the boiler turned "on" without any problems during each one of the ignition tests. After ignition, flames were stable and there was no flame lifting, flashback or yellow tipping.

| **Rated Input Test (Tuned w/ Base Gas)** | | |
|---|---|---|
| Gas | Start-Up # | Comment & Observation |
| Base | 1 | Normal and without delays |
| | 2 | Normal and without delays |
| | 3 | Normal and without delays |
| 3 | 1 | Normal and without delays |
| | 2 | Normal and without delays |
| | 3 | Normal and without delays |
| **Rated Input Test (Tuned w/ Gas 3)** | | |
| Gas | Start-Up # | Comment & Observation |
| 3 | 1 | Normal and without delays |
| | 2 | Normal and without delays |
| | 3 | Normal and without delays |
| Base | 1 | Normal and without delays |
| | 2 | Normal and without delays |
| | 3 | Normal and without delays |

### Hot Ignition Test

For each set-up gas (Base Gas and Gas 3), the boiler turned "on" without any problems for all ignition tests. After ignition, flames were stable and there was no flame lifting, flashback or yellow tipping.

| **Rated Input Test (Tuned w/ Base Gas)** | | |
|---|---|---|
| Gas | Start-Up # | Comment & Observation |
| Base | 1 | Normal and without delays |
| | 2 | Normal and without delays |
| | 3 | Normal and without delays |
| 3 | 1 | Normal and without delays |
| | 2 | Normal and without delays |
| | 3 | Normal and without delays |
| **Rated Input Test (Tuned w/ Gas 3)** | | |
| Gas | Start-Up # | Comment & Observation |
| 3 | 1 | Normal and without delays |
| | 2 | Normal and without delays |
| | 3 | Normal and without delays |
| Base | 1 | Normal and without delays |
| | 2 | Normal and without delays |
| | 3 | Normal and without delays |

**Appendix A:** Test Protocol

## 1. Standards

| | |
|---|---|
| **ANSI Z21.10.1-2001** | Standard for Gas Water Heaters, Volume 1 |
| **SCAQMD Rule 1121** | Control of $NO_X$ Emission from Residential Type Natural Gas - Fired Water Heaters (last amended December 10,1999) |
| **SCAQMD Protocol** | For Rule 1121 (last amended January 1998) |

## 2. Equipment Specifications

| | |
|---|---|
| **Description** | 40 Gallon FVIR Residential Water Heater (Manufactured 1995) |
| **Burner** | 4½ inch diameter atmospheric burner |
| **Maximum rated input** | 40,000 Btu/hr |
| **Type of fuel** | Natural Gas |
| **Required gas inlet pressure** | 5 – 14 in. w.c. |
| **Required manifold pressure** | 5 in. w.c. |

## 3. Test Arrangement

### 3.1. Basic Setup

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 §7.1.5 of the SCAQMD 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 floor temperature.

### 3.5. Flame Temperature

Due to the difficulties and cost involved in accurately measuring flame temperature continuously during each test, a simplistic method for measuring flame temperature will be used. This method requires the installation of a thermocouple tip inside the outer mantel of the flame such that it is fixed throughout the length of the test. Due to measurement method and changes in both flame shape and flame length, readings simply indicate temperature treads in the flame zone.

### 3.6. Water Piping

Water piping and temperature measurement sites are to be per Figure 4 of the SCAQMD Protocol for Rule 1121; with the exception of 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.

### 3.7. 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.

### 3.8. Vent Pipe

Per §2.1.8 of 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.

### 3.9. Instrumentation

Instrumentation must adhere as close as possible to the SCAQMD Protocol for Rules 1121 and SCAQMD Method 100.1.

## 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 (§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 135 ± 5°F (§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 Inlet Pressure

Per ANSI Z21.10, normal gas inlet pressure will be at 7.0 inches water column (in. w.c.).

### 4.5. Setup Gas Input Rate

The input rate is to be that combination of gas orifice size, inlet gas pressure and manifold pressure required to deliver the as received and/or appliance input rate with the Setup Gas. Input rate, inlet gas pressure and manifold pressure are to be within the tolerances specified by testing standards and/or manufacturers specifications. The appliance input rate will be verified after the appliance has been operated for 15 minutes from a cold start (i.e. all parts of the appliance are at room temperature). With gases other than the Setup Gas, the firing rate generally will *not* be at rated input.

## 5. Test Gases

All test gases will adhere to the Southern California Gas Company's Gas Quality Specification (Rule 30), which is approved by the California Public Utilities Commission (CPUC).

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

| **Gas** | **Wobbe Number** (Btu/cf) | **Heating Value** (Btu/cf) |
|---|---|---|
| Base | 1,303 (Low Wobbe) | 1,002 (Low heat content) |
| 3 | 1,436 (Highest Wobbe) | 1,152 (Highest heat content) |
| 5A | 1,362 (Medium Wobbe) | 1,099 (High heat content) |
| 6 | 1,412 (High Wobbe) | 1,107 (High heat content) |
| 7 | 1,395 (High Wobbe) | 1,142 (Highest heat content) |

# 6. Testing

## 6.1. As Received

At normal inlet pressure, operate the water heater with Base Gas and verify the input rate. Once steady-state conditions are achieved, begin testing and collection of temperature, pressure and emissions data while observing any occurrences of flashback, noise, instability, outage, yellow tipping and flame lifting. Unless otherwise specified, each run for Base Gas and Test Gases will be 10 minutes. Also, manual switching between test gases should take approximately 14 seconds.
Continue steady-state water heater operation with Base Gas 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.

If operational and/or safety problems were encountered while testing with Base Gas & Gas 3, all other Test Gases will be tested immediately after a 2nd Base Gas.

If no problems were encountered while testing with Base Gas & Gas 3, the test will conclude. 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.

## 6.2. Rated Input Test (Tuned w/ Base Gas)

Tune the water heater with Base Gas to achieve the maximum input rate allowed by manufacturer. Follow the same procedures as specified in §6.1. If it is discovered during the As Received Test that the water heater is operating at rated input, then the As Received Test becomes the Rated Input Test.

## 6.3. Rated Input Test (Tuned w/ Gas 3)

Tune the water heater with Gas 3 to achieve the same input rate and similar performance (including emissions, temperatures, etc.) as with Base Gas. Follow the same procedures as specified in §6.1.

## 6.4. Increased Manifold & Reduced Inlet Pressure Test (Tuned w/ Base Gas and Gas 3)

Based on the information from manufacturers, consultants and the requirements of the test standards adjust the water heater to operate over and under the input rate. The over the input rate should be achieved by increasing the manifold pressure to
5.7 in. w.c. and the under the input rate should be achieved by lowering the inlet pressure to 3.5 in. w.c. Both test may not be require depending on the Setup gas

or the type of water heater being tested.

From a cold start, record input and combustion data ($O_2$, $NO_X$, CO, $CO_2$ and HC) and verify that the firing rates are under and over the rated input after 15 minutes. If the burner modulates, automatically continue the test at operating input.

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

## 7. Ignitions Test

### 7.1. Cold Ignition Test (Tuned w/ Base Gas)

With the appliance at room temperature and at the maximum allowable input rate achieved during initial tuning with Base Gas, purge the gas delivery system with Base Gas. Using Base Gas, turn the appliance "ON" and document any combustion, ignition or flame irregularities. Allow the appliance to cool down to room temperature then repeat this procedure 2 more times.

Purge the gas delivery system with Gas 3. Using Gas 3, turn the appliance "ON" and document any combustion, ignition or flame irregularities. Allow the appliance to cool down to room temperature then repeat this procedure 2 more times.

### 7.2. Cold Ignition Test (Tuned w/ Gas 3)

Follow the same procedure as Cold Ignition Test (Tuned w/ Base Gas) but substitute Base Gas with Gas 3.

### 7.3. Hot Ignition Test (Tuned w/ Base Gas)

With the appliance at steady state temperatures and at the maximum allowable input rate achieved during initial tuning with Base Gas, purge the gas delivery system with Base Gas. Using Base Gas, turn the appliance "ON" and document any combustion, ignition or flame irregularities. Repeat this procedure 2 more times without allowing the appliance to cold down.

Purge the gas delivery system with Gas 3. Using Gas 3, turn the appliance "ON" and document any combustion, ignition or flame irregularities. Repeat this procedure 2 more times without allowing the appliance to cool down.

### 7.4. Hot Ignition Test (Tuned w/ Gas 3)

Follow the same procedure as Hot Ignition Test (Tuned w/ Base Gas) but substitute Base Gas with Gas 3.

## 8. Additional Testing

Conduct additional testing and/or testing with other gas blends when test results or observations indicate it is necessary.  If indicated additional testing is outside of the project scope, include appropriate comment in the test report.

## 9. 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.

## 10. Rationale – Test Setup and Procedures

### 10.1. Firing Rate

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 a 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.  A test with or without the vent stack should be performed to determine if there are any changes in the emissions.

### 10.2. Water piping connections

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 Base 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 inlet pressure required to achieve that condition with Base Gas are to be maintained during subsequent testing with other gas blends.

**Appendix B:** Table of Averages

As Received Test – Orifice 37

| Table of Averages<br>FVIR Water Heater<br>As Received Test<br>June 21, 2005 | | |
|---|---|---|
| **Gases** | **Base** | **3** |
| HHV (Btu/cf) | 1,005 | 1,150 |
| Wobbe (Btu/cf) | 1,309 | 1,433 |
| Input Rate (Btu/hr) | 31,289 | 34,713 |
| Corrected Gas Flow (scfh) | 31.1 | 30.2 |
| **Emissions** (not from certified tests) | | |
| $O_2$ (%) | 8.9 | 7.6 |
| $CO_2$ (%) | 7.0 | 7.9 |
| CO (ppm @ 3% $O_2$) | 0.0 | 0.0 |
| HC (ppm @ 3% $O_2$) | 1.3 | 1.0 |
| $NO_X$ (ppm @ 3% $O_2$) | 63.5 | 66.8 |
| Ultimate $CO_2$ (%) | 12.3 | 12.4 |
| Equivalence Ratio (Φ) | 0.60 | 0.66 |
| **Temperatures** (°F) | | |
| Ambient | 73.5 | 73.5 |
| Gas | 71.7 | 71.5 |
| Stack | 460.1 | 464.8 |
| Tank | 129.5 | 112.1 |
| Flame | 1,399 | 1,290 |
| Floor | 73.6 | 73.7 |
| Inlet Water | 73.3 | 73.8 |
| Outlet Water | 135.9 | 133.6 |
| **Pressures** (in. w.c.) | | |
| Inlet | 7.0 | 7.0 |
| Manifold | 5.0 | 5.1 |

Increased Manifold & Reduced Inlet Pressure Tests (As Received - Orifice 37)

| **Table of Averages**<br>FVIR Water Heater<br>Increased Manifold & Reduced Inlet Pressure Tests<br>Orifice 37 - Tuned w/ Base Gas<br>June 21, 2005 | | | | |
|---|---|---|---|---|
| **Pressure Test** | **Increased Manifold** | | **Reduced Inlet** | |
| **Gases** | **3** | **Base** | **Base** | **3** |
| HHV (Btu/cf) | 1,150 | 1,005 | 1,005 | 1,150 |
| Wobbe (Btu/cf) | 1,433 | 1,309 | 1,309 | 1,433 |
| Input Rate (Btu/hr) | 36,146 | 32,117 | 24,442 | 27,547 |
| Corrected Gas Flow (scfh) | 31.4 | 32.0 | 24.3 | 24.0 |
| **Emissions** (not from certified tests) | | | | |
| $O_2$ (%) | 6.8 | 8.2 | 11.6 | 10.6 |
| $CO_2$ (%) | 8.3 | 7.4 | 5.4 | 6.1 |
| CO (ppm @ 3% $O_2$) | 0.0 | 0.0 | 0.0 | 0.0 |
| HC (ppm @ 3% $O_2$) | 1.0 | 1.1 | 1.7 | 1.5 |
| $NO_X$ (ppm @ 3% $O_2$) | 65.1 | 63.0 | 67.7 | 69.8 |
| Ultimate $CO_2$ (%) | 12.3 | 12.3 | 12.3 | 12.3 |
| Equivalence Ratio (Φ) | 0.60 | 0.61 | 0.66 | 0.66 |
| **Temperatures** (°F) | | | | |
| Ambient | 73.7 | 74.0 | 74.0 | 74.0 |
| Gas | 71.8 | 72.0 | 72.4 | 72.0 |
| Stack | 471.1 | 466.7 | 448.7 | 454.4 |
| Tank | 123.2 | 129.3 | 133.6 | 124.1 |
| Flame | 1,355 | 1,461 | 1,737 | 1690.4 |
| Floor | 74.3 | 74.6 | 74.6 | 75.0 |
| Inlet Water | 74.2 | 73.8 | 73.8 | 74.2 |
| Outlet Water | 129.5 | 134.1 | 138.6 | 138.0 |
| **Pressures** (in. w.c.) | | | | |
| Inlet | 7.0 | 7.0 | 3.5 | 3.5 |
| Manifold | 5.6 | 5.6 | 3.2 | 3.2 |

Rated Input Test (2 gases – Orifice 33 – Tuned w/ Base Gas)

| **Table of Averages**<br>FVIR Water Heater<br>Rated Input Test (2 gases)<br>Orifice 33 - Tuned w/ Base Gas<br>June 21, 2005 | | |
|---|---|---|
| **Gases** | **Base** | **3** |
| HHV (Btu/cf) | 1,005 | 1,150 |
| Wobbe (Btu/cf) | 1,309 | 1,433 |
| Input Rate (Btu/hr) | 36,932 | 40,665 |
| Corrected Gas Flow (scfh) | 36.8 | 35.4 |
| **Emissions** (not from certified tests) | | |
| $O_2$ (%) | 6.2 | 4.9 |
| $CO_2$ (%) | 8.6 | 9.5 |
| CO (ppm @ 3% $O_2$) | 0.0 | 0.0 |
| HC (ppm @ 3% $O_2$) | 0.6 | 0.4 |
| $NO_X$ (ppm @ 3% $O_2$) | 61.8 | 65.8 |
| Ultimate $CO_2$ (%) | 12.2 | 12.4 |
| Equivalence Ratio (Φ) | 0.73 | 0.78 |
| **Temperatures** (°F) | | |
| Ambient | 76.7 | 76.9 |
| Gas | 74.1 | 74.6 |
| Stack | 472.0 | 488.3 |
| Tank | 117.9 | 133.0 |
| Flame | 1,267 | 1,358 |
| Floor | 76.1 | 76.4 |
| Inlet Water | 74.0 | 74.4 |
| Outlet Water | 136.4 | 135.9 |
| **Pressures** (in. w.c.) | | |
| Inlet | 7.0 | 7.0 |
| Manifold | 5.0 | 4.9 |

Increased Manifold & Reduced Inlet Pressure Tests (Orifice 33 – Tuned w/ Base Gas)

| **Table of Averages**<br>FVIR Water Heater<br>Increased Manifold & Reduced Inlet Pressure Tests<br>Orifice 33 - Tuned w/ Base Gas<br>June 21, 2005 | | | | |
|---|---|---|---|---|
| **Pressure Test** | **Increased Manifold** | | **Reduced Inlet** | |
| **Gases** | **3** | **Base** | **Base** | **3** |
| HHV (Btu/cf) | 1,150 | 1,005 | 1,034 | 1,150 |
| Wobbe (Btu/cf) | 1,433 | 1,309 | 1,333 | 1,433 |
| Input Rate (Btu/hr) | 43,883 | 38,932 | 30,158 | 32,913 |
| Corrected Gas Flow (scfh) | 38.2 | 38.7 | 29.2 | 28.6 |
| **Emissions** (not from certified tests) | | | | |
| $O_2$ (%) | 3.6 | 4.9 | 9.7 | 8.6 |
| $CO_2$ (%) | 10.3 | 9.4 | 6.5 | 7.3 |
| CO (ppm @ 3% $O_2$) | 0.0 | 0.0 | 0.0 | 0.0 |
| HC (ppm @ 3% $O_2$) | 0.7 | 0.5 | 0.9 | 0.7 |
| $NO_X$ (ppm @ 3% $O_2$) | 60.1 | 60.0 | 71.8 | 74.7 |
| Ultimate $CO_2$ (%) | 12.4 | 12.2 | 12.2 | 12.4 |
| Equivalence Ratio (Φ) | 0.84 | 0.79 | 0.56 | 0.61 |
| **Temperatures** (°F) | | | | |
| Ambient | 75.5 | 75.2 | 74.5 | 74.3 |
| Gas | 73.5 | 73.5 | 72.9 | 73.0 |
| Stack | 492.4 | 481.5 | 459.3 | 470.6 |
| Tank | 120.2 | 116.7 | 119.3 | 127.2 |
| Flame | 1,405 | 1,355 | 1,590 | 1,505 |
| Floor | 76.1 | 75.9 | 75.9 | 75.7 |
| Inlet Water | 73.8 | 74.0 | 74.3 | 74.3 |
| Outlet Water | 139.2 | 136.9 | 135.1 | 133.1 |
| **Pressures** (in. w.c.) | | | | |
| Inlet | 7.0 | 7.0 | 3.5 | 3.5 |
| Manifold | 5.7 | 5.7 | 3.2 | 3.1 |

Rated Input Test (4 Gases – Orifice 33 – Tuned w/ Base Gas)

| **Table of Averages**<br>FVIR Water Heater<br>Rated Input Test (4 Gases)<br>Orifice 33 - Tuned w/ Base Gas<br>June 21, 2005 | | | | | |
|---|---|---|---|---|---|
| **Gases** | **Base** | **6** | **7** | **5A** | **Base** |
| HHV (Btu/cf) | 1,005 | 1,106 | 1,143 | 1,100 | 1,005 |
| Wobbe (Btu/cf) | 1,309 | 1,408 | 1,396 | 1,362 | 1,309 |
| Input Rate (Btu/hr) | 37,465 | 40,558 | 40,208 | 37,717 | 37,109 |
| Corrected Gas Flow (scfh) | 37.3 | 36.7 | 35.2 | 34.3 | 36.9 |
| **Emissions** (not from certified tests) | | | | | |
| $O_2$ (%) | 6.2 | 4.9 | 4.9 | 5.2 | 6.1 |
| $CO_2$ (%) | 8.5 | 9.4 | 9.5 | 9.5 | 8.6 |
| CO (ppm @ 3% $O_2$) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| HC (ppm @ 3% $O_2$) | 0.6 | 0.6 | 0.4 | 0.5 | 0.4 |
| $NO_X$ (ppm @ 3% $O_2$) | 60.2 | 62.0 | 62.3 | 60.7 | 61.0 |
| Ultimate $CO_2$ (%) | 12.1 | 12.2 | 12.4 | 12.7 | 12.2 |
| Equivalence Ratio (Φ) | 0.73 | 0.78 | 0.79 | 0.77 | 0.73 |
| **Temperatures** (°F) | | | | | |
| Ambient | 71.7 | 71.9 | 72.1 | 72.1 | 72.3 |
| Gas | 69.3 | 69.7 | 69.8 | 70.0 | 70.2 |
| Stack | 473.4 | 484.1 | 488.4 | 482.6 | 473.9 |
| Tank | 120.1 | 126.0 | 130.5 | 113.7 | 117.5 |
| Flame | 1,286 | 1,352 | 1,356 | 1,346 | 1,308 |
| Floor | 71.8 | 71.8 | 72.0 | 72.3 | 72.3 |
| Inlet Water | 73.9 | 73.6 | 73.5 | 73.4 | 73.9 |
| Outlet Water | 135.0 | 132.9 | 137.1 | 136.6 | 132.6 |
| **Pressures** (in. w.c.) | | | | | |
| Inlet | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 |
| Manifold | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |

Rated Input Test (All Gases – Orifice 39- Tuned w/ Gas 3)

| **Table of Averages**<br>FVIR Water Heater<br>Rated Input Test (All Gases)<br>Orifice 39 - Tuned with Gas 3<br>June 28, 2005 | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Gases** | **3** | **6** | **7** | **3** | **5A** | **Base** | **3** |
| HHV (Btu/cf) | 1,150 | 1,106 | 1,143 | 1,150 | 1,099 | 1,005 | 1,150 |
| Wobbe (Btu/cf) | 1,433 | 1,408 | 1,396 | 1,433 | 1,362 | 1,309 | 1,433 |
| **Emissions** (not from certified tests) | | | | | | | |
| $O_2$ (%) | 8.9 | 8.9 | 8.8 | 8.7 | 9.1 | 9.8 | 8.7 |
| $CO_2$ (%) | 7.1 | 7.0 | 7.2 | 7.2 | 7.2 | 6.5 | 7.2 |
| CO (ppm @ 3% $O_2$) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| HC (ppm @ 3% $O_2$) | 0.2 | 0.3 | 0.2 | 0.3 | 0.2 | 0.2 | 0.2 |
| $NO_X$ (ppm @ 3% $O_2$) | 65.4 | 65.3 | 64.5 | 65.3 | 61.9 | 62.1 | 64.7 |
| Ultimate $CO_2$ (%) | 12.3 | 12.3 | 12.5 | 12.4 | 12.7 | 12.2 | 12.4 |
| Equivalence Ratio (Φ) | 0.60 | 0.60 | 0.60 | 0.61 | 0.59 | 0.39 | 0.61 |

Reduced Inlet Pressure Test (Base Gas Only - Orifice 39)

| **Table of Averages**<br>FVIR Water Heater<br>Reduced Inlet Pressure Test (Base Gas Only)<br>Orifice 39 - Tuned with Gas 3<br>June 28, 2005 | | |
|---|---|---|
| **Gases** | **Base w/o Vent Stack** | **Base w/ Vent Stack** |
| HHV (Btu/cf) | 1,005 | |
| Wobbe (Btu/cf) | 1,309 | |
| **Emissions** (not from certified tests) | | |
| $O_2$ (%) | 12.3 | 12.5 |
| $CO_2$ (%) | 5.0 | 4.9 |
| CO (ppm @ 3% $O_2$) | 1.4 | 2.1 |
| HC (ppm @ 3% $O_2$) | 0.3 | 0.5 |
| $NO_X$ (ppm @ 3% $O_2$) | 65.6 | 64.8 |
| Ultimate $CO_2$ (%) | 12.1 | 12.2 |
| Equivalence Ratio ($\Phi$) | 0.44 | 0.43 |

**Appendix C:** Test Gases

| Gas Analysis | Gas BASELINE | Gas 3 | Gas 5A | Gas 6 | Gas 7 |
|---|---|---|---|---|---|
| **SAMPLE DATE** | 7/1/05 | 7/1/05 | 7/15/05 | 7/1/05 | 6/20/05 |
| **COMPONENTS** | **MolPct** | **MolPct** | **MolPct** | **MolPct** | **MolPct** |
| C6 + 57/28/14 | 0.0213 | 0.0002 | 0.0098 | 0.0001 | 0.0232 |
| NITROGEN | 1.7436 | 0.1280 | 0.7160 | 0.2737 | 3.0250 |
| METHANE | 94.6797 | 86.5492 | 89.6933 | 91.1679 | 86.4659 |
| CARBON DIOXIDE | 1.2664 | 0.0345 | 2.1314 | 0.0032 | 0.0344 |
| ETHANE | 1.6701 | 9.4799 | 0.0000 | 5.7474 | 0.3119 |
| PROPANE | 0.3421 | 2.7246 | 7.3954 | 1.7268 | 9.9457 |
| i-BUTANE | 0.0581 | 1.0339 | 0.0308 | 0.5340 | 0.0940 |
| n-BUTANE | 0.0578 | 0.0000 | 0.0108 | 0.5312 | 0.0614 |
| NEOPENTANE | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| i-PENTANE | 0.0172 | 0.0000 | 0.0029 | 0.0000 | 0.0192 |
| n-PENTANE | 0.0115 | 0.0003 | 0.0024 | 0.0000 | 0.0156 |
| OXYGEN | 0.1322 | 0.0494 | 0.0000 | 0.0156 | 0.0038 |
| **TOTAL** | **100.0000** | **100.0000** | **100.0000** | **100.0000** | **100.0000** |
| | | | | | |
| Compressibility Factor | 0.998 | 0.9972 | 0.9973 | 0.9975 | 0.9971 |
| **HHV (Btu/real cubic foot)** | **1004.8** | **1150.00** | **1099.80** | **1106.00** | **1142.00** |
| LHV (Btu/real cubic foot) | 905.4 | 1039.90 | 993.90 | 998.90 | 1033.40 |
| Specific Gravity | 0.5895 | 0.6442 | 0.6520 | 0.6167 | 0.6697 |
| **WOBBE Index** | **1308.67** | **1432.81** | **1362.04** | **1408.37** | **1395.49** |

**Appendix D:** Zero, Span and Linearity Tables

As Received Test – Orifice 37

| | **Zero, Span & Linearity Data**<br>FVIR Water Heater - As Received Test<br>June 21, 2005 | $O_2$ (%) | $CO_2$ (%) | CO (ppm) | HC (ppm) | $NO_x$ (ppm) |
|---|---|---|---|---|---|---|
| | **Analyzer Emission Ranges** | **0 - 25** | **0 - 20** | **0 - 200** | **0 - 1000** | **0 - 100** |
| **Zero** | **Zero Calibration Gas (Low-Range Values)** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| **Zero** | **Allowable Zero Drift (Less Than ± 3% of Range)** | **0.75** | **0.60** | **6.00** | **30.00** | **3.00** |
| **Zero** | Zero Calibration - 7:30:26 AM | 0.08 | 0.03 | 0.22 | 0.49 | 0.00 |
| **Zero** | Zero Drift Check - 9:18:34 AM | 0.06 | 0.05 | 0.06 | 0.28 | 0.02 |
| **Zero** | **Total Drift Over Test Period** | **0.02** | **0.02** | **0.16** | **0.21** | **0.02** |
| **Zero** | **Was the Zero Drift Within Allowable Deviation?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| **Span** | **Span Calibration Gas (High-Range Values)** | **20.10** | **12.07** | **182.40** | **443.00** | **85.20** |
| **Span** | **Allowable Span Drift (Less Than ± 3% of Range)** | **0.75** | **0.60** | **6.00** | **30.00** | **3.00** |
| **Span** | Span Calibration - 7:39:53 AM | 20.11 | 12.13 | 183.45 | 441.79 | 85.35 |
| **Span** | Span Drift Check - 9:28:08 AM | 20.12 | 12.14 | 182.92 | 443.67 | 85.31 |
| **Span** | **Total Drift Over Test Period** | **0.01** | **0.01** | **0.53** | **1.88** | **0.04** |
| **Span** | **Was the Span Drift Within Allowable Deviation?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| **Linearity** | **Linearity Calibration Gas (Mid-Range Values)** | **8.97** | **8.00** | **78.20** | **443.00** | **18.30** |
| **Linearity** | **Allowable Linearity Drift (Less Than ±1% of Range)** | **0.25** | **0.20** | **2.00** | **10.00** | **1.00** |
| **Linearity** | Linearity Check - 7:46:54 AM | 9.07 | 12.15 | 74.87 | 442.19 | 17.59 |
| **Linearity** | **Difference From Mid-Range Values** | **0.10** | **4.15** | **3.33** | **0.81** | **0.71** |
| **Linearity** | **Was the Linearity Within Allowable Deviation?** | **Yes** | **No** | **No** | **Yes** | **Yes** |
| **Linearity** | Linearity Check - 9:32:01 AM | 9.08 | 8.03 | 74.76 | 443.93 | 17.24 |
| **Linearity** | **Difference From Mid-Range Values** | **0.11** | **0.03** | **3.44** | **0.93** | **1.06** |
| **Linearity** | **Was the Linearity Within Allowable Deviation?** | **Yes** | **Yes** | **No** | **Yes** | **No** |

Increased Manifold & Reduced Inlet Pressure Tests (As Received Test – Orifice 37)

| | **Zero, Span & Linearity Data**<br>FVIR Water Heater - Increased Manifold & Reduced Inlet Pressure Tests<br>Orifice 37 - Tuned w/ Base Gas<br>June 21, 2005 | $O_2$ (%) | $CO_2$ (%) | CO (ppm) | HC (ppm) | $NO_x$ (ppm) |
|---|---|---|---|---|---|---|
| | **Analyzer Emission Ranges** | **0 - 25** | **0 - 20** | **0 - 200** | **0 - 1000** | **0 - 100** |
| Zero | **Zero Calibration Gas (Low-Range Values)** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| Zero | **Allowable Zero Drift (Less Than ± 3% of Range)** | **0.75** | **0.60** | **6.00** | **30.00** | **3.00** |
| Zero | Zero Calibration - 7:30:26 AM | 0.08 | 0.03 | 0.22 | 0.49 | 0.00 |
| Zero | Zero Drift Check - 9:18:34 AM | 0.06 | 0.05 | 0.06 | 0.28 | 0.02 |
| Zero | **Total Drift Over Test Period** | **0.02** | **0.02** | **0.16** | **0.21** | **0.02** |
| Zero | **Was the Zero Drift Within Allowable Deviation?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| Span | **Span Calibration Gas (High-Range Values)** | **20.10** | **12.07** | **182.40** | **443.00** | **85.20** |
| Span | **Allowable Span Drift (Less Than ± 3% of Range)** | **0.75** | **0.60** | **6.00** | **30.00** | **3.00** |
| Span | Span Calibration - 7:39:53 AM | 20.11 | 12.13 | 183.45 | 441.79 | 85.35 |
| Span | Span Drift Check - 9:28:08 AM | 20.12 | 12.14 | 182.92 | 443.67 | 85.31 |
| Span | **Total Drift Over Test Period** | **0.01** | **0.01** | **0.53** | **1.88** | **0.04** |
| Span | **Was the Span Drift Within Allowable Deviation?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| Linearity | **Linearity Calibration Gas (Mid-Range Values)** | **8.97** | **8.00** | **78.20** | **443.00** | **18.30** |
| Linearity | **Allowable Linearity Drift (Less Than ±1% of Range)** | **0.25** | **0.20** | **2.00** | **10.00** | **1.00** |
| Linearity | Linearity Check - 7:46:54 AM | 9.07 | 12.15 | 74.87 | 442.19 | 17.59 |
| Linearity | **Difference From Mid-Range Values** | **0.10** | **4.15** | **3.33** | **0.81** | **0.71** |
| Linearity | **Was the Linearity Within Allowable Deviation?** | **Yes** | **No** | **No** | **Yes** | **Yes** |
| Linearity | Linearity Check - 9:32:01 AM | 9.08 | 8.03 | 74.76 | 443.93 | 17.24 |
| Linearity | **Difference From Mid-Range Values** | **0.11** | **0.03** | **3.44** | **0.93** | **1.06** |
| Linearity | **Was the Linearity Within Allowable Deviation?** | **Yes** | **Yes** | **No** | **Yes** | **No** |

Rated Input Test (2 gases – Orifice 33 – Tuned w/ Base Gas)

| | Zero, Span & Linearity Data<br>FVIR Water Heater - Rated Input Test (2 gases)<br>Orifice 33 - Tuned with Base Gas<br>June 21, 2005 | $O_2$ (%) | $CO_2$ (%) | CO (ppm) | HC (ppm) | $NO_x$ (ppm) |
|---|---|---|---|---|---|---|
| | **Analyzer Emission Ranges** | **0 - 25** | **0 - 20** | **0 - 200** | **0 - 1000** | **0 - 100** |
| Zero | **Zero Calibration Gas (Low-Range Values)** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| Zero | **Allowable Zero Drift (Less Than ± 3% of Range)** | **0.75** | **0.60** | **6.00** | **30.00** | **3.00** |
| Zero | Zero Calibration - 9:18:34 AM | 0.06 | 0.05 | 0.06 | 0.28 | 0.02 |
| Zero | Zero Drift Check - 1:14:00 PM | 0.09 | 0.06 | 0.61 | 0.24 | 0.00 |
| Zero | **Total Drift Over Test Period** | **0.03** | **0.01** | **0.55** | **0.04** | **0.02** |
| Zero | **Was the Zero Drift Within Allowable Deviation?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| Span | **Span Calibration Gas (High-Range Values)** | **20.10** | **12.07** | **182.40** | **443.00** | **85.20** |
| Span | **Allowable Span Drift (Less Than ± 3% of Range)** | **0.75** | **0.60** | **6.00** | **30.00** | **3.00** |
| Span | Span Calibration - 9:28:08 AM | 20.12 | 12.14 | 182.92 | 443.67 | 85.31 |
| Span | Span Drift Check - 1:32:33 PM | 20.11 | 12.09 | 183.19 | 442.50 | 85.32 |
| Span | **Total Drift Over Test Period** | **0.01** | **0.05** | **0.27** | **1.17** | **0.01** |
| Span | **Was the Span Drift Within Allowable Deviation?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| Linearity | **Linearity Calibration Gas (Mid-Range Values)** | **8.97** | **8.00** | **78.20** | **443.00** | **18.30** |
| Linearity | **Allowable Linearity Drift (Less Than ±1% of Range)** | **0.25** | **0.20** | **2.00** | **10.00** | **1.00** |
| Linearity | Linearity Check - 9:32:01 AM | 9.08 | 8.03 | 74.76 | 443.93 | 17.24 |
| Linearity | **Difference From Mid-Range Values** | **0.11** | **0.03** | **3.44** | **0.93** | **1.06** |
| Linearity | **Was the Linearity Within Allowable Deviation?** | **Yes** | **Yes** | **No** | **Yes** | **No** |
| Linearity | Linearity Check - 1:26:32 PM | 9.09 | 8.01 | 75.23 | 442.17 | 17.10 |
| Linearity | **Difference From Mid-Range Values** | **0.12** | **0.01** | **2.97** | **0.83** | **1.20** |
| Linearity | **Was the Linearity Within Allowable Deviation?** | **Yes** | **Yes** | **No** | **Yes** | **No** |

Increased Manifold & Reduced Inlet Pressure Tests – Orifice 33

| | Zero, Span & Linearity Data<br>FVIR Water Heater - Increased Manifold & Reduced Inlet Pressure Tests<br>Orifice 33 - Calibrated w/ Base Gas<br>June 21, 2005 | $O_2$ (%) | $CO_2$ (%) | CO (ppm) | HC (ppm) | $NO_x$ (ppm) |
|---|---|---|---|---|---|---|
| | **Analyzer Emission Ranges** | **0 - 25** | **0 - 20** | **0 - 200** | **0 - 1000** | **0 - 100** |
| Zero | **Zero Calibration Gas (Low-Range Values)** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| Zero | **Allowable Zero Drift (Less Than ± 3% of Range)** | **0.75** | **0.60** | **6.00** | **30.00** | **3.00** |
| Zero | Zero Calibration - 9:18:34 AM | 0.06 | 0.05 | 0.06 | 0.28 | 0.02 |
| Zero | Zero Drift Check - 1:14:00 PM | 0.09 | 0.06 | 0.61 | 0.24 | 0.00 |
| Zero | **Total Drift Over Test Period** | **0.03** | **0.01** | **0.55** | **0.04** | **0.02** |
| Zero | **Was the Zero Drift Within Allowable Deviation?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| Span | **Span Calibration Gas (High-Range Values)** | **20.10** | **12.07** | **182.40** | **443.00** | **85.20** |
| Span | **Allowable Span Drift (Less Than ± 3% of Range)** | **0.75** | **0.60** | **6.00** | **30.00** | **3.00** |
| Span | Span Calibration - 9:28:08 AM | 20.12 | 12.14 | 182.92 | 443.67 | 85.31 |
| Span | Span Drift Check - 1:32:33 PM | 20.11 | 12.09 | 183.19 | 442.50 | 85.32 |
| Span | **Total Drift Over Test Period** | **0.01** | **0.05** | **0.27** | **1.17** | **0.01** |
| Span | **Was the Span Drift Within Allowable Deviation?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| Linearity | **Linearity Calibration Gas (Mid-Range Values)** | **8.97** | **8.00** | **78.20** | **443.00** | **18.30** |
| Linearity | **Allowable Linearity Drift (Less Than ±1% of Range)** | **0.25** | **0.20** | **2.00** | **10.00** | **1.00** |
| Linearity | Linearity Check - 9:32:01 AM | 9.08 | 8.03 | 74.76 | 443.93 | 17.24 |
| Linearity | **Difference From Mid-Range Values** | **0.11** | **0.03** | **3.44** | **0.93** | **1.06** |
| Linearity | **Was the Linearity Within Allowable Deviation?** | **Yes** | **Yes** | **No** | **Yes** | **No** |
| Linearity | Linearity Check - 1:26:32 PM | 9.09 | 8.01 | 75.23 | 442.17 | 17.10 |
| Linearity | **Difference From Mid-Range Values** | **0.12** | **0.01** | **2.97** | **0.83** | **1.20** |
| Linearity | **Was the Linearity Within Allowable Deviation?** | **Yes** | **Yes** | **No** | **Yes** | **No** |

Rated Input Test (4 Gases – Orifice 33 – Tuned w/ Base Gas)

**Zero, Span & Linearity Data**
FVIR Water Heater - Rated Input Test (4 Gases)
Orifice 33 - Tuned with Base Gas
June 21, 2005

| | | $O_2$ (%) | $CO_2$ (%) | CO (ppm) | HC (ppm) | $NO_x$ (ppm) |
|---|---|---|---|---|---|---|
| | **Analyzer Emission Ranges** | **0 - 25** | **0 - 20** | **0 - 200** | **0 - 1000** | **0 - 100** |
| Zero | **Zero Calibration Gas (Low-Range Values)** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| Zero | **Allowable Zero Drift (Less Than ± 3% of Range)** | **0.75** | **0.60** | **6.00** | **30.00** | **3.00** |
| Zero | Zero Calibration - 1:14:00 PM | 0.09 | 0.06 | 0.61 | 0.24 | 0.00 |
| Zero | Zero Drift Check - 2:30:52 PM | 0.07 | 0.06 | 0.79 | 0.16 | 0.00 |
| Zero | **Total Drift Over Test Period** | **0.02** | **0.00** | **0.18** | **0.08** | **0.00** |
| Zero | **Was the Zero Drift Within Allowable Deviation?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| Span | **Span Calibration Gas (High-Range Values)** | **20.10** | **12.07** | **182.40** | **443.00** | **85.20** |
| Span | **Allowable Span Drift (Less Than ± 3% of Range)** | **0.75** | **0.60** | **6.00** | **30.00** | **3.00** |
| Span | Span Calibration - 1:32:33 PM | 20.11 | 12.09 | 183.19 | 442.50 | 85.32 |
| Span | Span Drift Check - 2:27:08 PM | 20.03 | 12.12 | 183.21 | 445.94 | 85.66 |
| Span | **Total Drift Over Test Period** | **0.08** | **0.03** | **0.02** | **3.44** | **0.34** |
| Span | **Was the Span Drift Within Allowable Deviation?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| Linearity | **Linearity Calibration Gas (Mid-Range Values)** | **8.97** | **8.00** | **78.20** | **443.00** | **18.30** |
| Linearity | **Allowable Linearity Drift (Less Than ±1% of Range)** | **0.25** | **0.20** | **2.00** | **10.00** | **1.00** |
| Linearity | Linearity Check - 1:26:32 PM | 9.09 | 8.01 | 75.23 | 442.17 | 17.10 |
| Linearity | **Difference From Mid-Range Values** | **0.12** | **0.01** | **2.97** | **0.83** | **1.20** |
| Linearity | **Was the Linearity Within Allowable Deviation?** | **Yes** | **Yes** | **No** | **Yes** | **No** |

Rated Input Test – All Gases – Orifice 39

| | Zero, Span & Linearity Data<br>FVIR Water Heater - Rated Input Test (All Gases)<br>Orifice 39 - Tuned with Gas 3<br>June 28, 2005 | $O_2$ (%) | $CO_2$ (%) | CO (ppm) | HC (ppm) | $NO_x$ (ppm) |
|---|---|---|---|---|---|---|
| | **Analyzer Emission Ranges** | **0 - 25** | **0 - 20** | **0 - 200** | **0 - 1000** | **0 - 100** |
| Zero | **Zero Calibration Gas (Low-Range Values)** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| Zero | **Allowable Zero Drift (Less Than ± 3% of Range)** | **0.75** | **0.60** | **6.00** | **30.00** | **3.00** |
| Zero | Zero Calibration - 7:39:50 AM | 0.07 | 0.07 | 0.20 | 0.33 | 0.06 |
| Zero | Zero Drift Check - 10:00:04 AM | 0.11 | 0.05 | 0.60 | 0.00 | 0.11 |
| Zero | **Total Drift Over Test Period** | **0.04** | **0.02** | **0.40** | **0.33** | **0.05** |
| Zero | **Was the Zero Drift Within Allowable Deviation?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| Span | **Span Calibration Gas (High-Range Values)** | **20.10** | **12.07** | **182.40** | **443.00** | **85.20** |
| Span | **Allowable Span Drift (Less Than ± 3% of Range)** | **0.75** | **0.60** | **6.00** | **30.00** | **3.00** |
| Span | Span Calibration - 7:47:41 AM | 20.09 | 12.13 | 182.79 | 441.91 | 85.39 |
| Span | Span Drift Check - 9:56:34 AM | 20.07 | 12.12 | 183.56 | 440.42 | 85.78 |
| Span | **Total Drift Over Test Period** | **0.02** | **0.01** | **0.77** | **1.49** | **0.39** |
| Span | **Was the Span Drift Within Allowable Deviation?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| Linearity | **Linearity Calibration Gas (Mid-Range Values)** | **8.97** | **8.00** | **78.20** | **443.00** | **18.30** |
| Linearity | **Allowable Linearity Drift (Less Than ±1% of Range)** | **0.25** | **0.20** | **2.00** | **10.00** | **1.00** |
| Linearity | Linearity Check - 7:53:13 AM | 9.08 | 8.04 | 74.76 | 442.01 | 17.38 |
| Linearity | **Difference From Mid-Range Values** | **0.11** | **0.04** | **3.44** | **0.99** | **0.92** |
| Linearity | **Was the Linearity Within Allowable Deviation?** | **Yes** | **Yes** | **No** | **Yes** | **Yes** |
| Linearity | Linearity Check - 10:18:37 AM & 10:24:20 AM (HC Only) | 9.09 | 8.01 | 75.67 | 440.34 | 17.44 |
| Linearity | **Difference From Mid-Range Values** | **0.12** | **0.01** | **2.53** | **2.66** | **0.86** |
| Linearity | **Was the Linearity Within Allowable Deviation?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

Reduced Inlet Pressure Test - Base Gas Only – Orifice 39

| | **Zero, Span & Linearity Data**<br>FVIR Water Heater - Reduced Inlet Pressure Test - Base Gas Only<br>Orifice 39 - Tuned with Gas 3<br>June 28, 2005 | **$O_2$ (%)** | **$CO_2$ (%)** | **CO (ppm)** | **HC (ppm)** | **$NO_x$ (ppm)** |
|---|---|---|---|---|---|---|
| | **Analyzer Emission Ranges** | **0 - 25** | **0 - 20** | **0 - 200** | **0 - 1000** | **0 - 100** |
| Zero | **Zero Calibration Gas (Low-Range Values)** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| Zero | **Allowable Zero Drift (Less Than ± 3% of Range)** | **0.75** | **0.60** | **6.00** | **30.00** | **3.00** |
| Zero | Zero Calibration - 7:39:50 AM | 0.07 | 0.07 | 0.20 | 0.33 | 0.06 |
| Zero | Zero Drift Check - 10:00:04 AM | 0.11 | 0.05 | 0.60 | 0.00 | 0.11 |
| Zero | **Total Drift Over Test Period** | **0.04** | **0.02** | **0.40** | **0.33** | **0.05** |
| Zero | **Was the Zero Drift Within Allowable Deviation?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| Span | **Span Calibration Gas (High-Range Values)** | **20.10** | **12.07** | **182.40** | **443.00** | **85.20** |
| Span | **Allowable Span Drift (Less Than ± 3% of Range)** | **0.75** | **0.60** | **6.00** | **30.00** | **3.00** |
| Span | Span Calibration - 7:47:41 AM | 20.09 | 12.13 | 182.79 | 441.91 | 85.39 |
| Span | Span Drift Check - 9:56:34 AM | 20.07 | 12.12 | 183.56 | 440.42 | 85.78 |
| Span | **Total Drift Over Test Period** | **0.02** | **0.01** | **0.77** | **1.49** | **0.39** |
| Span | **Was the Span Drift Within Allowable Deviation?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| Linearity | **Linearity Calibration Gas (Mid-Range Values)** | **8.97** | **8.00** | **78.20** | **443.00** | **18.30** |
| Linearity | **Allowable Linearity Drift (Less Than ±1% of Range)** | **0.25** | **0.20** | **2.00** | **10.00** | **1.00** |
| Linearity | Linearity Check - 7:53:13 AM | 9.08 | 8.04 | 74.76 | 442.01 | 17.38 |
| Linearity | **Difference From Mid-Range Values** | **0.11** | **0.04** | **3.44** | **0.99** | **0.92** |
| Linearity | **Was the Linearity Within Allowable Deviation?** | **Yes** | **Yes** | **No** | **Yes** | **Yes** |
| Linearity | Linearity Check - 10:18:37 AM & 10:24:20 AM (HC Only) | 9.09 | 8.01 | 75.67 | 440.34 | 17.44 |
| Linearity | **Difference From Mid-Range Values** | **0.12** | **0.01** | **2.53** | **2.66** | **0.86** |
| Linearity | **Was the Linearity Within Allowable Deviation?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

**Appendix E:** Calculations

**Emission Concentrations**

Corrected to $O_2$ Standard (3% $O_2$)

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

Where

Raw Concentration = Measured CO, HC & $NO_x$ concentrations, by volume (ppm)

% $O_2$ = Measured $O_2$ Concentration

**Ultimate $CO_2$**

$$\text{Ultimate CO}_2\ (\%) = \text{Raw CO}_2 \times \left[ \frac{20.9}{20.9 - \text{Raw O}_2} \right]$$

Where

Raw $CO_2$ = Measured $CO_2$ Concentration (%)

Raw $O_2$ = Measured $O_2$ Concentration (%)

## % Excess Air

To determine the % Excess Air, the theoretical air and theoretical flue gas values for each gas tested must be calculated. The table above lists the constituents found in natural gas, the balanced chemical equations for each constituent and their respective theoretical air and theoretical flue gas values (expressed in moles).

The theoretical air value for each constituent is the sum of moles for both $O_2$ and $N_2$ on the

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

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

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

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

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

Where *C* is the theoretical air value for each constituent, *D* is the theoretical flue gas value for each constituent and *P* is the percent composition for each constituent (expressed as a decimal, not a percentage). Therefore, the % Excess Air is calculated as follows:

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

**Air/Fuel Ratio**

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

**Equivalence Ratio (ϕ)**

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

**Gas Meter Accuracy Table**

The gas meter used during testing was compared to a certified bell prover to determine its accuracy (error percentage) at various flow rates.

The gas meter accuracy table (below) shows the prover flow rates that the meter was tested, error percentage for each accuracy test and an average meter error.

Also included on the table is a gas meter flow rate. The gas meter flow rate is the meter's reading at each prover flow rate when the average meter error is factored in. This flow rate was calculated using the meter accuracy equation:

$$\%\ \text{Error} = \left(\frac{\text{Gas Meter Flow - Prover Flow}}{\text{Prover Flow}}\right) \times 100$$

Through algebraic manipulation, the gas meter flow is determined using the following equation:

$$\text{Gas Meter Flow} = \text{Prover Flow} \times \left(1 + \frac{\%\ \text{Error}}{100}\right)$$

A negative error percentage indicates the gas meter flow rate was below the prover flow rate whereas a positive error percentage indicates the gas meter flow rate was above the prover flow rate.

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

### Actual Gas Flow with Meter Correction (acfh)

To correct the actual gas flow that was measured during testing, a gas meter flow rate range is selected from the meter accuracy table. The gas meter flow rates and the average meter error (divided by 100) will be used to calculate the meter correction factor at any given gas flow rate.

Setting y = average meter error (divided by 100) and x = gas meter flow rate, the error can be calculated using the following equation:

$$\frac{y - y_0}{y_1 - y_0} = \frac{x - x_0}{x_1 - x_0}$$

Manipulating the right side of the equation algebraically:

$$\alpha = \frac{x - x_0}{x_1 - x_0}$$

The equation would then simplify into:

$$y = \frac{y_1 - y_0}{x_1 - x_0}(x - x_0) + y_0$$

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

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

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

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

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

**Corrected Gas Flow (scfh)**

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

Where

$F_{corrected}$ = Gas flow corrected to standard temperature and pressure (scfh)

$F_{meter}$ = Actual gas flow with meter correction (acfh)

$P_{Fuel}$ = Natural gas inlet pressure (psig)

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

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

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

$T_{Fuel}$ = Fuel temperature (°F)

**Input Rate (Btu/cf)**

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

Where

HHV = Higher Heating Value (Btu/cf)

**Wobbe Number (Btu/cf)**

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

Where

$W_0$ = Wobbe Number (Btu/cf)

HHV = Higher Heating Value (Btu/cf)

G = Specific gravity of gas sample

## **Appendix F:** Test Equipment

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

**Emissions Analyzer**

| Analyzer | Manufacturer | Model | Type | Accuracy |
|---|---|---|---|---|
| $NO/NO_X$ | 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 | Logic Beach | Hyperlogger | n/a |
| Gas Chromatograph | Agilent | 6890 | ± 0.5 BTU/scf |
| K | Omega Engineering Co. | KMQSS | 2.2°C or 0.75% |
| J | Omega Engineering Co. | JMQSS | 2.2°C or 0.75% |
| T | Omega Engineering Co. | TMQSS | 2.2°C or 0.75% |
| Dry Test Gas Meter 200 cf/h max | American Meter Company | DTM-200A | @ 200 cf/h – 100.1 % @60 cf/h – 99.9 % |
| Gas Meter Pulser 2 pulses per 1/10 cf | Rio Tronics | 4008468 | n/a |
| Gas Pressure Regulator | Fisher | 299H | ± 1.0 % |
| Differential Pressure Transmitter | Dwyer | 607-4 | ±0.25 -0.50% |
| Pressure Transducer | Omega | PX205-100GI | ±0.25% of full scale |
| Water Temperature Mixing Valve | Powers | 434 | n/a |

**<u>Appendix G:</u>** Test Set-Up/Schematic

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