LNG Research Study

Legacy Clothes Dryer

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Prepared By:

The Southern California Gas Company
Engineering Analysis Center – Applied Technologies

Jorge Gutierrez
Edgar Llamas

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Monica Clemens
Johnny Lozano
Larry Sasadeusz
Rod Schwedler
Kevin Shea
Dale Tomlinson
Robert Munoz

Disclaimer

Table of Contents

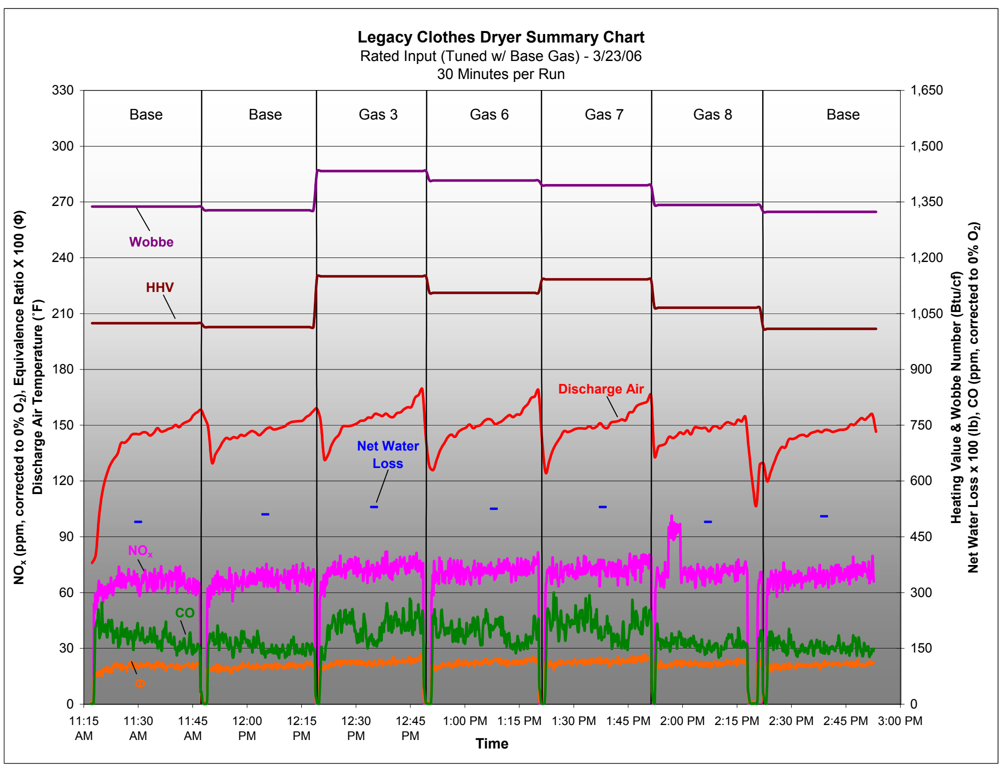
Results Summary

Results obtained from all tests conducted revealed: (a) There were no operational, ignition, safety, flame stability, flame lifting, flashback or yellow tipping problems; (b) None of the temperatures monitored had critical changes; (c) NO_x emissions and combustion chamber temperature increased with the richer gases; (d) Tuning the unit with Gas 8 did not create any significant safety, emissions, performance or operational changes.

CO, NO_x and HC emissions are corrected to 0% O_2.

Rated Input Test (Tuned w/ Base Gas)

NO_X emissions ranged from 66.3 ppm (Gas 8) to 72.6 ppm (Gas 3) and CO emissions ranged from 147.8 ppm (Gas 8) to 210.6 ppm (Gas 7). Discharge air temperatures followed a similar trend as the NO_x emissions, where the richer gases produced a slight temperature increase – from 143.2˚F (Base Gas) to 152.7˚F (Gas 3). Equivalence ratio ranged from 0.20 (Base Gas) to 0.23 (Gas 7). Lowest net water loss during the thirty minute drying cycle was 4.9 lb (Gas 8), while the highest was 5.3 lb (Gas 7). An undetermined spike in NO_X emissions was observed during the Gas 8 run, while all other parameters remained consistent. We are unable to explain the temporary jump in the NO_X emissions while running on Gas 8.



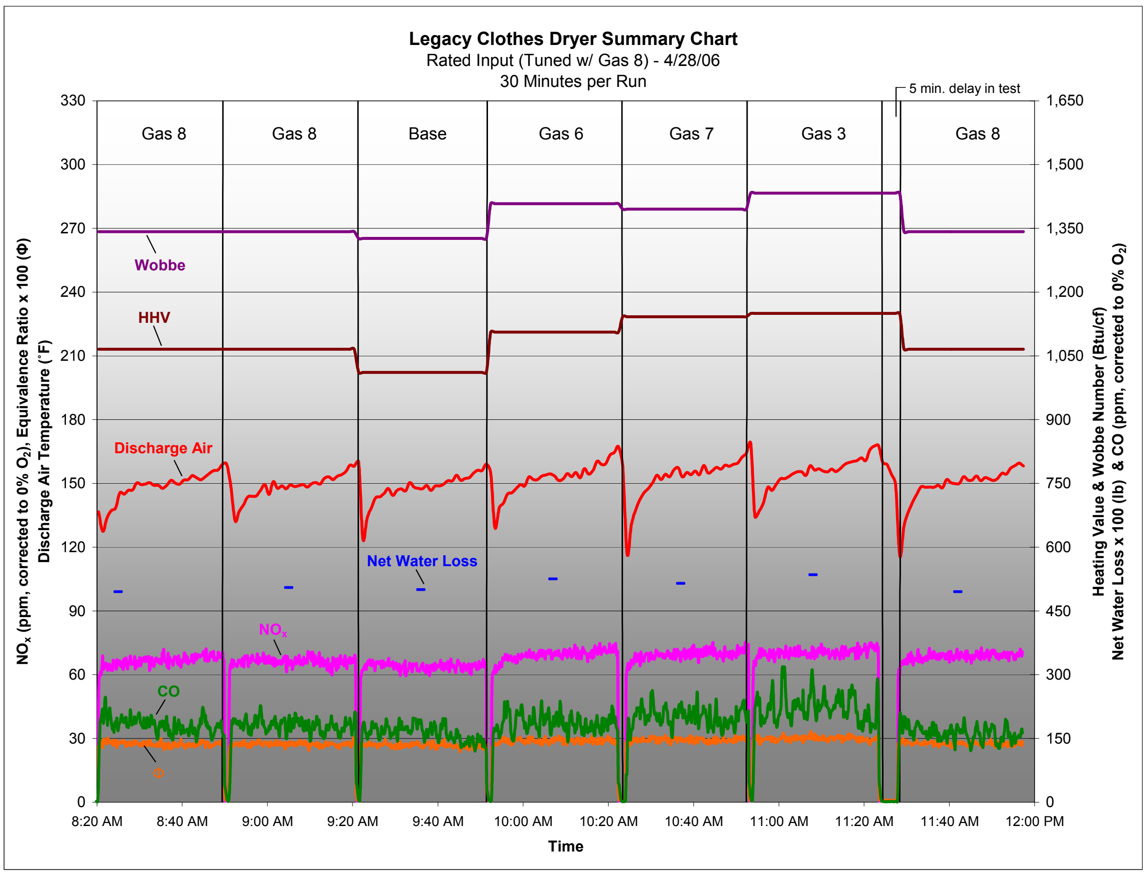
NOTE: Emission test results are for information purposes, they were not the result of certified tests.

Rated Input Test (Tuned w/ Gas 8)

Compared with values when the appliance was tuned with Base Gas:

- NO_X emissions decreased for Base Gas (63.9 ppm), Gas 6 (69.1 ppm), Gas 7 (69.3 ppm) and Gas 3 (70.3 ppm) but increased slightly for Gas 8 (67.0 ppm).
- CO emissions were the lowest with Base Gas and last run of Gas 8 (162). The highest CO emissions were with Gas 3 (222 ppm).
- Discharge air temperatures increased slightly and net water loss varied by 2.8% (0.15 lb) or less for all test gases.

There was a five minute delay in the final test transition, from Gas 3 to Gas 8. This delay was caused by not having the clothing load ready.

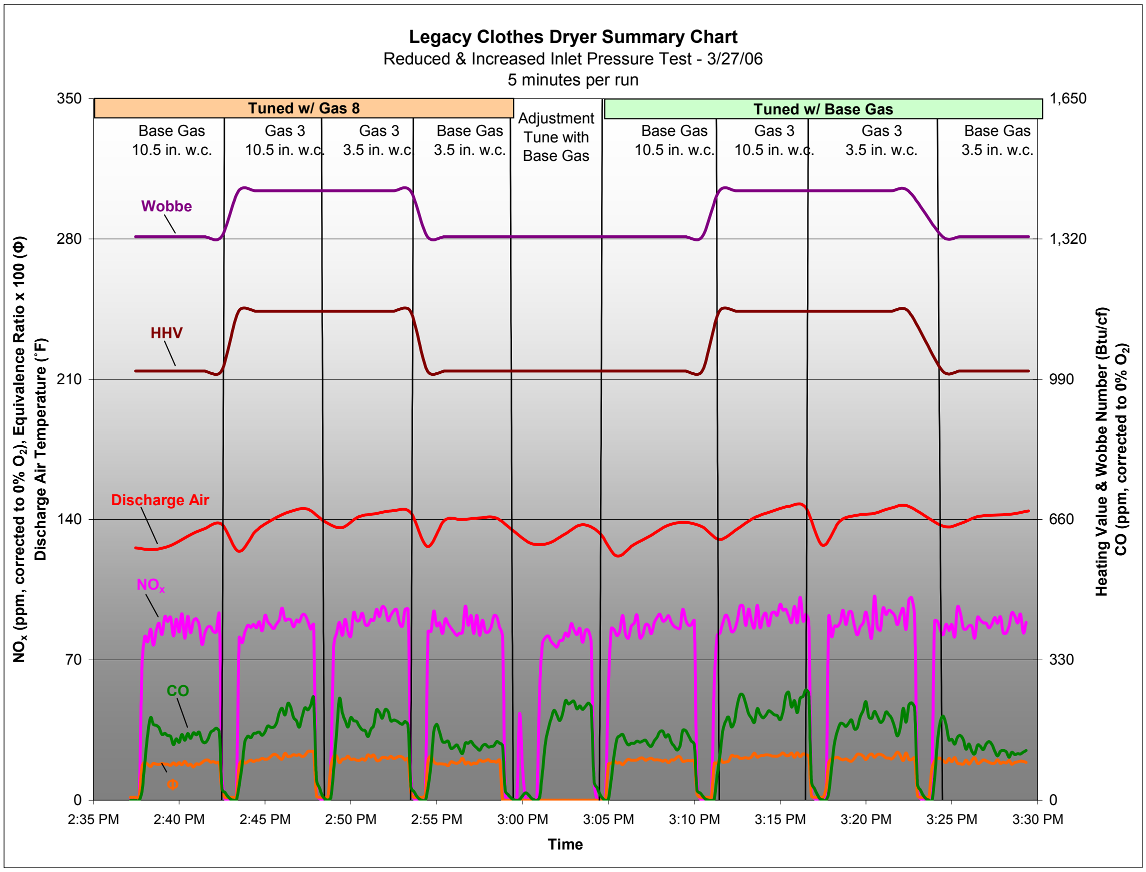


NOTE: Emission test results are for information purposes, they were not the result of certified tests.

Reduced & Increased Inlet Pressure Tests - (Tuned w/ Gas 8 & Base Gas)

When tuned with Gas 8, the highest CO and NO_X emissions were observed for Gas 3 at increased inlet pressure; 176 ppm and 87.9 ppm, respectively. Changes in CO and NO_X emissions for Gas 3 at reduced inlet pressure were negligible. For Base Gas, NO_X emissions were highest at reduced inlet pressure (87.2 ppm) while CO emissions were highest at increased inlet pressure (147.5 ppm). Discharge air temperature was highest with Gas 3 with negligible changes occurring at each pressure setting while Base Gas discharge air temperature increased at reduced inlet pressure.

When tuned with Base Gas, CO and NO_X emissions were highest at increased inlet pressure for Base Gas (CO: 133.1 ppm/NO_X: 86.4 ppm) and Gas 3 (CO: 189.4 ppm/NO_X: 89.6 ppm). While CO and NO_X emissions decreased for both gases at reduced inlet pressure, the largest decrease was observed with Gas 3. Changes in discharge air temperature were negligible for Gas 3 but increased from 133.8°F at increased inlet pressure to 142.1°F at reduced inlet pressure.



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

Equipment Selection Criteria

This type of (legacy) clothes dryer was selected to investigate concerns by industry experts, related to induced combustion systems with rich gases. In addition, this equipment was selected because:

- There are a large number of these types of units in the Southern California Gas Company territory and they have a long life expectancy.
- Safety concerns related to flue gas if they are not vented properly.
- Gas dryers are the appliances most frequently associated with fires within residences.

Equipment Specification

Description	Legacy Clothes Dryer
Burner	Induced Combustion System (see image on the right) 
Maximum rated input	22,000 Btu/hr
Type of fuel	Natural Gas
Required gas supply pressure	4.5 - 10.5 in. 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 Z21.5.1-2002 **CSA 7.1 -2002**	Gas Clothes Dryers, Vol. I
SCAQMD **Method 100.1**	Instrumental analyzer procedure for continuous gaseous emissions

Installation

Instrumentation was installed following the cited test standards and input from manufacturers and industry experts. The legacy clothes dryer was installed in an area within a test laboratory, adjacent to its matching clothes washer. Thermocouples were installed to measure ambient, gas, discharge air, high limit switch, thermostat, drum discharge, average external surface, combustion chamber, combustion air intake, & rear panel (behind firebox) temperatures. Pressure transducers were installed to measure manifold and gas delivery system pressures. A gas meter was used to measure the gas flow and an emissions probe was built and placed in the flue vent (Type B round) of the dryer.

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	1,330 (Low Wobbe)	1,014 (Low heat content)
3	1,433 (Highest Wobbe)	1,150 (Highest heat content)
6	1,408 (High Wobbe)	1,106 (High heat content)
7	1,395 (High Wobbe)	1,142 (Highest heat content)
8	1,342 (Medium Wobbe)	1,066 (Medium heat content)

Test Procedure

Test procedures were developed based on the above test standards. However, due to time limitations and variations between the cited 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 checked for linearity.
- Data logger was enabled to verify temperature, pressure and gas flow readings.
- Before each test, one of the three loads of clothing of identical dry weight, was placed in the washing machine to undergo the rinse cycle.
- After the rinse cycle, each load was weighed and water was added to achieve a predetermined weight of 14.40 pounds.

During every test, the following steps were performed:

- Base and Test Gases were run continuously, with switching between gases taking less than 14 seconds. However, the overall switching took longer because a new load of wet clothes was placed in the dryer after each run.
- Emissions, pressure and temperature data was observed before, during and after changeover.

After every test the following steps were performed:

- Final clothing load weight was recorded after 30 minute drying cycle.
- Test data was downloaded.
- Linearity and drift inspections were performed on all emissions analyzers.

Rated Input Test (Tuned w/ Base Gas)

Since it was verified that the dryer's "as received" input rate was the same as the rated input, the As Received Test was changed to the Rated Input Test. Using Base Gas, an input rate of 22,000 Btu/hr ± 2% was achieved, while supply and manifold pressures were 8.1 and 2.9 in. w.c., respectively. Once readings were stable, data collection began and the gases were introduced in the following order:

- Begin testing with Base Gas for 30 minutes.
- Remain with Base Gas for additional 30 minutes.
- Switch to Gas 3 for 30 minutes.
- Switch to Gas 6 for 30 minutes.
- Switch to Gas 7 for 30 minutes.
- Switch to Gas 8 for 30 minutes.
- Conclude testing with Base Gas for 30 minutes.

Rated Input Test (Tuned w/ Gas 8)

Using Gas 8, the manifold pressure was adjusted to operate at the dryer's rated input. Once readings were stable, data collection began and the gases were introduced in the following order:

- Begin testing with Gas 8 for 30 minutes.
- Remain with Gas 8 for additional 30 minutes.
- Switch to Base Gas for 30 minutes.
- Switch to Gas 6 for 30 minutes.
- Switch to Gas 7 for 30 minutes.
- Switch to Gas 3 for 30 minutes.
- Conclude testing with Gas 8 for 30 minutes.

Reduced & Increased Inlet Pressure Tests (Tuned w/ Gas 8 & Base Gas)

While tuned with Gas 8, the inlet pressure was increased to 10.5 in. w.c. for the Increased Inlet Pressure Test. Once readings were stable, data collection began and the gases were introduced in the following order:

- Base Gas for 5 minutes at increased inlet pressure.
- Gas 3 for 5 minutes at increased inlet pressure.
- Decreased inlet pressure to 3.5 in. w.c. for the Reduced Inlet Pressure Test (tuned w/ Gas 8).
- Gas 3 for 5 minutes at reduced inlet pressure.
- Base Gas for 5 minutes at reduced inlet pressure.

The dryer was then tuned with Base Gas by adjusting manifold and inlet pressures to obtain the dryer's rated input. Once rated input conditions were achieved, the inlet pressure was increased to 10.5 in. w.c. for the Increased Inlet Pressure Test. Once readings were stable, data collection began and the gases were introduced in the following order:

- Base Gas for 5 minutes at increased inlet pressure.
- Gas 3 for 5 minutes at increased inlet pressure.
- Decreased inlet pressure to 3.5 in. w.c. for the Reduced Inlet Pressure Test (tuned w/ Base Gas).
- Gas 3 for 5 minutes at reduced inlet pressure.
- Base Gas for 5 minutes at reduced inlet pressure.

Cold Ignition Test

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

Hot Ignition Test

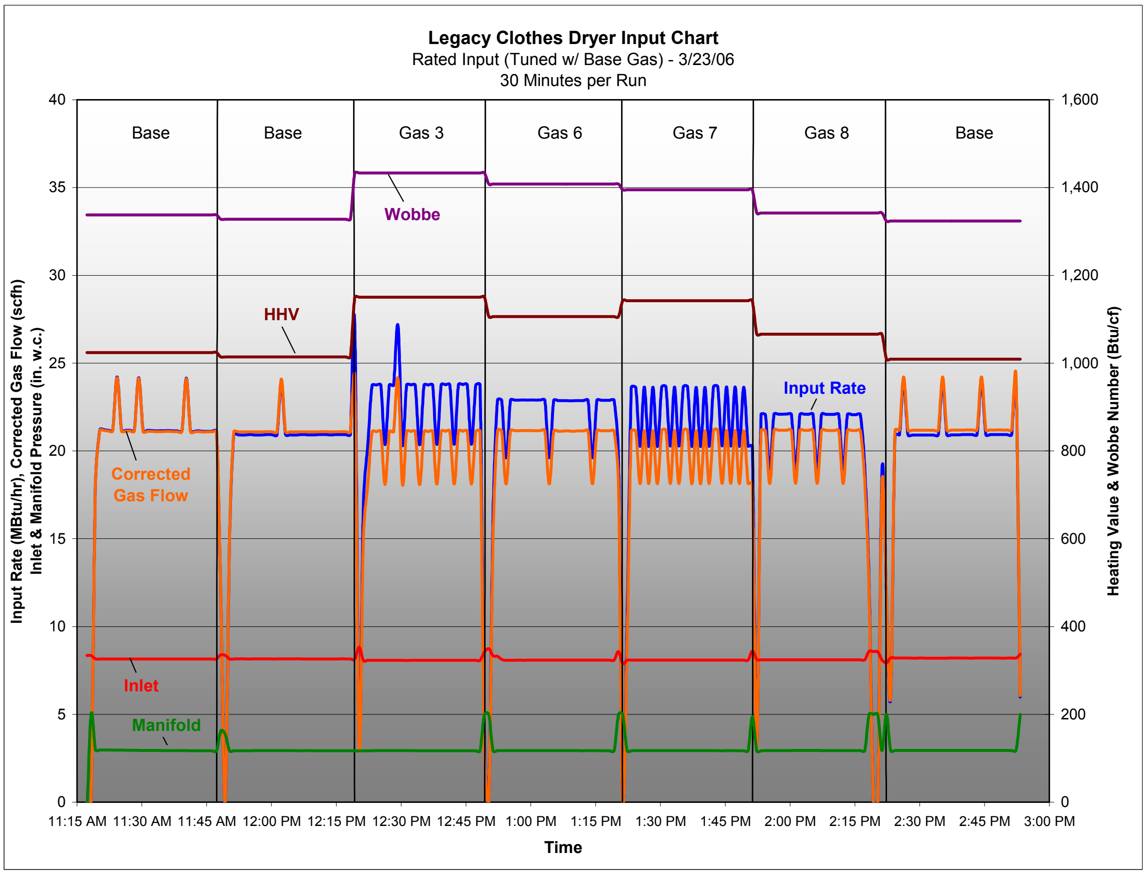
The unit was tuned with each test gas. After steady-state operating conditions were achieved, three ignition tests were conducted, with each test gas, following the protocol detailed in Appendix A.

Results[1,2,3]

Rated Input Test (Tuned w/ Base Gas)

Input

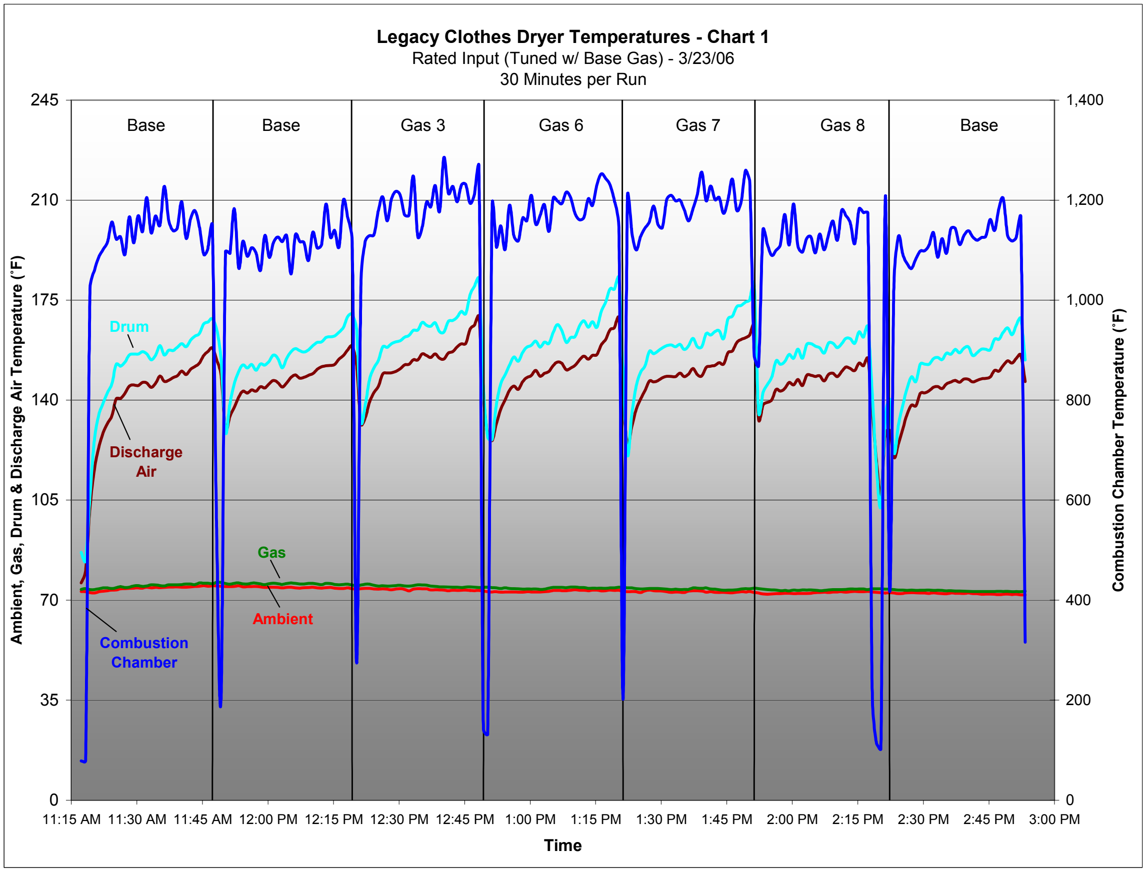
The input rate corresponded with changes in the Wobbe Number and heating value of each gas, with the minimum and maximum input rates being 21,170 Btu/hr (Base Gas) and 22,787 Btu/hr (Gas 3), respectively. The corrected gas flow ranged from 19.8 scfh to 20.9 scfh. Inlet and manifold pressures remained stable throughout the course of the test.



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

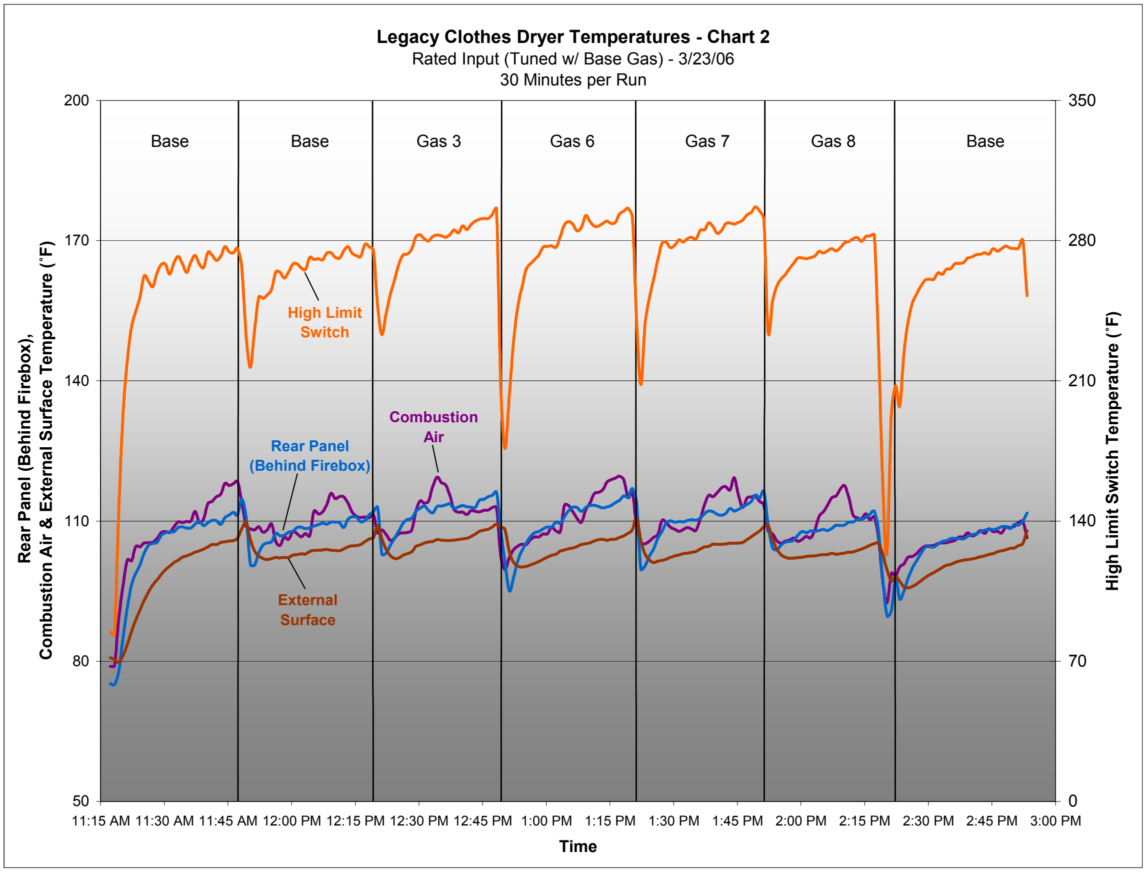
Temperatures (Chart 1)

Combustion chamber temperatures ranged from 1,029°F (Gas 8) to 1,147°F (Gas 7), with Base Gas observed at 1,070°F. Drum temperature with Base Gas was 152.6°F and increased with richer gases, up to 162.4°F (Gas 3). Discharge air temperatures followed the same characteristics as drum temperatures, increasing approximately 10°F from Base to Gas 3. During testing, ambient and gas temperatures remained stable at 74 ± 2°F.



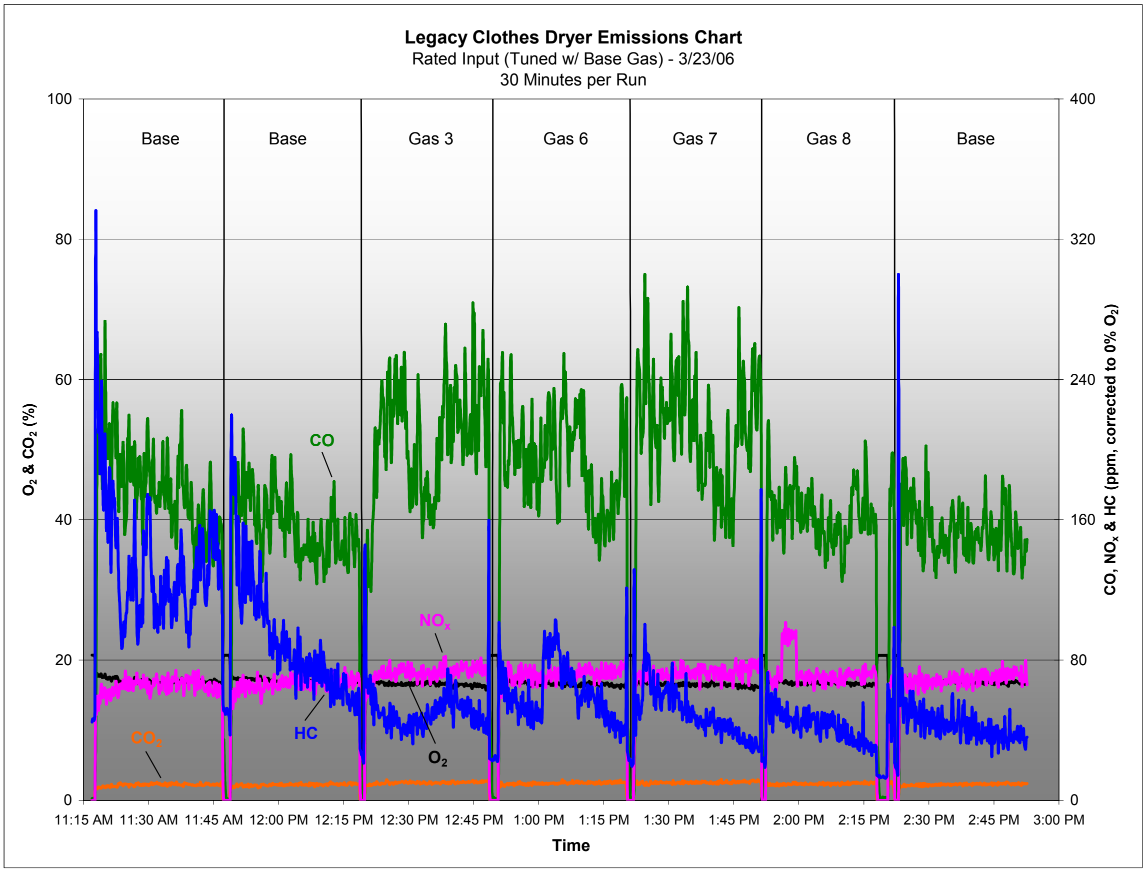
Temperatures (Chart 2)

Results revealed high limit switch temperature to be highest with Gas 7 (277.9°F), and lowest with Base Gas (257.4°F). Rear panel temperatures (Behind firebox) ranged from 106°F (Base Gas) to 111.5°F (Gas 3). Average external temperatures were 103 ± 3°F and combustion air temperatures were at 108 ± 3°F



Emissions

NO_X emissions experienced small changes with the different test gases, ranging from 66.3 ppm (Gas 8) to 72.6 ppm (Gas 3) and CO emissions ranged from 147.8 ppm (Gas 8) to 210.6 ppm (Gas 7). Base Gas NO_X and CO emissions were 66.9 ppm and 162.2 ppm, respectively. HC emissions ranged from 40.6 ppm (Gas 8) to 91.3 ppm (Base Gas). Changes in CO_2 & O_2 percentages remained negligible throughout the test.

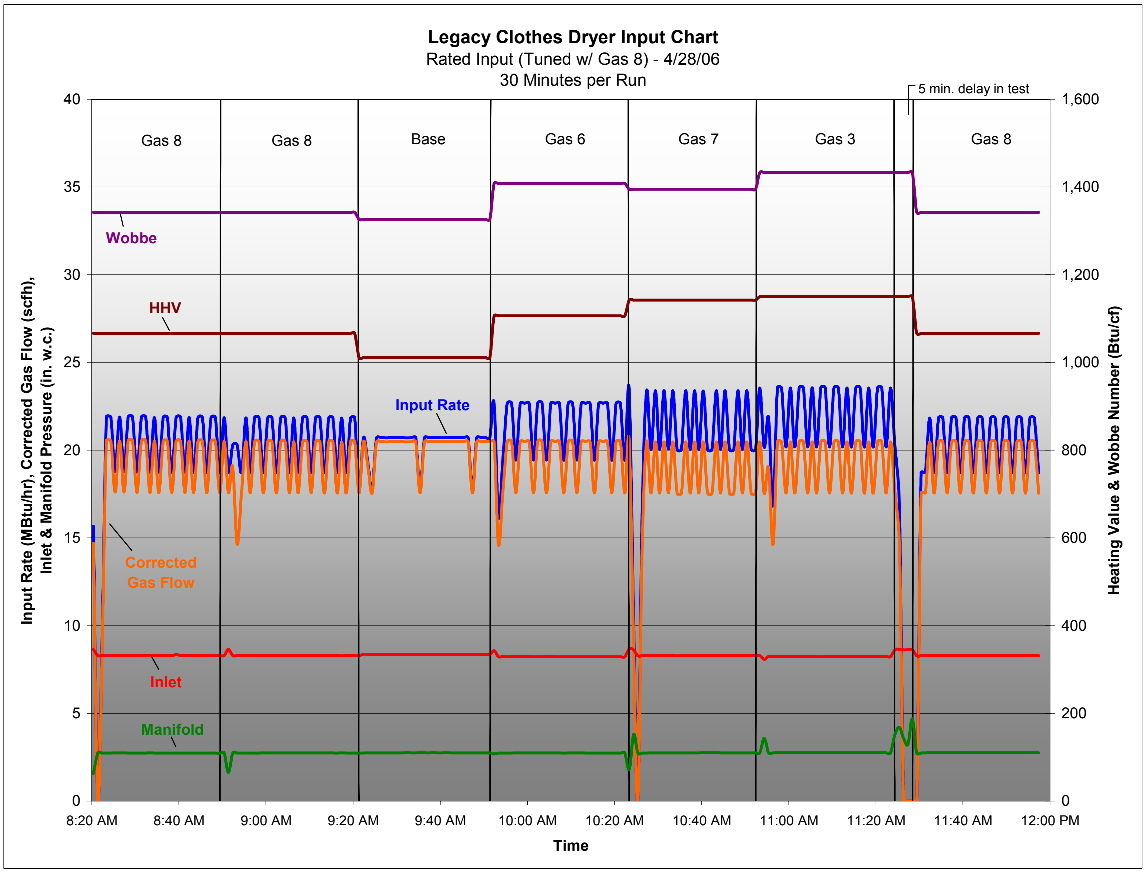


NOTE: Emission test results are for information purposes, they were not the result of certified tests.

Rated Input Test (Tuned w/ Gas 8)

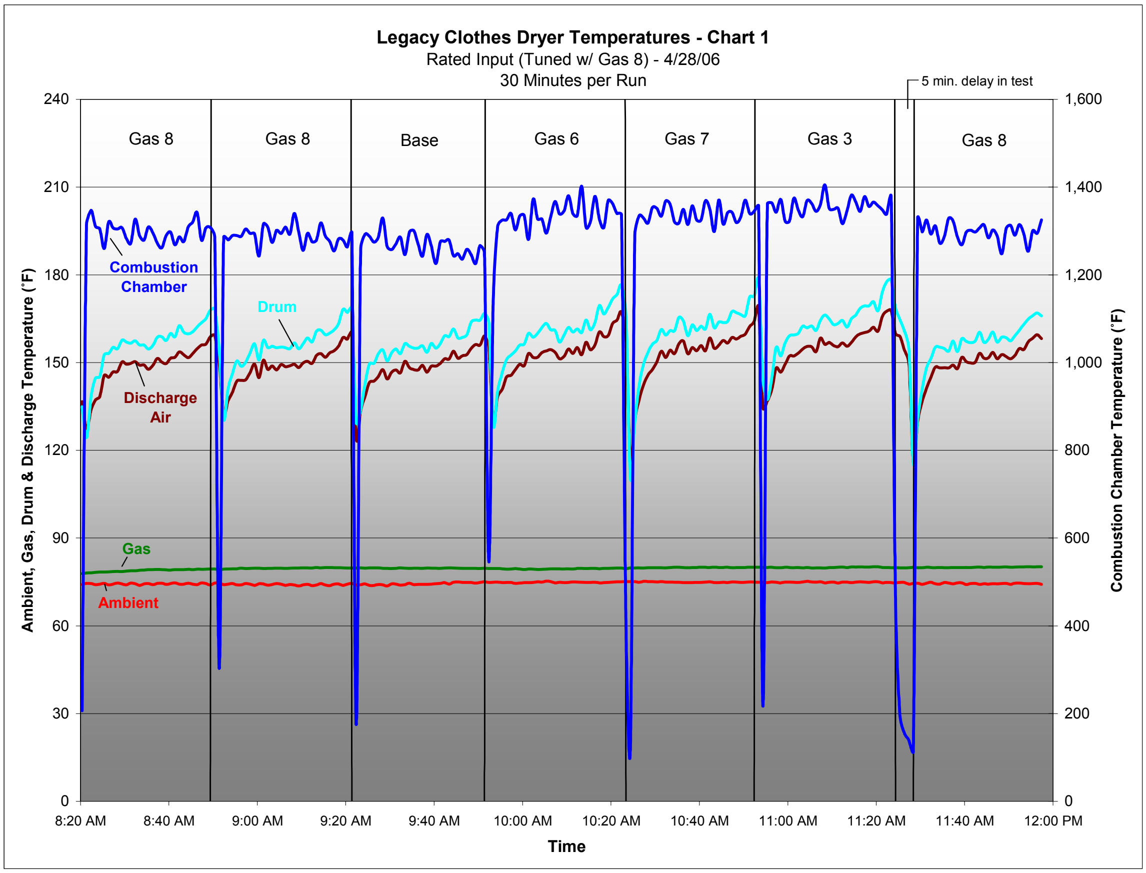
Input

The highest input rate was observed with Gas 3 (22,079 Btu/hr) and the lowest with Base Gas (20,397 Btu/hr). Corrected gas flow was 19.4 ± 0.8 scfh for all test gases. Manifold and inlet pressures were within tolerances specified in the test protocol.



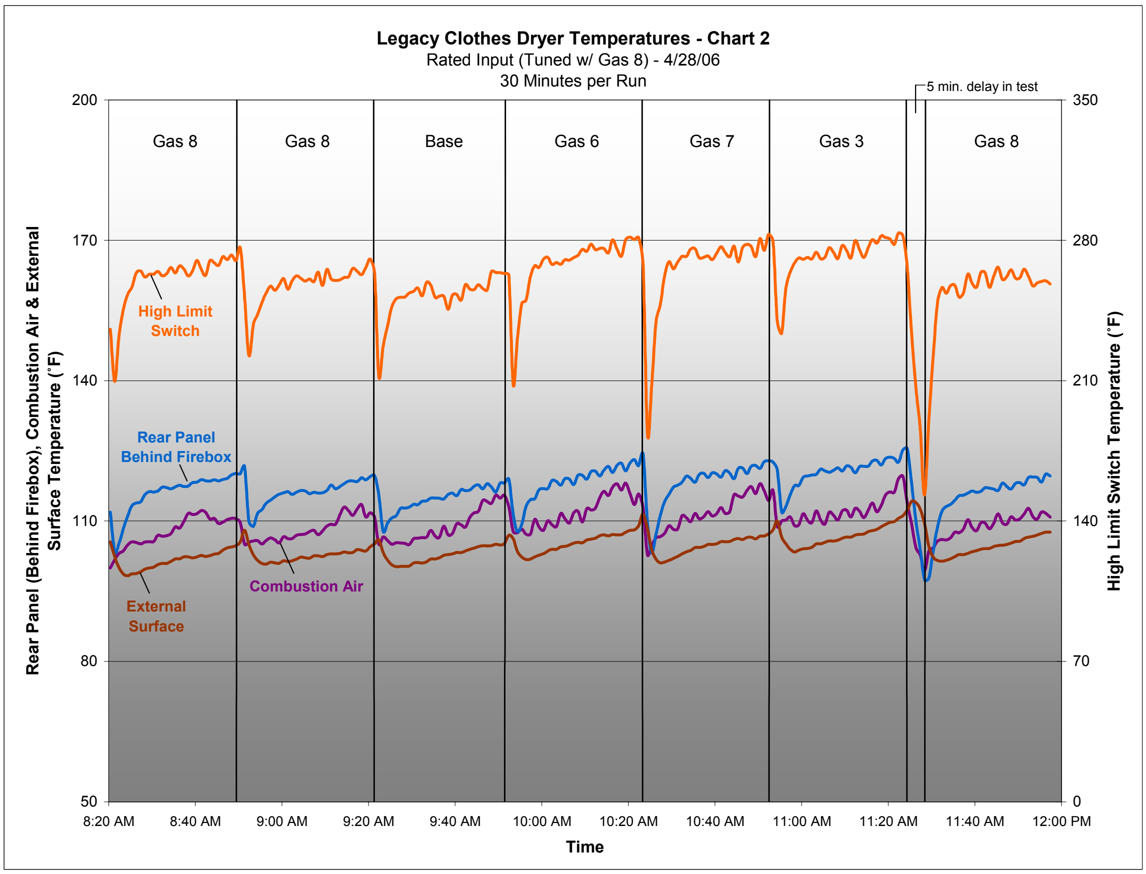
Temperatures (Chart 1)

Combustion chamber temperatures ranged from 1,233°F (Base Gas) to 1,337°F (Gas 3). Drum temperatures were 159 ± 5°F and discharge air temperatures were 152 ± 4°F for all test gases. Ambient and gas temperatures were steady throughout the course of the test.



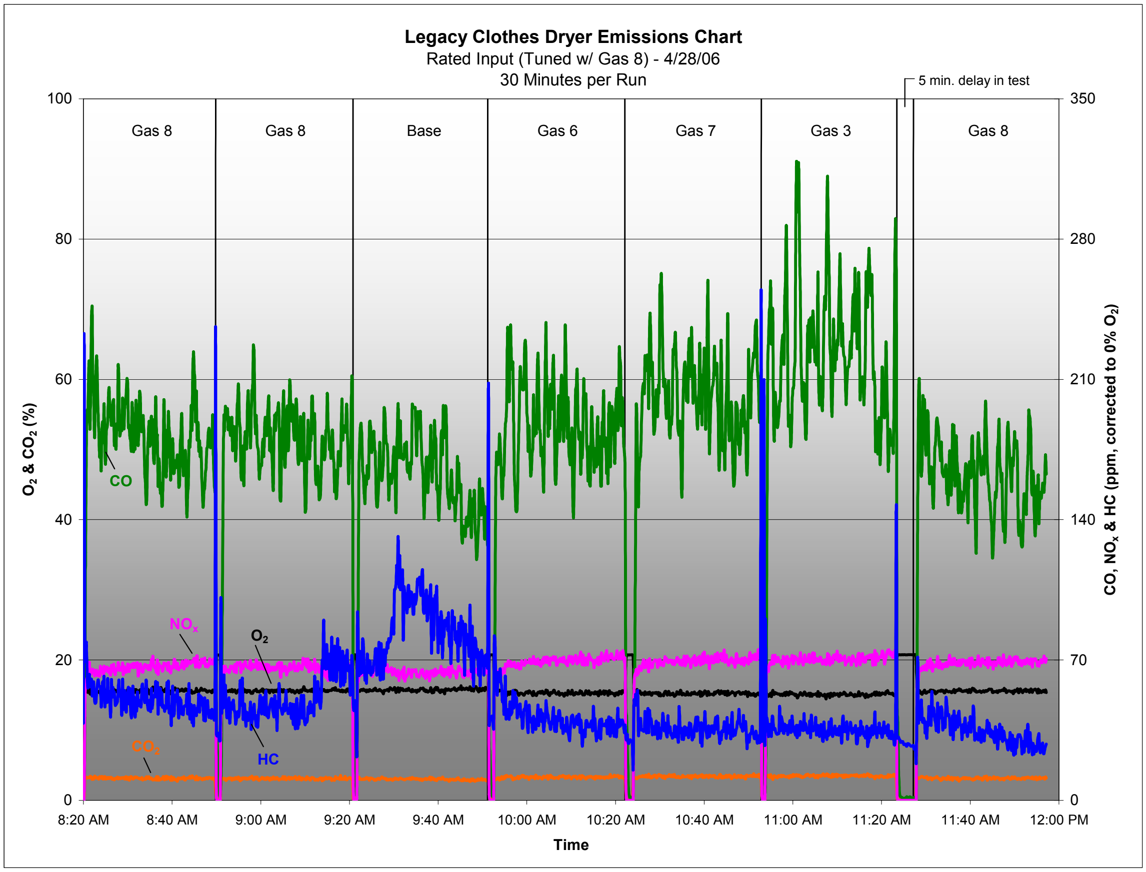
Temperatures (Chart 2)

High limit switch temperatures ranged from 252.5°F (Base Gas) to 273°F (Gas 3). Rear panel temperature was 118 ± 3°F, external surface temperature was 104 ± 3°F and combustion air temperature was 111 ± 2°F for all gases during the test.



Emissions

NO_X emissions ranged from 63.9 ppm (Base Gas) to 70.4 ppm (Gas 3), CO emissions ranged from 162 ppm (Base Gas) to 222 ppm (Gas 3) and HC emissions ranged from 35.7 ppm (Gas 3) to 84.4 ppm (Base Gas). Change in CO_2 & O_2 percentages remained negligible throughout the test.



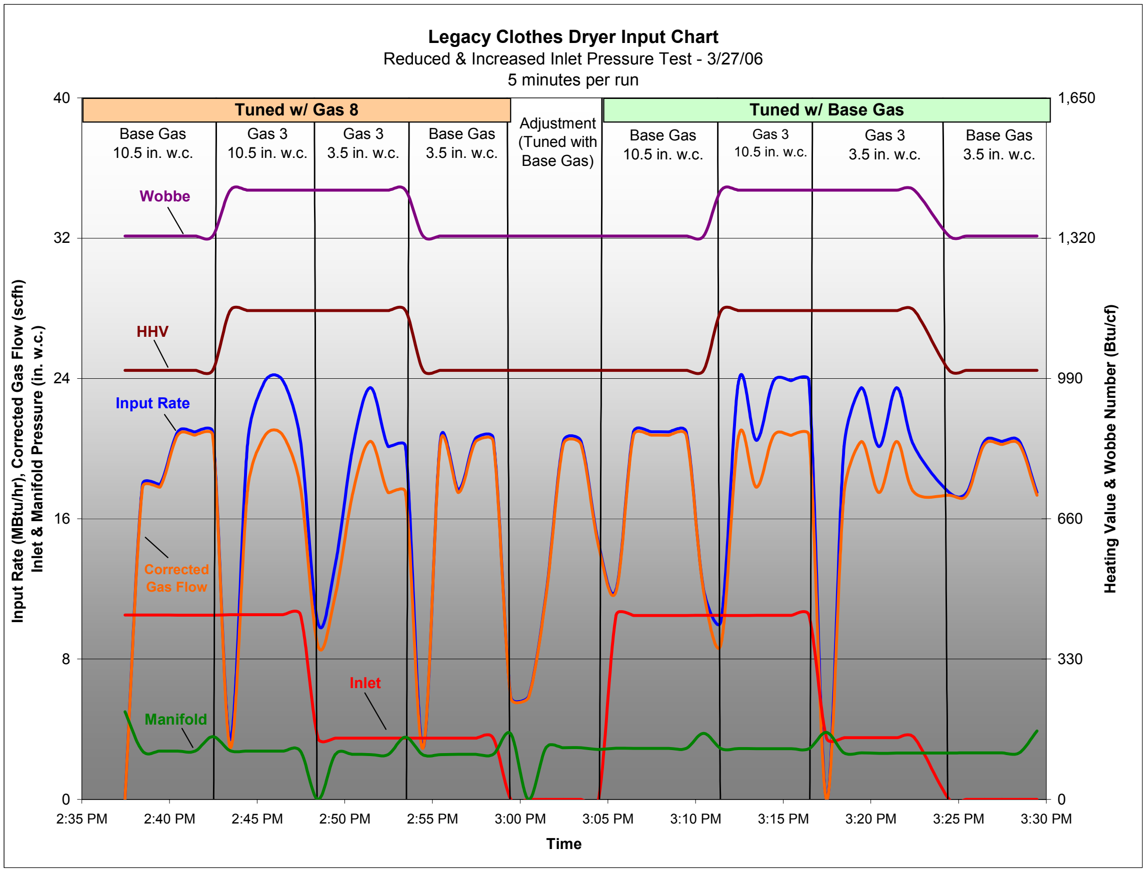
NOTE: Emission test results are for information purposes, they were not the result of certified tests.

Reduced & Increased Inlet Pressure Tests - (Tuned w/ Gas 8 & Base Gas)

Input

When tuned with Gas 8, the highest input rate for Gas 3 (22,741 Btu/hr) was observed at increased inlet pressure (10.5 in. w.c.) and the highest input rate for Base Gas (19,860 Btu/hr) was observed at reduced inlet pressure (3.5 in. w.c.). The corrected gas flow rate was 19.7 ± 0.2 scfh except for Gas 3 at reduced inlet pressure (18.2 scfh). Both manifold and inlet pressures were stable throughout the course of the test.

When tuned with Base Gas, the highest input rates for Gas 3 (23,197 Btu/hr) and Base Gas (20,954 Btu/hr) were observed at increased manifold pressure (10.5 in. w.c.). The corrected gas flow rate was 20.5 ± 0.4 scfh except for Gas 3 at reduced inlet pressure (19.0 scfh). Both manifold and inlet pressures were stable throughout the course of the test.

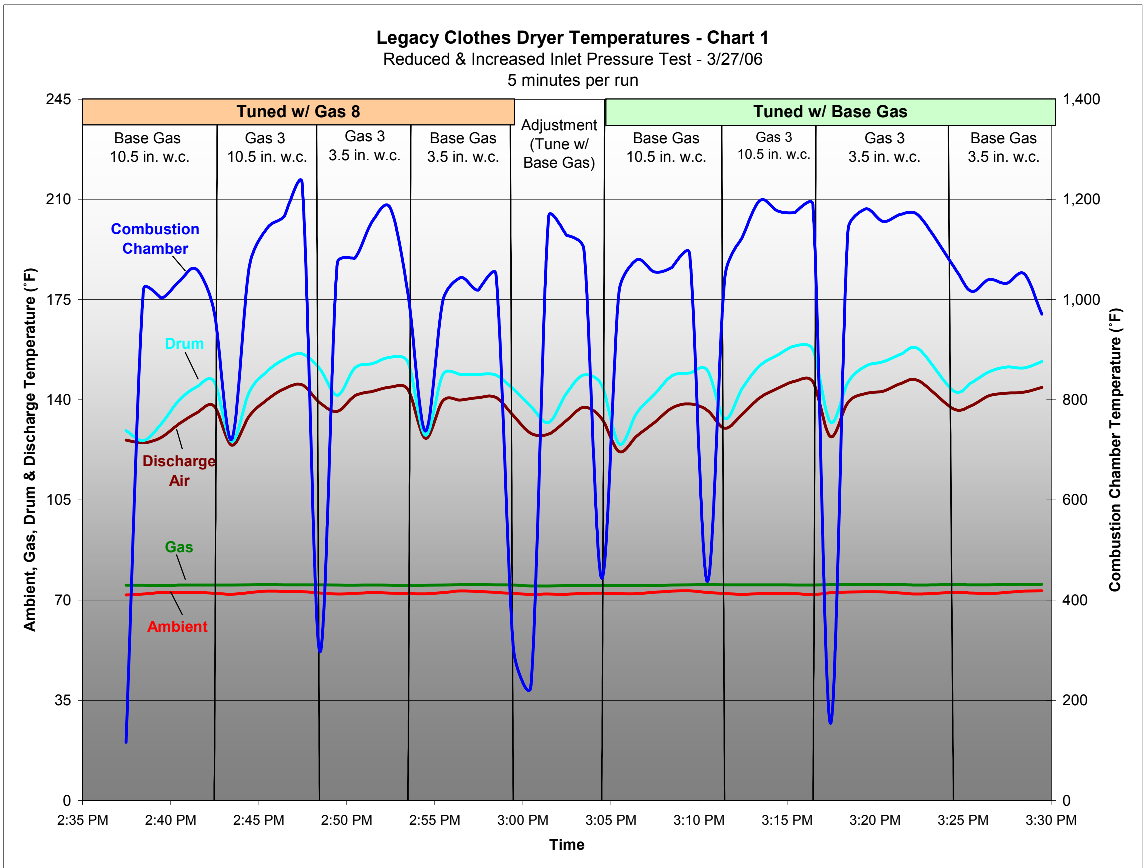


Temperatures (Chart 1)

When tuned with Gas 8, combustion chamber temperature ranged from 1,019°F (Base Gas at increased inlet pressure) to 1,180°F (Gas 3 at increased inlet pressure), drum temperature ranged from 137.6°F (Base Gas at increased inlet pressure) to 153.4°F (Gas 3 at increased inlet pressure) and discharge air temperature ranged from 131.3°F (Base Gas at increased inlet pressure) to 143.1°F (Gas 3 at reduced inlet pressure).

When tuned with Base Gas, combustion chamber temperature ranged from 1,041°F (Base Gas at reduced inlet pressure) to 1,173°F (Gas 3 at increased inlet pressure), drum temperature ranged from 143.7°F (Base Gas at increased inlet pressure) to 153.6°F (Gas 3 at increased inlet pressure) and discharge air temperature ranged from 133.8°F (Base Gas at increased inlet pressure) to 142.5°F (Gas 3 at reduced inlet pressure).

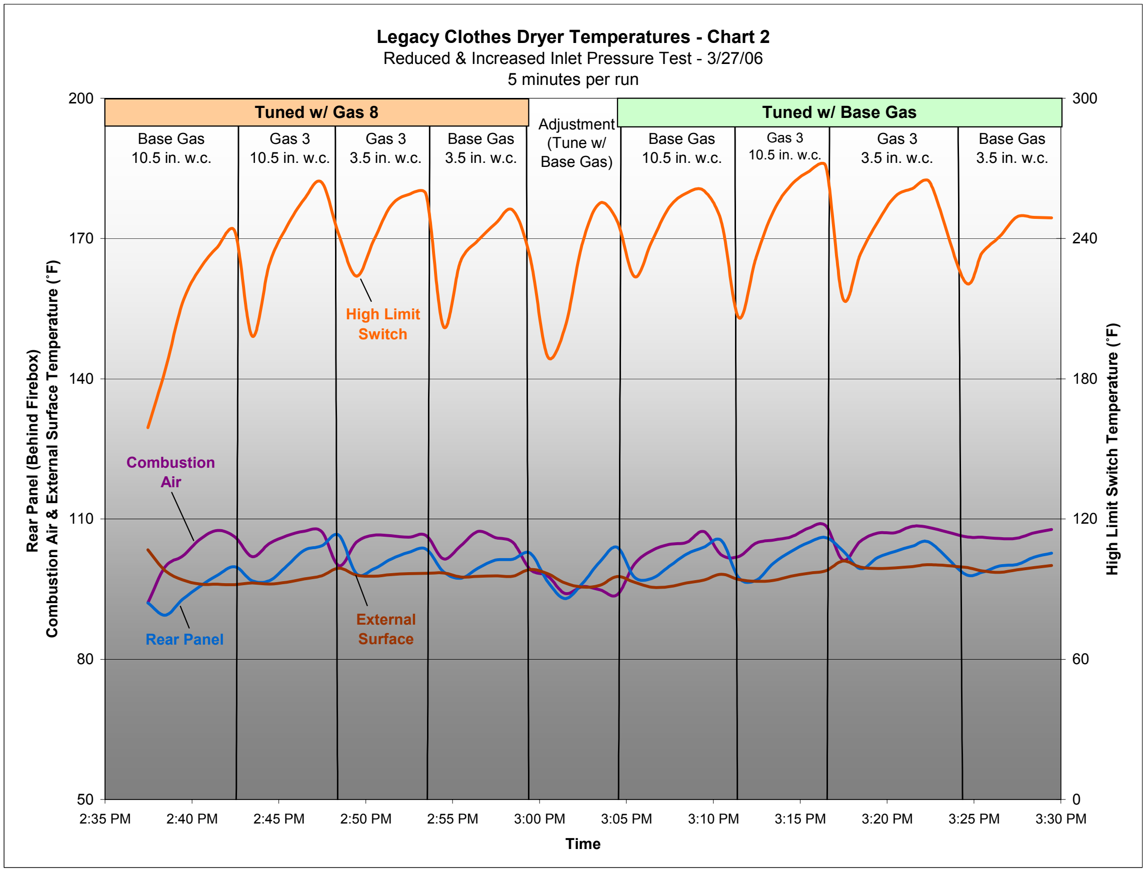
Ambient temperature (72.6 ± 0.5°F) and gas temperature (75.3 ± 0.2°F) were within tolerances specified in the test protocol and remained stable throughout the course of the test.



Temperatures (Chart 2)

When tuned with Gas 8, high limit switch temperature ranged from 220.6°F (Base Gas at increased inlet pressure) to 255.4°F (Gas 3 at increased inlet pressure). Rear panel temperature (99.8 ± 5°F), external surface temperature (97.4 ± 1°F) and combustion air temperature (105.8 ± 2°F) were stable during this portion of the test.

When tuned with Base Gas, high limit switch temperature ranged from 246.4°F (Base Gas at reduced inlet pressure) to 257.2°F (Gas 3 at increased inlet pressure). Rear panel temperature (101.5 ± 1°F), external surface temperature (98 ± 2°F) and combustion air temperature (106.2 ± 2°F) were stable during this portion of the test.

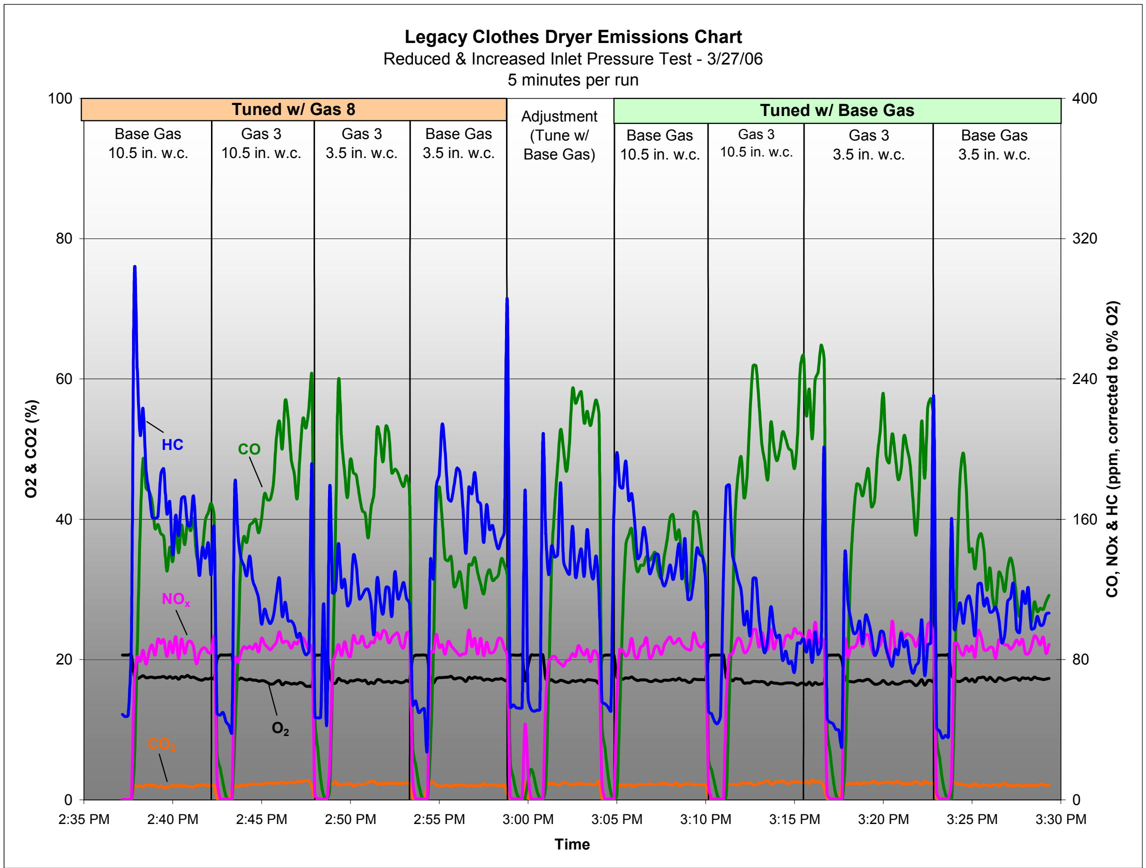


Emissions

When tuned with Base Gas, NO_X emissions ranged from 84.9 ppm (Base Gas at increased inlet pressure) to 87.9 ppm (Gas 3 at increased inlet pressure), CO emissions ranged from 127.7 ppm (Base Gas at reduced inlet pressure) to 176.0 ppm (Gas 3 at increased inlet pressure) and HC emissions ranged from 116.5 ppm (Gas 3 at increased inlet pressure) to 172.2 ppm (Base Gas at increased inlet pressure).

When tuned with Base Gas, NO_X emissions ranged from 78.3 ppm (Gas 3 at reduced inlet pressure) to 89.6 ppm (Gas 3 at increased inlet pressure), CO emissions ranged from 123.3 ppm (Base Gas at reduced inlet pressure) to 189.4 ppm (Gas 3 at increased inlet pressure) and HC emissions ranged from 86.2 ppm (Gas 3 at reduced inlet pressure) to 144.0 ppm (Base Gas at increased inlet pressure).

Change in CO_2 & O_2 percentages remained negligible throughout the course of the test.



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

Cold Ignition Test

For each set-up gas (Base Gas and Gas 3), the appliance was turned "on" without any problems during all the ignition tests. After ignition, flames were stable and there was not 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 8)		
Gas	Start-Up #	Comment & Observation
Base	1	Normal and without delays
	2	Normal and without delays
	3	Normal and without delays
3	1	Normal and without delays
	2	Normal and without delays
	3	Normal and without delays

Hot Ignition Test

For each set-up gas (Base Gas and Gas 3), the appliance turned "on" without any problems during all ignition tests. After ignition, flames were stable and there was not 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 8)		
Gas	Start-Up #	Comment & Observation
Base	1	Normal and without delays
	2	Normal and without delays
	3	Normal and without delays
3	1	Normal and without delays
	2	Normal and without delays
	3	Normal and without delays

Appendix A: Test Protocol

1. Standards

ANSI Z21.5.1-2002 **CSA 7.1-2002**	Gas Clothes Dryers, Vol. I
SCAQMD Method 100.1	Instrumental analyzer procedure for continuous gaseous emissions

2. Gas Clothes Dryer Description

Description	Legacy Clothes Dryer
Burner	Induced Combustion System
Rated input	22,000 Btu/hr
Type of fuel	Natural Gas
Required gas supply pressure	4.5-10.5 in. w.c.
Required manifold supply pressure	3.0 in. w.c.

3. Test Arrangement

3.1. Basic Setup

The gas clothes dryer shall be connected to an exhaust duct, equal in length to the maximum length recommended by the manufacturer but not less than 14 feet of duct plus two 90 degree elbows. The exhaust duct static pressure shall be set at 0.30 inches water column, measured at one foot from the end of the exhaust duct. The appliance shall be installed with the minimum clearances specified by the manufacturer.

3.2. Clothing Load selection

Referenced protocol requires a load to consist of a suitable number of test clothes prepared from a white cotton fabric of uniform texture and permanent finish, having a warp of 55 threads per inch and a filling of 48 threads per inch and weighing approximately 0.33 pounds per square yard.

Due to time and feasibility constraints, it was determined that a realistic load would consist of five pairs of denim jeans. Three loads of jeans, of identical sizes and weight, were utilized for the purpose of this test. Denim jeans were a good selection for this test since they hold a fair amount of water; therefore, it can be assured the dryer's burner will remain ON during the selected thirty minute drying cycle.

4. Test Gases

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

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

Gas	**Wobbe Number** (Btu/cf)	**Heating Value** (Btu/cf)
Base	1,330 (Low Wobbe)	1,014 (Low heat content)
3	1,433 (Highest Wobbe)	1,150 (Highest heat content)
6	1,408 (High Wobbe)	1,106 (High heat content)
7	1,395 (High Wobbe)	1,142 (Highest heat content)
8	1,342 (Medium Wobbe)	1,066 (medium heat content)

5. Basic Operating Condition

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

5.1. Room temperature

Room temperature shall be maintained between 67 – 87°F. The temperature shall be determined by means of 4 J-Type thermocouples, the junctions of which are shielded from radiation. These thermocouple junctions shall be located so room temperature can be measured at points approximately 24 inches away from the approximate midpoints of each of the 4 sides of the appliance. 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. Drying Chamber Temperatures

The protocol requires a temperature indicator to be attached to the garments, to monitor that the chamber temperature does not exceed 240˚F. For simplification purposes, the chamber temperature was recorded by installing a thermocouple at the discharge of the chamber.

Drying cycle time was selected to be thirty minutes, which is equivalent to approximately 75% of the moisture being evaporated from the drying load.

5.3. Test Pressures and Burner Adjustments

Unless otherwise stated, all tests will be conducted at an inlet pressure of 8.0 ± 0.8 in. w.c and at the rated input of the appliance (within ± 5%). When operated for 15 minutes (starting with all parts of the appliance at room temperature) the burner adjustments shall be within ± 5% 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.

5.4. Burner Operating Characteristics

The gas from the main burners and ignition devices shall be effectively ignited without delayed ignition or flashback when turned on and off at an inlet pressure of 8.0 ± 0.8 in. w.c and at the rated input of the appliance (within ± 5%), 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.

5.5. Wall, Floor and Ceiling Temperatures

The temperatures on the surface of any exterior portion of the test wall in contact with the dryer shall not be more than 117˚F above room temperature, nor shall the temperature on the floor of the dryer be more than 90˚F above room temperature, when the appliance is operated as required in the following method of test.

5.6. Flue Gas Temperature

With the operating control dial set to the position for maximum temperature, an operating temperature control shall limit the temperature of the air and/or flue gases to not more than 250˚F.

5.7. 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 trends in the flame zone.

5.8. Limiting Devices

This test shall be conducted in accordance with section 2.10 of the ANSI Z21.5.1-2002.

5.9. Inlet and Manifold Pressures

Inlet pressure will be measured just before the boiler gas control and manifold pressure will be measured after the boiler gas control or at the supplied pressure taps.

5.10. 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 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**.**

6. Testing

6.1. Rated Input — Tuned with Base Gas

Operate the clothes dryer at an inlet pressure of 8.0 ± 0.8 in. w.c and at the rated input of the appliance (within ± 5%) with Base Gas. Start collecting temperature, pressure and emissions data while verifying proper operation of all equipment and instrumentation. Overall drying cycle shall be thirty minutes.

Continue steady dryer operation with Base Gas for a specified duration and conduct a high-speed switch to the first test gas. Place a new load of wet clothes in the dryer at each change from gas-to-gas. Record data before, during and after changeover and observe transient phenomena. Possible phenomena include flame flashback, yellow tipping, noise, instability or outage, etc.

With the dryer continuing to operate at steady state on the first test gas, conduct a high-speed switch to another test gas and record observations and data.

Conduct a high-speed switch to the Base Gas and record observations and data as indicated above. Continue testing by reestablishing steady state conditions with the Base Gas after two or three runs with test gases.

When testing has been conducted with all gases, shut down the dryer and examine flue collector and vent connection area for presence of soot by means of the swab technique. If soot is found, clean surfaces and repeat testing with suspect gas blend(s), selected on the basis of earlier yellow tipping observations, to establish which gas(es) deposited soot in the appliance.

6.2. Rated Input — Tuned with Gas 8

Tune the appliance with Gas 8 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

6.3. Reduced and Increased Pressure Test — Tuned with Base Gas & Gas 8

Based on the information from manufacturers, consultants and the requirements of the test standards, adjust the appliance to operate under and over the rated input. For this dryer, the under rate input should be achieved by reducing the inlet pressure to 3.5 in. w.c. The over rate input should be achieved by increasing the inlet pressure to 10.5 in. w.c. Since the manifold pressure remained unaffected by the change in inlet pressure, per ANZI protocol:

"When the manifold pressure at increased inlet test pressure is not greater than the manifold pressure at normal inlet test pressure, the tests at increased inlet test pressure need not be applied."

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 and flame lifting or 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 found, clean surfaces and repeat testing with suspect gas blend(s), selected on the basis of earlier yellow tipping observations, to establish which gas(es) deposited soot in the appliance.

7. **Ignition Tests**

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

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 8)

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

7.3. Hot Ignition Test (Tuned 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 cool 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 8)

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

8. Special tests

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

9. Additional Testing

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

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

Appendix B: Tables of Averages

Rated Input Test (Tuned w/ Base Gas)

Table of Averages Gas Clothes Dryer Rated Input Test (Tuned with Base Gas) March 23, 2006							
Gases	**Base**	**Base**	**3**	**6**	**7**	**8**	**Base**
HHV (Btu/cf)	1,024	1,014	1,150	1,106	1,142	1,066	1,009
Wobbe (Btu/cf)	1,338	1,328	1,433	1,408	1,395	1,342	1,324
Input Rate (Btu/hr)	21,364	20,817	22,787	22,228	22,124	21,447	21,330
Corrected Gas Flow (scfh)	20.9	20.7	19.8	20.1	19.4	20.1	21.1
Emissions (not from certified tests)							
O_2 (%)	17.1	17.1	16.6	16.6	16.5	17.1	16.9
CO_2 (%)	2.2	2.2	2.5	2.5	2.6	2.2	2.3
CO (ppm @ 0% O_2)	177.9	156.0	204.7	192.9	210.6	147.8	152.7
HC (ppm @ 0% O_2)	135.9	91.3	50.9	60.9	50.6	40.6	43.0
NO_X (ppm @ 0% O_2)	65.2	66.5	72.6	71.8	72.4	66.3	69.0
Ultimate CO_2 (%)	12.1	12.2	12.3	12.0	12.1	11.6	11.9
Equivalence Ratio (Φ)	0.20	0.20	0.22	0.22	0.23	0.20	0.21
Temperatures (°F)							
Ambient	75.1	75.6	75.2	74.5	74.2	73.8	73.6
Gas	74.9	75.8	74.9	74.2	73.9	73.7	73.2
Discharge Air	138.6	146.9	152.7	149.8	149.5	143.5	144.0
High Limit Switch	246.5	264.0	275.2	274.4	277.9	258.6	261.8
Thermostat	132.4	140.2	145.6	143.3	143.2	138.6	137.9
Drum Discharge	148.7	155.3	162.4	159.9	159.4	151.8	153.9
Average External Surface	97.3	103.9	105.8	104.1	104.5	103.2	101.0
Combustion Chamber	1,068	1,068	1,124	1,145	1,147	1,029	1,074
Combustion Air Intake	106.8	110.0	111.5	110.9	111.6	108.4	105.8
Rear Panel (Behind Firebox)	103.1	108.2	111.5	109.7	110.3	106.6	105.3
Pressures (in. w.c.)							
Inlet	8.2	8.2	8.1	8.1	8.1	8.2	8.2
Manifold	2.9	3.0	3.0	3.1	3.1	3.1	3.1
Drying Performance (30 minute cycle)							
Net Water Loss (lb)	4.9	5.1	5.3	5.3	5.3	4.9	5.1

Rated Input Test (Tuned w/ Gas 8)

Table of Averages Gas Clothes Dryer Rated Input Test (Tuned with Gas 8) April 28, 2006							
Gases	**8**	**8**	**Base**	**6**	**7**	**3**	**8**
HHV (Btu/cf)	1,066	1,066	1,011	1,106	1,142	1,150	1,066
Wobbe (Btu/cf)	1,342	1,342	1,326	1,408	1,395	1,433	1,342
Input Rate (Btu/hr)	20,712	20,633	20,397	21,738	21,458	22,079	20,746
Corrected Gas Flow (scfh)	19.4	19.2	20.2	19.7	18.8	19.2	19.5
Emissions (not from certified tests)							
O_2 (%)	15.6	15.6	15.7	15.3	15.2	15.1	15.6
CO_2 (%)	3.13	3.10	3.00	3.29	3.40	3.46	3.13
CO (ppm @ 0% O_2)	180.9	179.5	162.2	185.5	199.9	222.0	162.1
HC (ppm @ 0% O_2)	51.1	51.1	84.4	41.3	37.2	35.7	34.7
NO_X (ppm @ 0% O_2)	66.4	66.2	63.9	69.1	69.3	70.4	68.5
Ultimate CO_2 (%)	12.4	12.3	12.2	12.3	12.5	12.5	12.3
Equivalence Ratio (Φ)	0.27	0.27	0.27	0.29	0.29	0.30	0.28
Temperatures (°F)							
Ambient	74.3	74.1	74.3	74.9	74.9	74.9	74.4
Gas	78.9	79.7	79.7	79.5	79.9	80.0	80.0
Discharge Air	148.5	148.6	148.3	152.6	153.5	155.7	150.2
High Limit Switch	261.4	257.8	252.5	268.2	268.8	273.0	255.7
Thermostat	139.9	140.3	140.3	143.6	143.7	145.9	140.8
Drum Discharge	155.7	155.2	155.1	159.6	160.7	163.0	156.7
Average External Surface	101.5	102.5	102.9	105.3	104.6	106.6	104.4
Combustion Chamber	1,298	1,288	1,233	1,330	1,337	1,356	1,298
Combustion Air Intake	108.0	108.3	108.9	111.9	111.8	112.2	109.0
Rear Panel (Behind Firebox)	116.0	116.0	115.0	118.2	118.4	120.5	115.5
Pressures (in. w.c.)							
Inlet	8.3	8.3	8.3	8.2	8.3	8.2	8.3
Manifold	2.7	2.7	2.7	2.7	2.7	2.7	2.7
Drying Performance (30 minute cycle)							
Net Water Loss (lb)	5.0	5.1	5.0	5.3	5.2	5.4	5.0

Reduced & Increased Inlet Pressure Tests (Tuned w/ Gas 8 & Base Gas)

Table of Averages Gas Clothes Dryer Reduced & Increased Inlet Pressure Test (Tuned w/ Gas 8 & Base Gas) March 27, 2006								
Gases	**Tuned w/ Gas 8**				**Tuned w/ Base Gas**			
	Incr. Inlet Pressure (10.5 in. w.c.)		**Red. Inlet Pressure (3.5 in. w.c.)**		**Incr. Inlet Pressure (10.5 in. w.c.)**		**Red. Inlet Pressure (3.5 in. w.c.)**	
	Base	**Gas 3**	**Gas 3**	**Base**	**Base**	**Gas 3**	**Gas 3**	**Base**
HHV (Btu/cf)	1,009	1,150	1,150	1,009	1,009	1,150	1,150	1,009
Wobbe (Btu/cf)	1,325	1,433	1,433	1,325	1,325	1,433	1,433	1,325
Input Rate (Btu/hr)	19,758	22,741	20,965	19,860	20,954	23,197	21,794	20,420
Corrected Gas Flow (scfh)	19.6	19.8	18.2	19.7	20.8	20.2	19.0	20.2
Emissions (not from certified tests)								
O_2 (%)	17.4	16.8	16.9	17.3	17.1	16.8	17.3	17.2
CO_2 (%)	2.0	2.3	2.3	2.1	2.2	2.4	2.1	2.1
CO (ppm @ 0% O_2)	147.5	176.0	175.4	127.7	133.1	189.4	165.5	123.3
HC (ppm @ 0% O_2)	172.2	116.5	121.1	167.0	144.0	105.9	86.2	108.7
NO_X (ppm @ 0% O_2)	84.9	87.9	87.2	87.2	86.4	89.6	78.3	85.5
Ultimate CO_2 (%)	11.9	11.9	12.1	12.0	12.1	12.2	12.8	12.1
Equivalence Ratio (Φ)	0.18	0.21	0.21	0.19	0.20	0.21	0.19	0.19
Temperatures (°F)								
Ambient	72.5	73.1	72.5	72.9	72.9	72.2	72.8	72.7
Gas	75.2	75.4	75.2	75.4	75.2	75.3	75.5	75.4
Discharge Air	131.3	143.0	143.1	140.3	133.8	142.5	142.5	142.1
High Limit Switch	220.6	255.4	252.8	242.0	253.0	257.2	250.0	246.4
Thermostat	126.3	136.0	136.5	134.3	128.4	135.9	136.2	136.5
Drum Discharge	137.6	153.4	153.0	148.8	143.7	153.6	151.8	150.8
Average External Surface	96.8	97.2	98.1	97.7	96.0	97.7	99.6	99.1
Combustion Chamber	1,019	1,180	1,109	1,028	1,073	1,173	1,162	1,041
Combustion Air Intake	104.2	107.0	106.4	105.7	105.0	106.6	106.9	106.2
Rear Panel (Behind Firebox)	95.1	102.5	101.8	99.8	100.9	102.3	102.1	100.7
Pressures (in. w.c.)								
Inlet	10.5	10.5	3.5	3.5	10.5	10.5	3.5	3.5
Manifold	2.9	2.8	2.8	2.6	2.9	2.9	2.6	2.7

Appendix C: Test Gases

Gas Sample Date	**Baseline** 4/28/2006	**3** 7/1/2005	**6** 7/1/2005	**7** 6/20/2005	**8** 8/5/2005
COMPONENTS	**MolPct**	**MolPct**	**MolPct**	**MolPct**	**MolPct**
C6 + 57/28/14	0.000	0.000	0.000	0.023	0.001
NITROGEN	0.491	0.128	0.274	3.025	3.839
METHANE	95.492	86.549	91.168	86.466	89.998
CARBON DIOXIDE	1.081	0.035	0.003	0.034	0.120
ETHANE	2.226	9.480	5.747	0.312	0.000
PROPANE	0.473	2.725	1.727	9.946	5.997
i-BUTANE	0.080	1.034	0.534	0.094	0.041
n-BUTANE	0.085	0.000	0.531	0.061	0.000
NEOPENTANE	0.000	0.000	0.000	0.000	0.000
i-PENTANE	0.027	0.000	0.000	0.019	0.001
n-PENTANE	0.019	0.000	0.000	0.016	0.001
OXYGEN	0.000	0.049	0.016	0.004	0.003
TOTAL	**100.000**	**100.000**	**100.000**	**100.000**	**100.000**
Compressibility Factor	0.9979	0.9972	0.9975	0.9971	0.9976
HHV (Btu/real cubic foot)	**1014.00**	**1150.00**	**1106.00**	**1142.00**	**1066.30**
LHV (Btu/real cubic foot)	995.00	1039.90	998.90	1033.40	963.10
Specific Gravity	0.5810	0.6442	0.6167	0.6697	0.6312
WOBBE Index	**1330.30**	**1432.81**	**1408.37**	**1395.49**	**1342.13**

Appendix D: Zero, Span and Linearity Tables

Rated Input Test (Tuned w/ Base Gas)

	Zero, Span & Linearity Data Legacy Clothes Dryer Rated Input (Tuned w/ Base Gas) March 23, 2006	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 - 10:27:00 AM	-0.01	0.08	1.39	-0.58	-0.04
Zero	Zero Drift Check - 3:33:30 PM	-0.04	0.03	-0.18	-0.05	-0.01
Zero	**Total Drift Over Test Period**	**0.03**	**0.05**	**1.57**	**0.53**	**0.03**
Zero	**Was the Zero Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Span	**Span Calibration Gas (High-Range Values)**	**20.19**	**11.99**	**181.00**	**443.00**	**85.19**
Span	**Allowable Span Drift (Less Than ± 3% of Range)**	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
Span	Span Calibration - 10:28:50 AM	20.19	12.05	181.60	442.93	84.26
Span	Span Drift Check - 3:26:10 PM	20.15	11.91	183.26	437.40	84.80
Span	**Total Drift Over Test Period**	**0.04**	**0.14**	**1.66**	**5.53**	**0.54**
Span	**Was the Span Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**8.97**	**9.22**	**82.00**	**443.00**	**44.70**
Linearity	**Allowable Linearity Drift (Less Than ±1% of Range)**	**0.25**	**0.20**	**2.00**	**10.00**	**1.00**
Linearity	Linearity Check - 10:30:20 AM	8.97	9.39	71.27	442.68	45.35
Linearity	**Difference From Mid-Range Values**	**0.00**	**0.17**	**10.73**	**0.32**	**0.65**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**Yes**	**No**	**Yes**	**Yes**
Linearity	Linearity Check - 3:30:50 PM	8.94	9.27	81.40	438.06	45.98
Linearity	**Difference From Mid-Range Values**	**0.03**	**0.05**	**0.60**	**4.94**	**1.28**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**No**

Rated Input Test (Tuned w/ Gas 8)

	Zero, Span & Linearity Data Legacy Clothes Dryer Rated Input (Tuned w/ Gas 8) April 28, 2006	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 - 7:36:55 PM	0.00	0.00	0.10	0.00	0.00
Zero	Zero Drift Check - 12:11:27 PM	0.00	0.00	0.20	0.00	0.00
Zero	**Total Drift Over Test Period**	**0.00**	**0.00**	**0.10**	**0.00**	**0.00**
Zero	**Was the Zero Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Span	**Span Calibration Gas (High-Range Values)**	**20.19**	**12.15**	**181.00**	**443.00**	**84.50**
Span	**Allowable Span Drift (Less Than ± 3% of Range)**	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
Span	Span Calibration - 7:46:51 AM	20.20	12.20	181.30	443.90	84.40
Span	Span Drift Check - 12:00:47 PM	20.20	12.20	181.90	442.00	84.60
Span	**Total Drift Over Test Period**	**0.00**	**0.00**	**0.60**	**1.90**	**0.20**
Span	**Was the Span Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**8.97**	**9.22**	**82.00**	**443.00**	**44.70**
Linearity	**Allowable Linearity Drift (Less Than ±1% of Range)**	**0.25**	**0.20**	**2.00**	**10.00**	**1.00**
Linearity	Linearity Check - 7:55:23 AM	8.90	9.40	81.20	443.30	43.70
Linearity	**Difference From Mid-Range Values**	**0.07**	**0.18**	**0.80**	**0.30**	**1.00**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**No**
Linearity	Linearity Check - 12:08:33 PM	8.90	9.30	81.80	441.50	44.50
Linearity	**Difference From Mid-Range Values**	**0.07**	**0.08**	**0.20**	**1.50**	**0.20**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

Reduced & Increased Inlet Pressure Tests - (Tuned w/ Gas 8 & Base Gas)

	Zero, Span & Linearity Data Legacy Clothes Dryer Input Pressure Test (Tuned w/ Gas 8 & Base Gas) March 27, 2006	**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 - 2:20:20 PM	-0.03	0.09	-1.92	-0.30	-0.04
Zero	Zero Drift Check - 3:35:30 PM	-0.05	0.08	-1.66	-0.29	0.05
Zero	**Total Drift Over Test Period**	**0.02**	**0.01**	**0.26**	**0.01**	**0.09**
Zero	**Was the Zero Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Span	**Span Calibration Gas (High-Range Values)**	**20.19**	**11.99**	**181.00**	**443.00**	**85.19**
Span	**Allowable Span Drift (Less Than ± 3% of Range)**	**0.75**	**0.60**	**6.00**	**30.00**	**3.00**
Span	Span Calibration - 2:11:00 PM	20.11	11.99	180.22	444.29	84.43
Span	Span Drift Check - 3:31:00 PM	20.12	12.01	180.31	443.89	84.37
Span	**Total Drift Over Test Period**	**0.01**	**0.02**	**0.09**	**0.40**	**0.06**
Span	**Was the Span Drift Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Linearity	**Linearity Calibration Gas (Mid-Range Values)**	**8.97**	**9.22**	**82.00**	**443.00**	**44.70**
Linearity	**Allowable Linearity Drift (Less Than ±1% of Range)**	**0.25**	**0.20**	**2.00**	**10.00**	**1.00**
Linearity	Linearity Check - 2:17:10 PM	8.91	9.35	82.42	443.08	44.29
Linearity	**Difference From Mid-Range Values**	**0.06**	**0.13**	**0.42**	**0.08**	**0.41**
Linearity	**Was the Linearity Within Allowable Deviation?**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

<u>Appendix E:</u> Calculations

Emission Concentrations

Corrected to O_2 Standard (0% O_2)

$$\text{CO, HC \& NO}_x \text{ Concentrations (corrected to 3\% O}_2) = \text{Raw Concentrations (ppm)} \times \left[\frac{20.9 - 0}{20.9 - \%\,O_2} \right]$$

Where

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

% O_2 = Measured O_2 Concentration

Ultimate CO_2

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

Where

Raw CO_2 = Measured CO_2 Concentration (%)

Raw O_2 = Measured O_2 Concentration (%)

% Excess Air

To determine the % Excess Air, the theoretical air and theoretical flue gas values for each gas tested must be calculated. The table 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).

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

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

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

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

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

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

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

Equivalence Ratio (ϕ)

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

Gas Meter Accuracy Table

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

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

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

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

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

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

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

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

Actual Gas Flow with Meter Correction (acfh)

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

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

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

Manipulating the right side of the equation algebraically:

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

The equation would then simplify into:

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

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

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

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

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

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

Corrected Gas Flow (scfh)

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

Where

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

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

P_{Fuel} = Natural gas 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

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

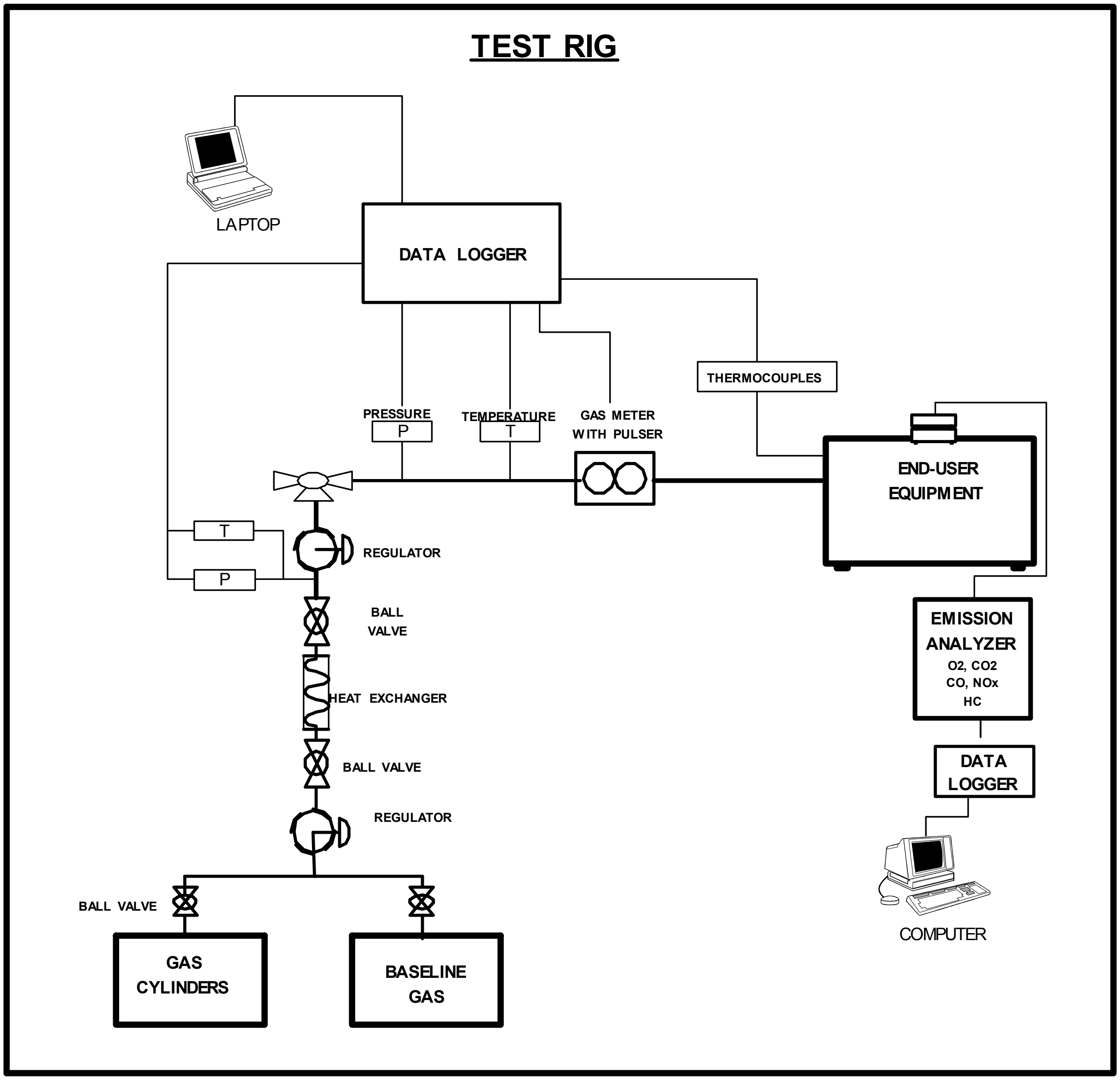
Emissions Analyzer				
Analyzer	**Manufacturer**	**Model**	**Type**	**Accuracy**
NO/NO_X	California Analytical Instruments, Inc.	650	Chemiluminescent	± 1% of full scale
CO	Thermo Environmental Instruments Inc.	48	Nondispersive infrared (NDIR) gas analyzer	± 1% of full scale
CO_2	Fuji	ZRH	Nondispersive 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	± 2%
NO/NO_X	Matheson Tri Gas	Certified Master Class	± 2%
CO	Matheson Tri Gas	Certified Master Class	± 2%
CO_2	Matheson Tri Gas	Certified Master Class	± 2%
HC	Scott Specialty Gases	Certified Master Class	± 2%
O_2	Scott Specialty Gases	Certified Master Class	± 2%

Test Equipment			
Equipment	**Manufacturer**	**Model**	**Accuracy**
Datalogger	Delphin	D51515	n/a
Gas Chromatograph	Agilent	6890	± 0.5 BTU/scf
K	Omega Engineering Co.	KMQSS	2.2°C or 0.75%
J	Omega Engineering Co.	JMQSS	2.2°C or 0.75%
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
Water Temperature Mixing Valve	Powers	434	n/a

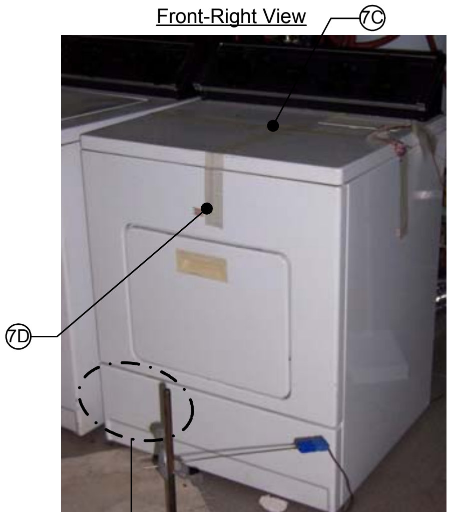
Appendix G: Test Set-Up/Schematic

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

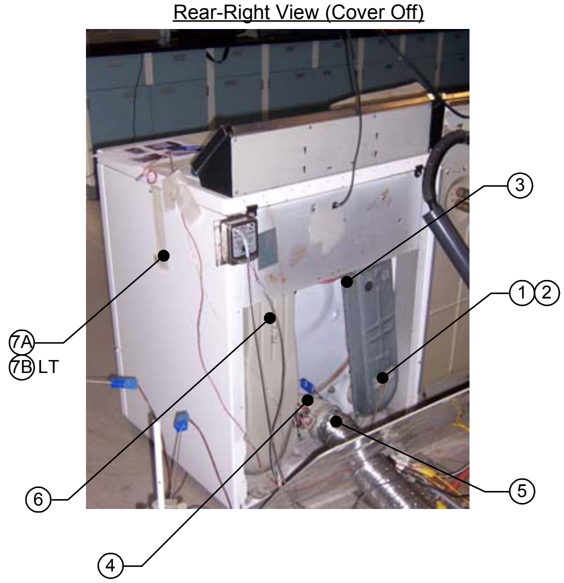


Appendix H: Test Set-Up Description

Front-Right View

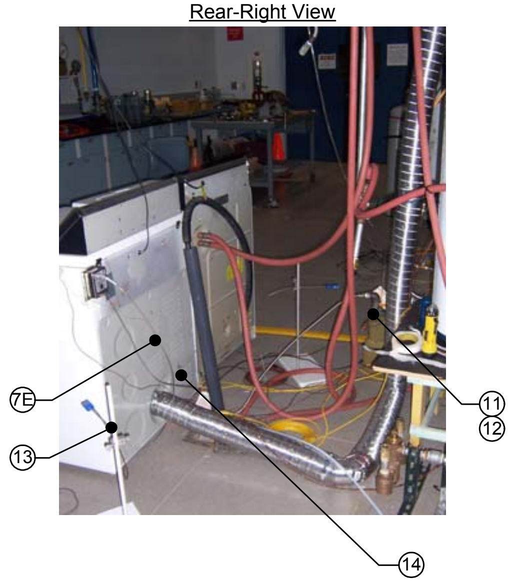


Rear-Right View (Cover Off)



Detail: Combustion Chamber

Rear-Right View



KEY NOTES:

1. Emissions Probe
2. Firebox Temperature
3. High Limit Temperature Switch
4. Thermostat Temperature
5. Discharge Air Temperature
6. Drum Discharge Air Temperature
7. 7A-7E: Average External Surface Temperature
8. Combustion Chamber Temperature
9. Combustion Air Intake
10. Manifold Pressure
11. Gas Inlet Temperature
12. Inlet Pressure
13. Average Ambient Temperature
14. Rear Panel Temperature (Behind Firebox)