LNG RESEARCH STUDY - PHASE 1

TESTING OF A SMALL LOW NO_X BOILER

The Southern California Gas Company

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Prepared by:

Engineering Analysis Center – Applied Technologies

Jorge H. Gutierrez

Andre R. Saldivar

Juan R. Mora

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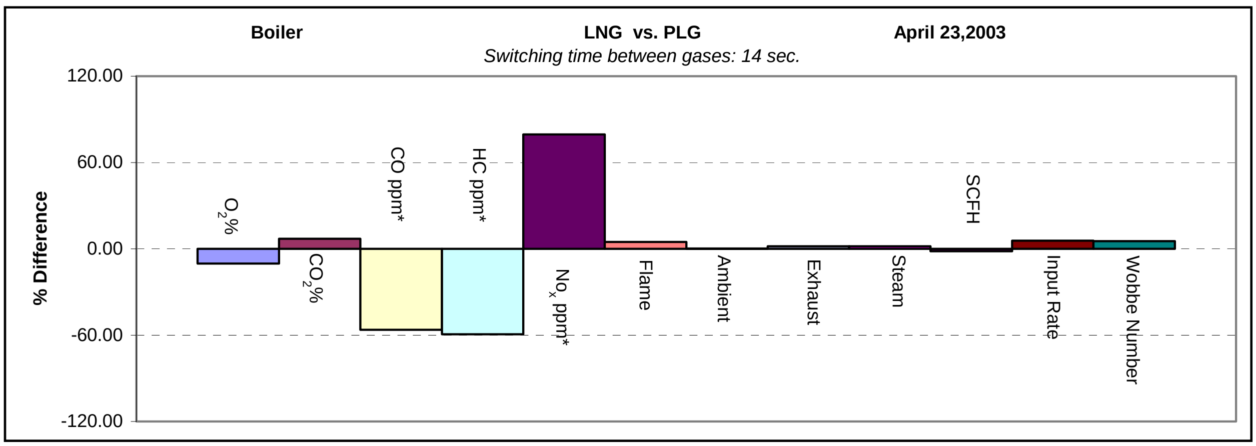
Results Summary

When the LNG was introduced the NO_x increased from 15 to 27 (ppm @ 3% O_2), which approaches the limit for this type of equipment by the SCAQMD (30 ppm @ 3% O_2). The CO and HC decreased 56% and 59% respectively. Combustion was stable; the flame was a little yellow, but not yellow tipping while running on LNG. The following graph and table depict the tests results.

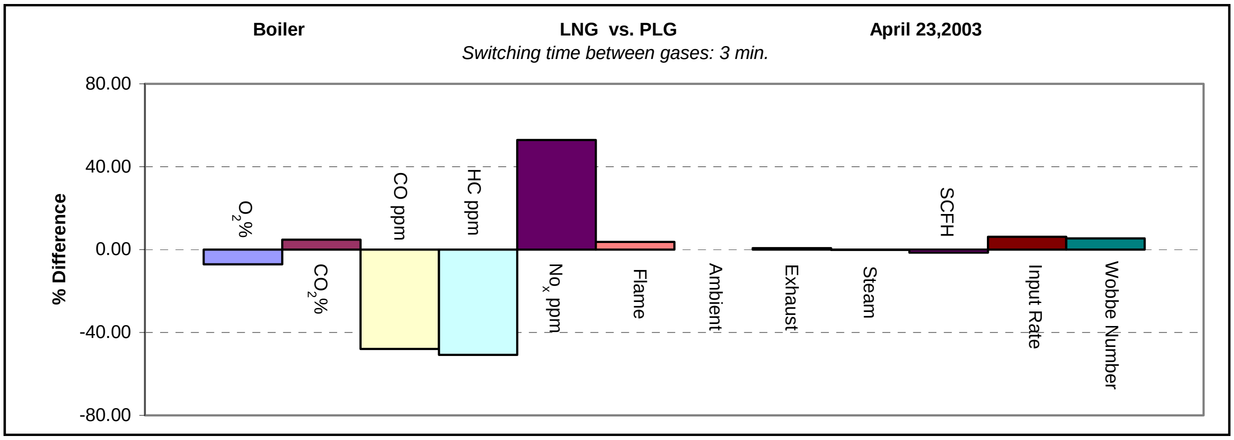


Boiler Data (April 23, 2003) - Switching time between gases: 14 sec.												
	EMISSIONS					TEMPERATURES (°F)				GAS INPUT		
	O_2%	CO_2%	CO* ppm	HC* ppm	NO_x* ppm	Flame	Ambient	Exhaust Gases	Steam	SCFH	Input Rate (Btu/cf)	Wobbe Number (Btu/cf)
LNG 9:33 - 9:48 AM	7.2	8.0	23.8	20.8	27.4§	2307	72.7	478.0	263.7	614.9	678233	1410
PLG 9:48 - 10:03 AM	8.0	7.5	53.8	50.6	15.4	2212	72.6	472.1	256.7	608.3	623813	1339
LNG 10:03 - 10:18 AM	7.2	8.0	24.1	21.5	27.7§	2316	73.0	479.5	256.7	582.1	642069	1410
PLG 10:18 - 10:33 AM	8.0	7.5	55.6	53.4	15.3	2201	72.7	469.1	255.3	609.2	624959	1339
% Difference	-10.33	6.98	-56.23	-59.30	79.47	4.77	0.27	1.73	1.64	-1.68	5.73	5.26

*** Corrected to 3% O_2**
§ Approaching SCAQMD NO_x limit of 30 ppm @ 3% O_2

Figure 1: LNG vs. PLG (top) & **Table 1:** Average Values (bottom)

To determinate if switching time between gases made any difference to the boiler performance, the tests were repeated slowing switching time from 14 seconds to 3 minutes. The only difference in test results was boiler took longer to reach steady conditions.



Boiler Data (April 23, 2003) - Switching time between gases: 3 min.												
	EMISSIONS					TEMPERATURES (°F)				GAS INPUT		
	O_2%	CO_2%	CO* ppm	HC* ppm	NO_x* ppm	Flame	Ambient	Exhaust	Steam	SCFH	Input Rate (Btu/cf)	Wobbe Number (Btu/cf)
LNG 10:48 - 11:03 AM	7.3	7.9	26.3	23.9	26.2§	2304	72.6	475.2	258.0	615.5	678949	1410
PLG 11:03 - 11:18 AM	7.9	7.6	50.3	48.5	17.2	2224	72.4	473.3	259.3	606.7	621177	1338
LNG 11:18 - 11:33 AM	7.3	7.9	26.2	23.8	26.4§	2310	72.2	477.2	259.8	580.3	640094	1410
% Difference	-7.17	4.78	-47.89	-50.86	52.95	3.74	0.03	0.60	-0.15	-1.44	6.17	5.36

*** Corrected to 3% O_2**
§ Approaching SCAQMD NO_x limit of 30 ppm @ 3% O_2

Figure 2: LNG vs. PLG (top) & **Table 2:** Average Values (bottom)

Equipment Selection Criteria

This unit was selected because it has a low NO_x atmospheric burner that is very sensitive to changes in the gas manifold pressure, wind draft and other environmental factors. The manufacturer and industry experts were concerned that with such a sensitive burner this boiler may be more susceptible to safety, emissions or operational problems with richer gases. In addition, it has been challenging for the manufacturers of low NO_x boilers to meet Rule 1146.2 from the SCAQMD while adhering to sections of both the Gas-Fired Low Pressure Steam and Hot Water Boilers standard (ANSI Z21.13) and/or UL–795 from the Underwriters Laboratory. SCAQMD Rule 1146.2 controls the NO_x from natural gas boilers to 30 ppm @ 3% O_2. The ANSI Z21.13 and UL standards cover safety, construction and performance. Under both standards the performance section has a combustion test that limits the CO emissions to 400 ppm air free.

Equipment Specifications

Horse Power: 9.5 HP

Type of Boiler: Steam

Maximum Steam Pressure: 90 psig

Maximum Input Rating: 400,000 Btu/hr

Installation

The boiler was installed by the manufacturer according to their specifications. The outlet steam valve was adjusted to maintain approximately 80 psig inside the boiler, allowing the boiler to run without opening the pressure relive valve. Thermocouples were installed to measure flame, make up water, steam, flue gas, ambient and gas temperatures and pressure transducers were installed to measure manifold, skid, supply and steam pressures inside the boiler. A gas meter was installed to measure the gas flow and an emissions probe was installed in the flue vent of the boiler.

Test Method

1. All emissions analyzers were calibrated.
2. The boiler was turned “on” and allowed to reach steady state conditions using PLG.
3. Outlet steam valve was adjusted to maintain around 80 psig inside the boiler.
4. Data loggers were synchronized and temperatures, pressures and gas flow readings were verified.
5. The gas supply was switched to LNG in 14 seconds. Emissions, pressures, temperatures and gas usage were monitored and recorded for 15 minutes.
6. The gas supply was switched to PLG in 14 seconds. Emissions, pressures, temperatures and gas usage were monitored and recorded for 15 minutes.
7. Steps 5 and 6 were repeated twice.
8. Steps 5, 6 and 7 were repeated for a gas switching time of 3 minutes.
9. Drift inspections were performed on all emissions analyzers.

Results

Emissions Data

Switching Time: 14 Seconds - When LNG was introduced, NO_x emissions values increased from 15 to 27 (ppm @ 3% O_2) - approaching the limit of 30 (ppm @ 3% O_2) established by the SCAQMD. The average CO and HC emissions values decreased 56% and 59% respectively. The figure below depicts the tests results.

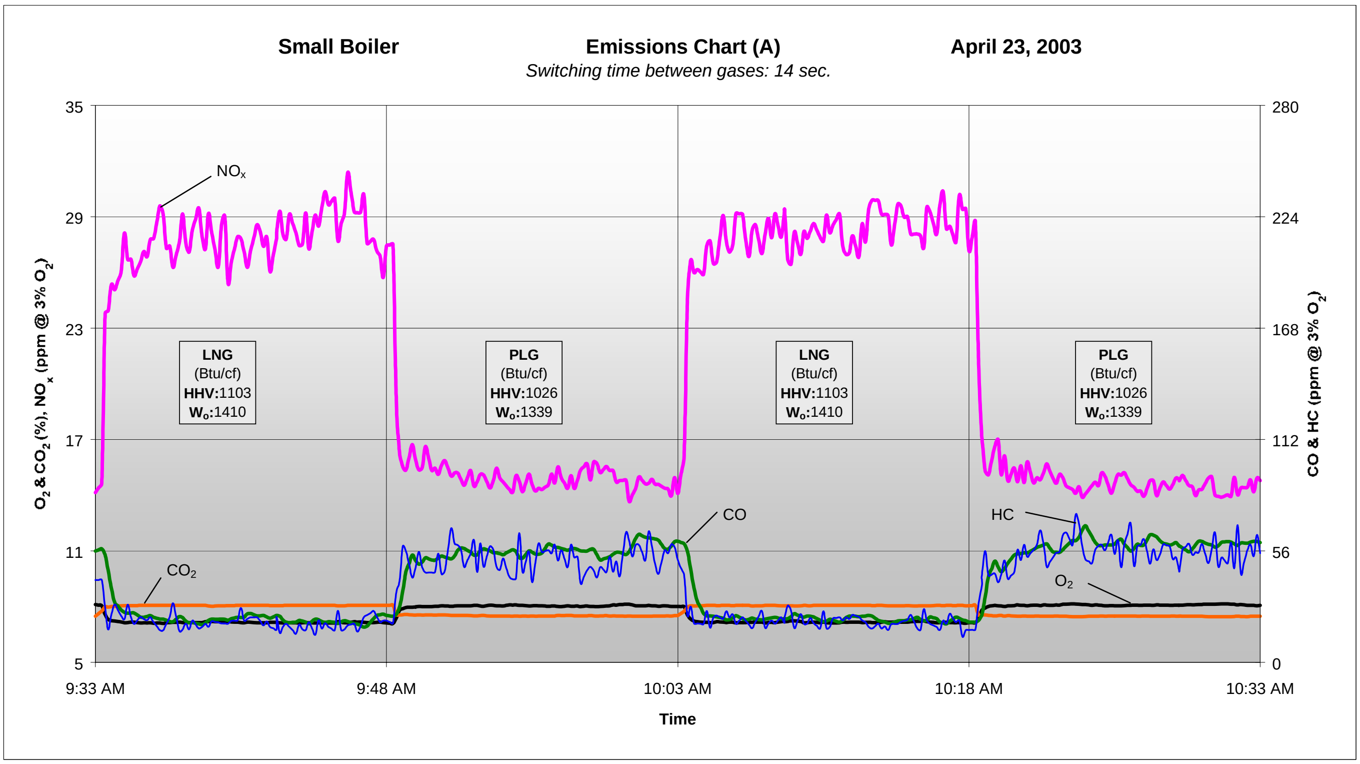


Figure 3

Switching Time: 3 minutes – Slowing down the switching time between gases only increased the time necessary for the boiler to reach steady-state conditions, but the final results were very similar when switching the gases in 14 seconds. LNG increased the NO_x after a few minutes from 17 to 26 (ppm @ 3% O_2), which approaches the limit for this equipment from the SCAQMD (30 ppm @ 3% O_2). The CO and HC decreased 48% and 51% respectively. Combustion was stable, the flame was a little yellow but not yellow tipping while running on LNG. The figure below depicts the tests result.

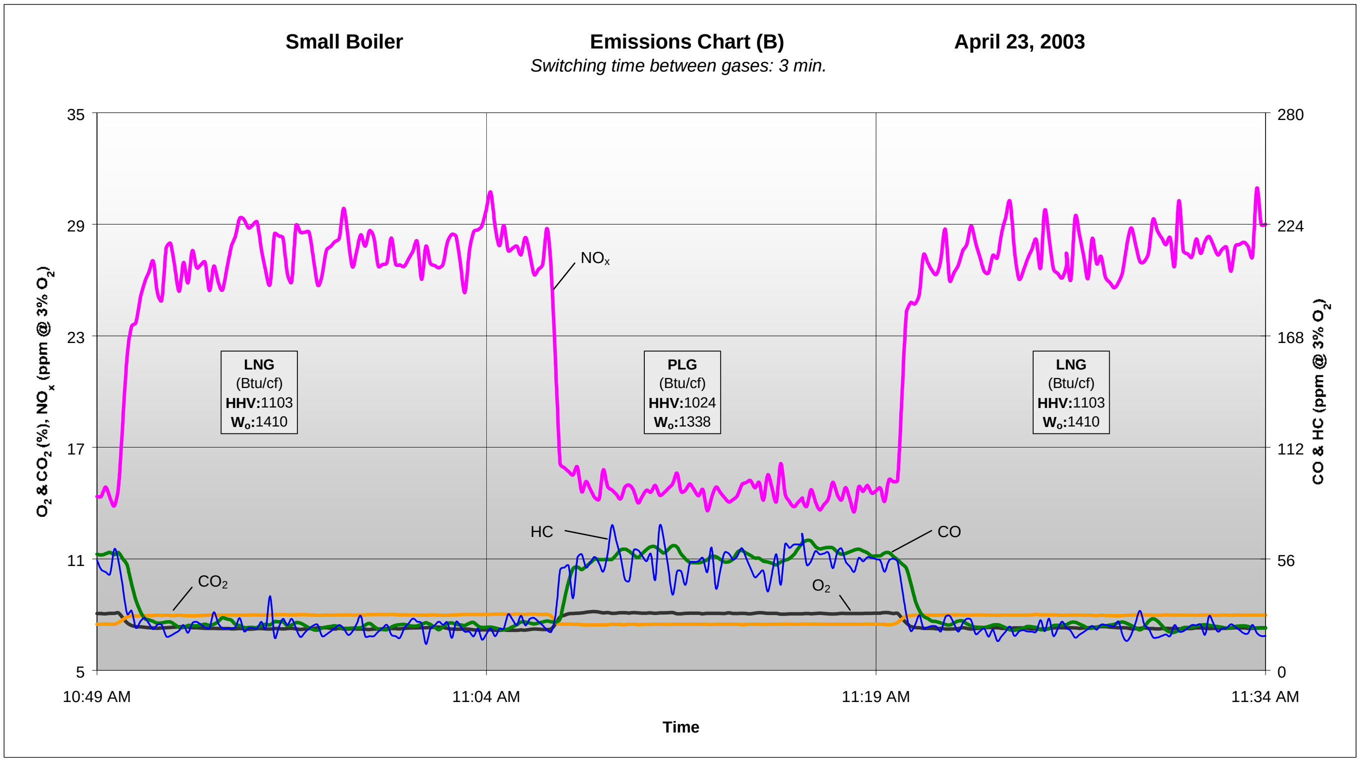
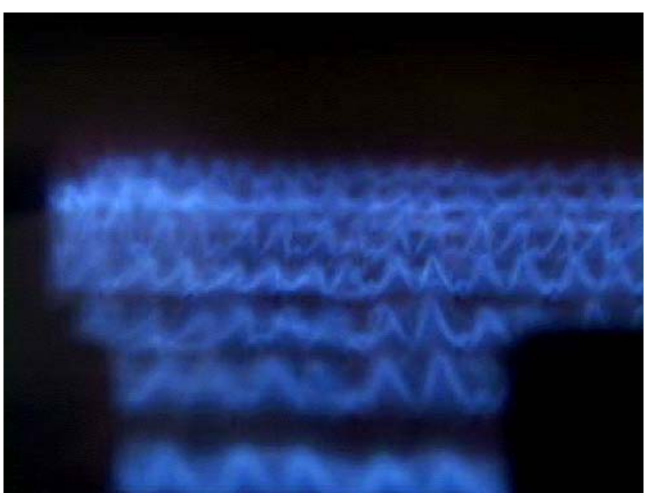


Figure 4

Below are pictures taken of the boiler burners during a test run. On PLG (Fig. 4), the flame maintained a blue color. However, when LNG was introduced (Fig. 5), the flame had a yellow color throughout most of the run but it was not yellow tipping.



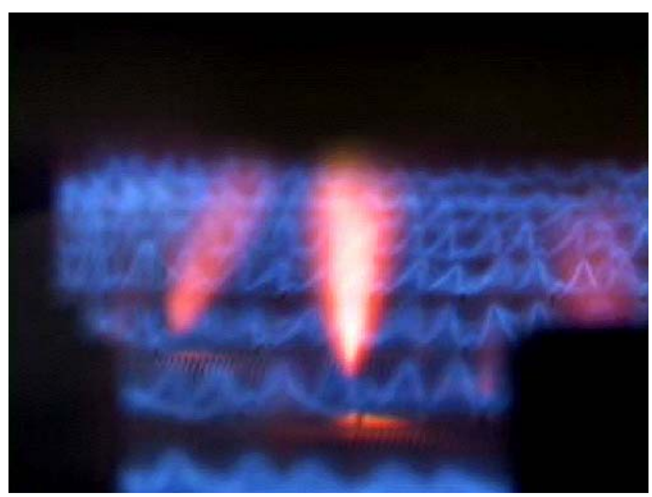


Figure 5: Flame using PLG (left) & **Figure 6:** Flame using LNG (right).

Temperature Data

The temperatures followed the same pattern on both the 14 seconds and the 3 minutes tests. On LNG and PLG the exhaust, flame and ambient temperatures remained very constant during the entire test. On LNG the temperature of the combustion area increased by 5 % and the gas temperature decrease gradually. The gas temperature decreased due to the pressure drop through the two-stage regulator. This also affected the gas temperature during the first half of the PLG test, because the regulators and piping were cooled considerably while running on LNG. Results are illustrated below.

Switching Time: 14 Seconds

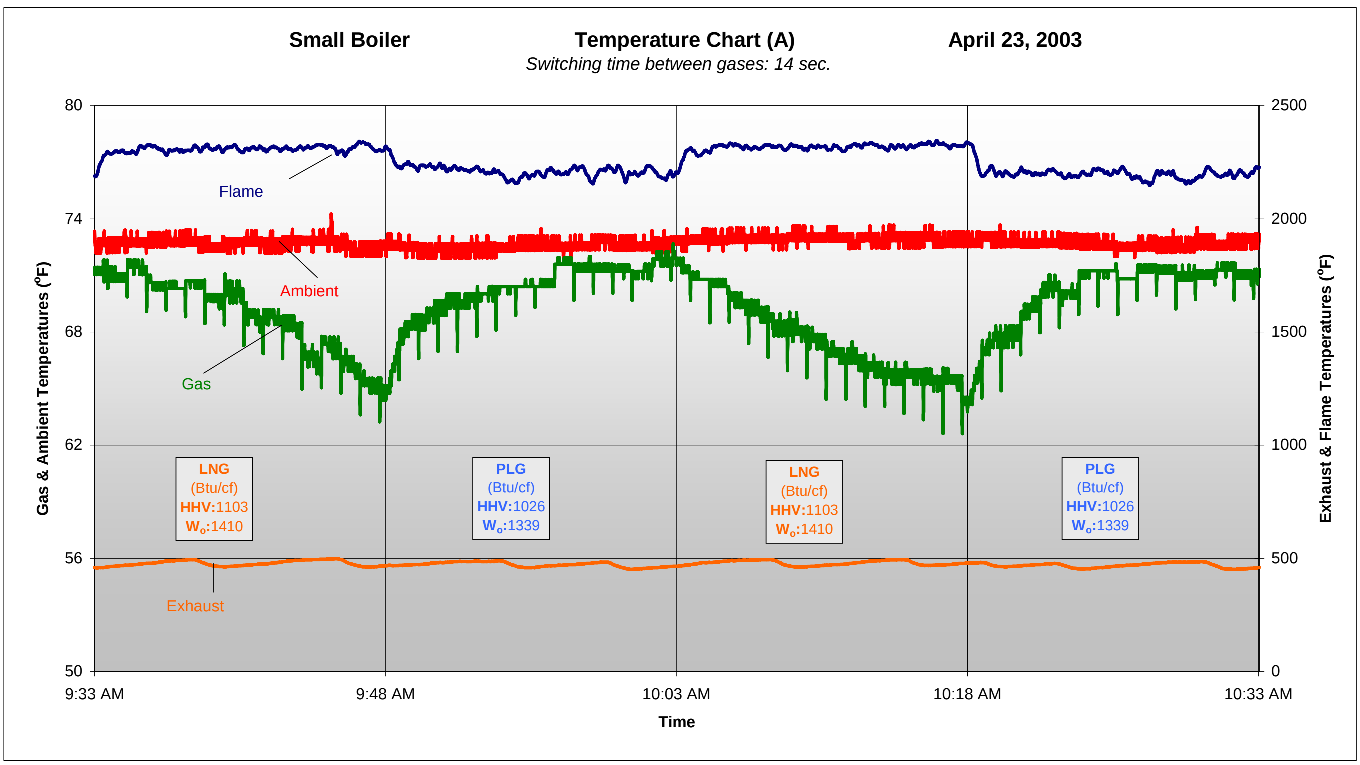


Figure 7

Switching Time: 3 minutes

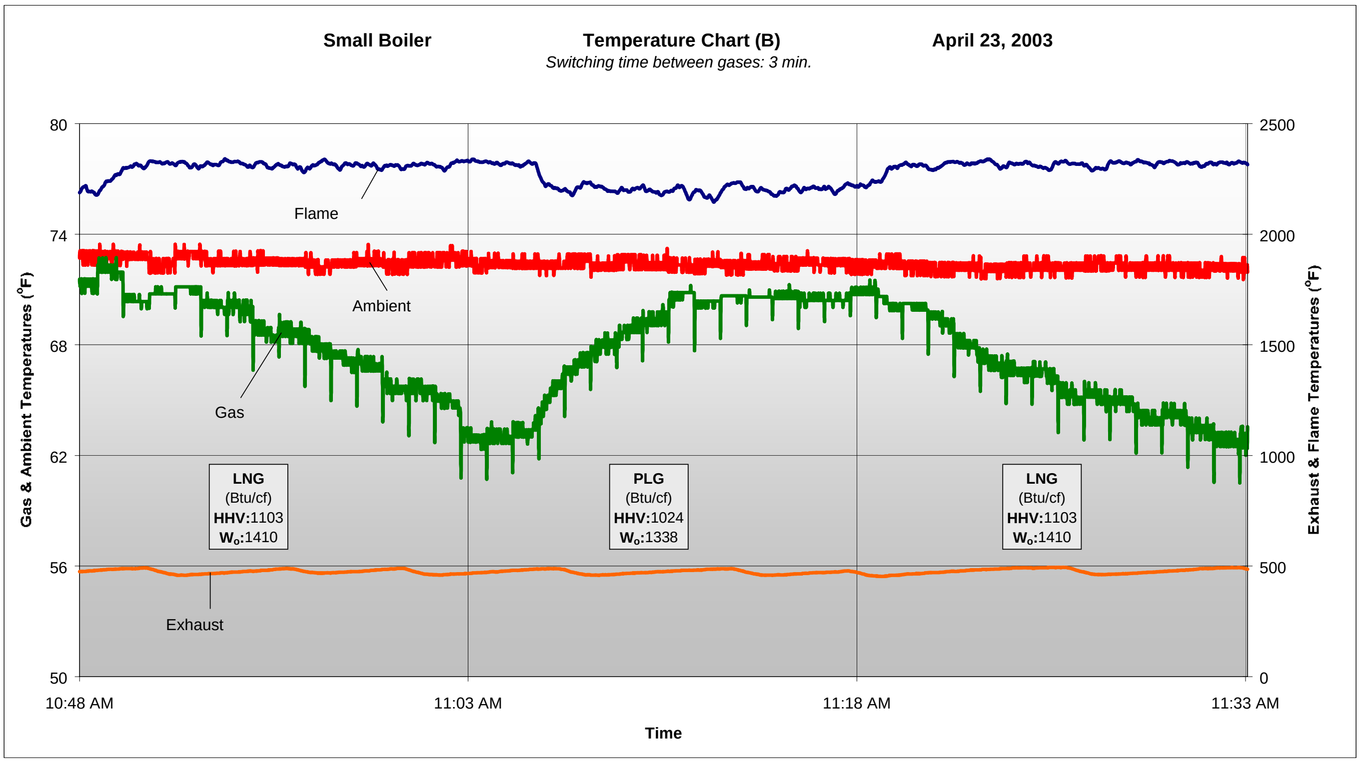


Figure 8

Input Data

For both tests the small changes in the supply pressure are due to adjustments made to maintain a constant manifold pressure or because a new gas cylinder was installed. These small changes in the manifold pressure didn't affect the manifold pressure, which remained constant throughout the tests. Results are illustrated below.

Switching Time: 14 Seconds

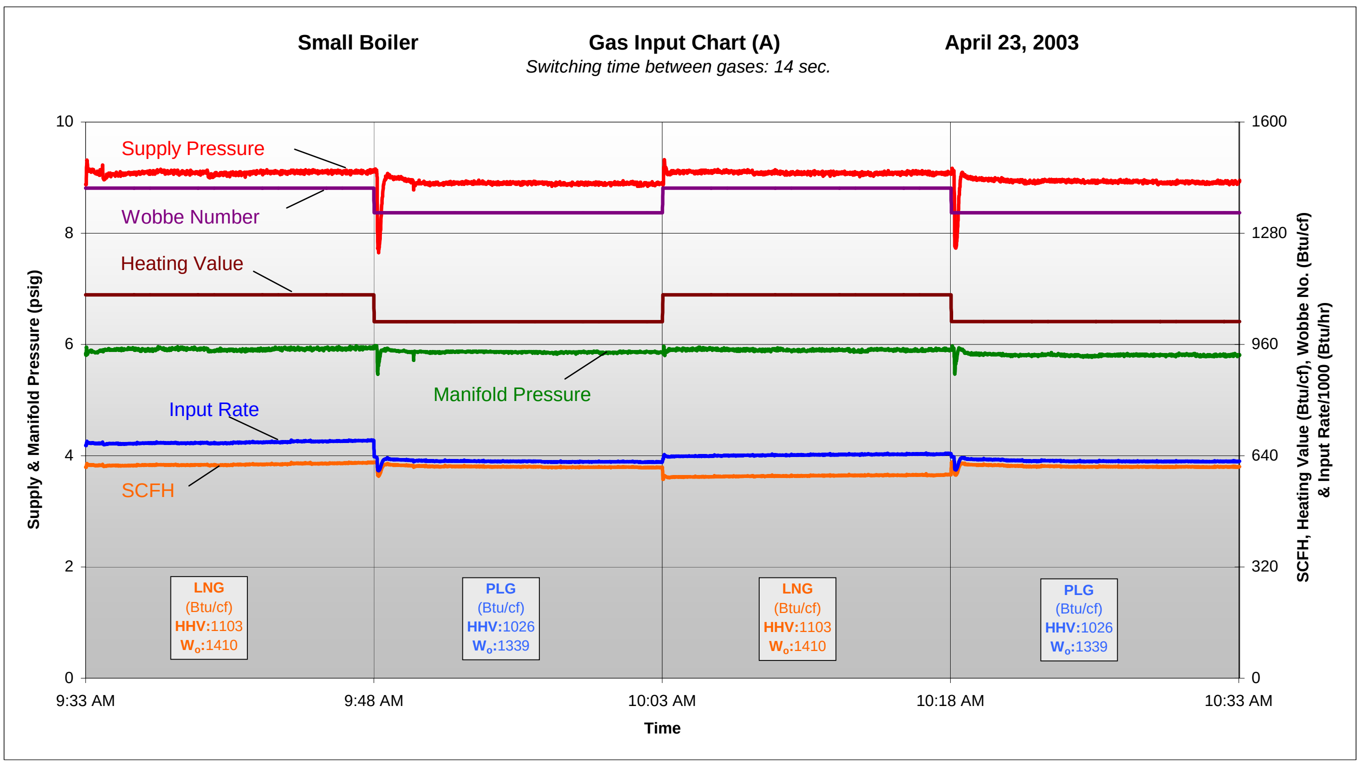


Figure 9

Switching Time: 3 minutes

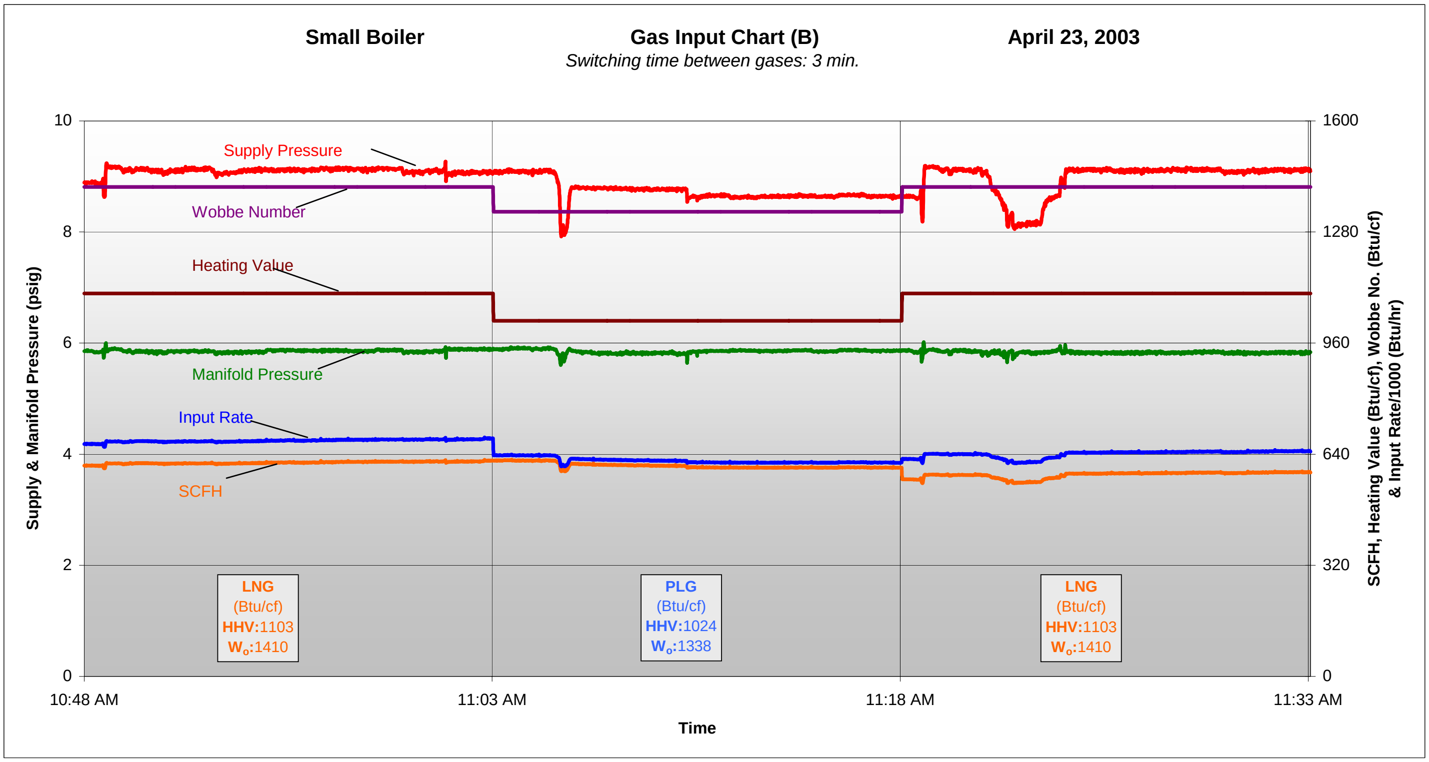


Figure 10

Boiler Performance Data

Comparisons between the LNG and PLG intervals all showed small increases in average steam temperature, and average boiler and outlet steam pressure when LNG was introduced. Results are illustrated below.

Switching Time: 14 Seconds

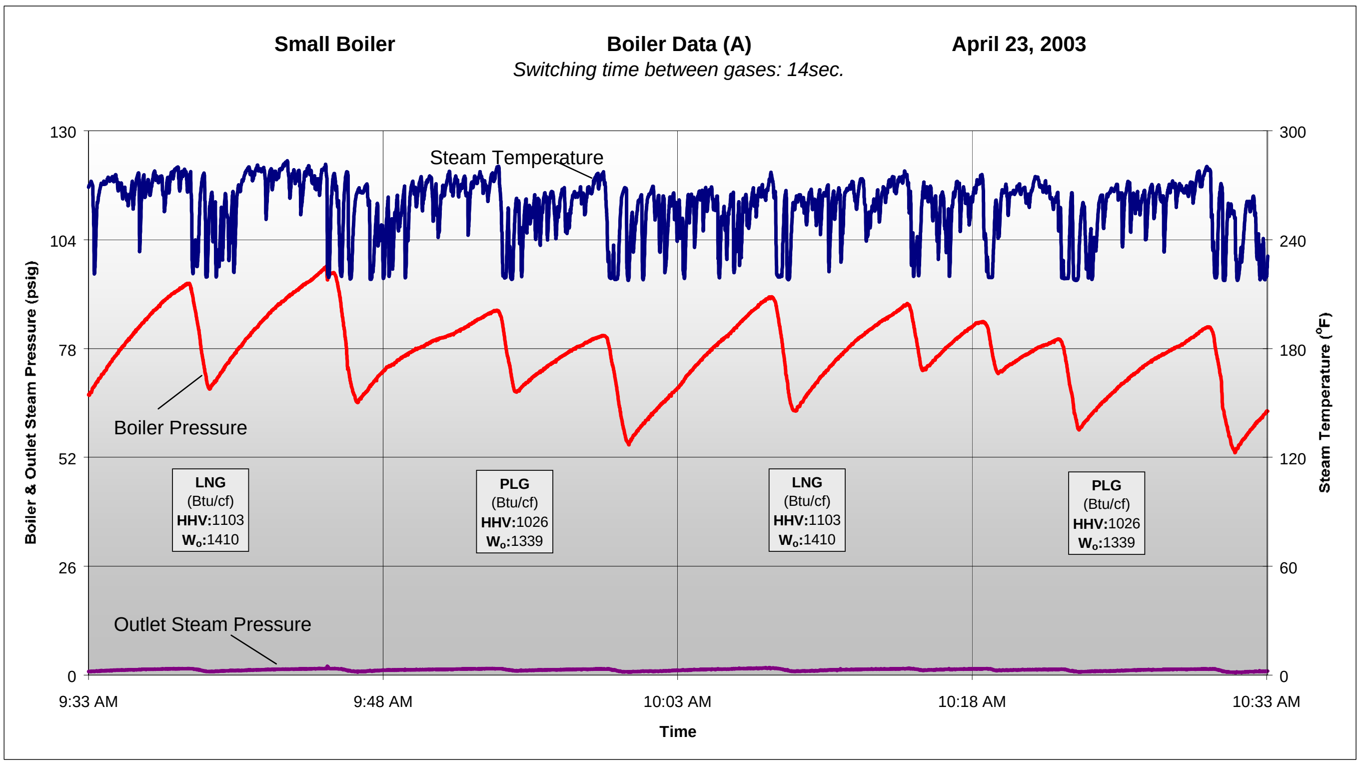


Figure 11

Switching Time: 3 minutes

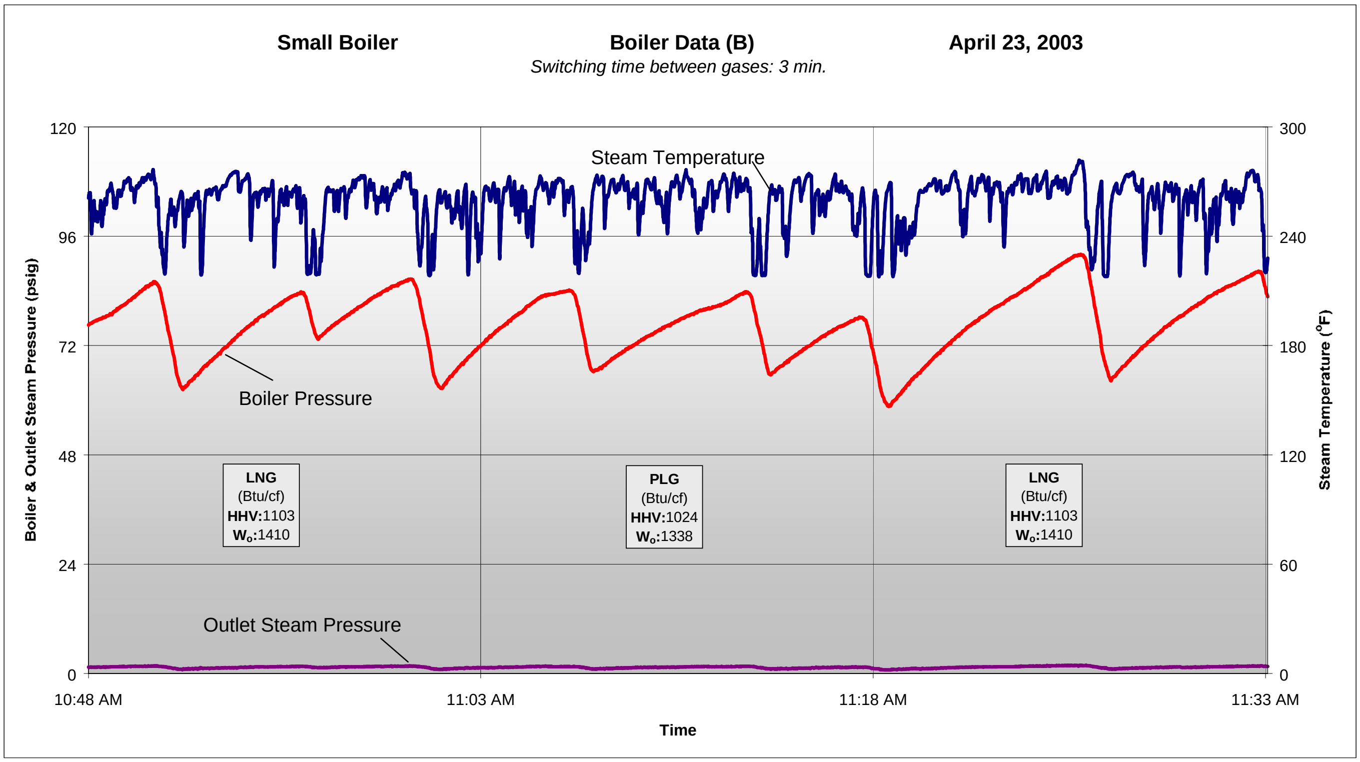


Figure 12

Test Equipment

Equipment utilized for testing adherers to industry standards for testing laboratories (ANSI Z21.13 and SCAQMD Rule 1146.2). The test rig is transportable and includes a data logger, emissions cart, gas chromatograph, gas meter, thermocouples and pressure transducers; plus, a gas regulation system that can take natural gas from 3,000 PSIG and deliver up to 2,000,000 CFH at low pressure (~8" w.c.). The test rig is illustrated in the following figure.

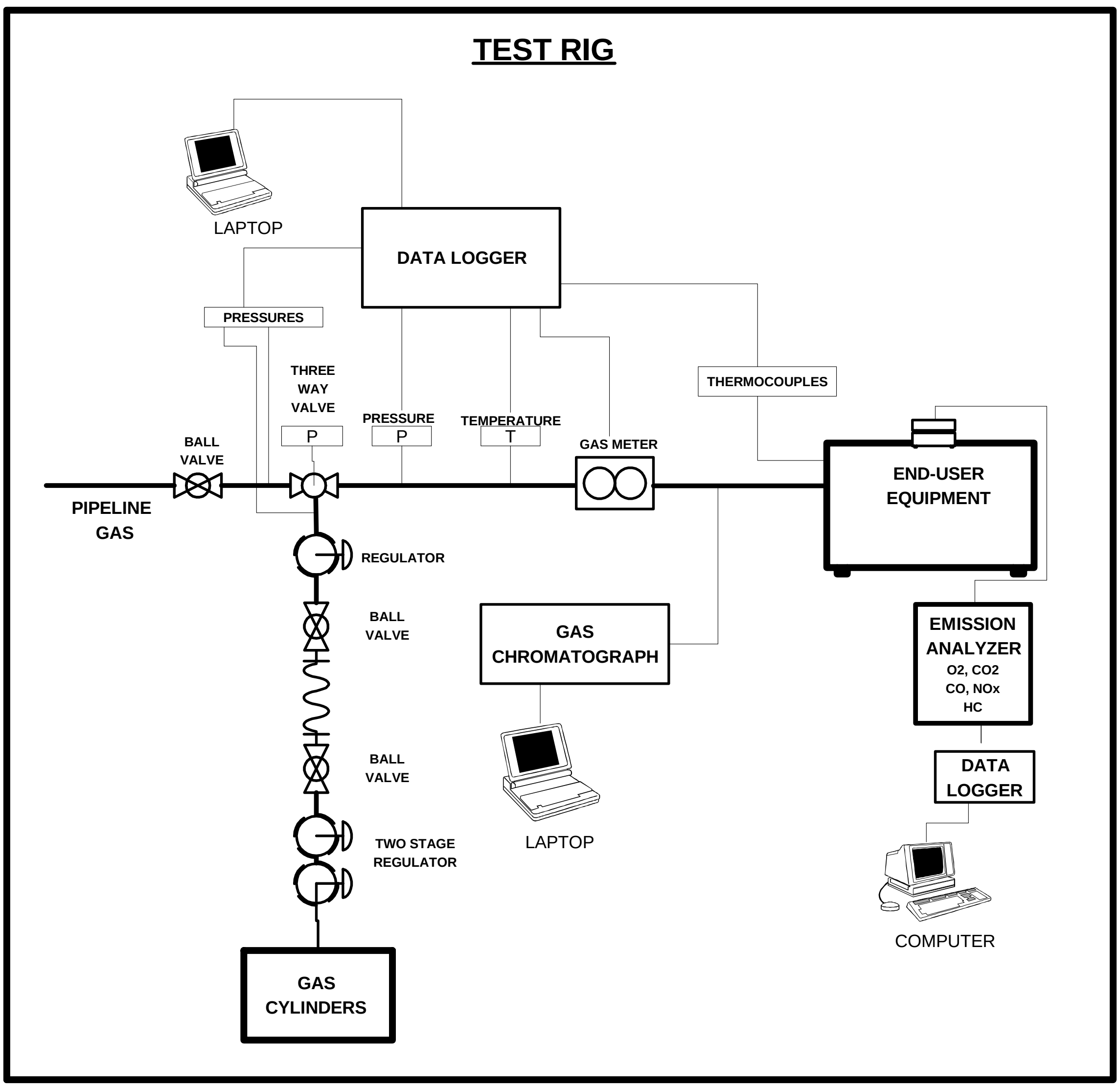


Figure 13

Emissions analyzers meet CARB and SCAQMD standards. Test gases are certified by the manufacturers as Master Class. Following is a list of the test equipment used with the manufacturers' stated accuracy (Tables 3 & 4).

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
Portable	Horiba Instruments Inc.	PG-250A	Portable gas analyzer (Backup) - NO/NO_x, CO, CO_2, O_2	± 1 % of full scale
Gas Delivery System				
Equipment	**Manufacturer**	**Model**	**Type**	**Accuracy**
3 Way Valve	Power Controls Inc.	SX4B-10-1VP	Variable speed 3 way valve	n/a
Controller	Fluke	743B	Documenting process calibrator	n/a
GC	Daniel Flow Products Inc.	2350A	Gas chromatograph	± 0.5 BTU/ cu ft
Datalogger	Logic Beach Inc.	4.61	Data logging system	n/a

Table 3

Gas Meter & Pulser				
Equipment	**Manufacturer**	**Model**	**Type**	**Accuracy**
Test Meter	American Meter Company	DTM-200A	Dry test meter- 200 chh max	@ 200 cfh 100.1 %
Pulser	Rio Tronics	4008468	2 pulses per 1/10 cu ft	@ 60 cfh
3M	Roots Meter	3M175	Dry meter - 3000 cfh max	99.90%
Pulser	IMAC System Inc	n/a	50 pulses per 10 cu ft	n/a
8C	Roots Meter	8C175	Dry meter - 800 cfh max	n/a
Pulser	IMAC System Inc	300-5D-100	100 pulses per 10 cu ft	n/a
Calibration & Test Gases				
Gas	**Manufacturer**	**Type**		**Accuracy**
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 %
Zero	Scott Specialty Gases	Certified Master Class - 0 %		± 2 %
LNG	Matheson Tri Gas	Natural gas blend (HHV-1105, Wobbe-1412)		± 2 %
Thermocouples				
Type	**Manufacturer**	**Model**		**Accuracy**
K	Omega Engineering Co.	KMQSS		$2.2^{o}C$ or 0.75%
J	Omega Engineering Co.	JMQSS		$2.2^{o}C$ or 0.75%
R	Omega Engineering Co.	RMQSS		$2.2^{o}C$ or 0.75%
T	Omega Engineering Co.	TMQSS		$2.2^{o}C$ or 0.75%

Figure 4

Calculations

Emission Concentrations (Corrected to 3 % O_2)

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

Where:

ppm ………. Measured CO, HC & NO_x concentrations, by volume

O_2 Std. …… Oxygen Standard/ Correction value (%)

% O_2 ……… Measured O_2 concentration

SCFH

$$\text{SCFH} = \text{ACFH} \times \left[\frac{(\text{Fuel Press.} + 14.62)}{14.735}\right] \times \left[\frac{519.67}{(\text{Gas Temp} + 459.67)}\right]$$

Where:

SCFH ……. Standard cubic feet per hour (cf/hr.)

ACFH ……. Actual cubic feet per hour (cf/hr.)

Fuel Press. …Fuel Pressure (psig)

Gas Temp. …Gas temperature (°F)

Input Rate (Btu/cf)

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

Where:

SCFH ……. Standard cubic feet per hour (cf/hr.)

HHV ..……. Higher heating value (Btu/cf)

Wobbe Number (Btu/cf)

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

Where:

W_0 ………. Wobbe Number (Btu/cf)

HHV ..……. Higher heating value (Btu/cf)

G .. ……….. Specific gravity of gas sample

Attachment A

Gases

PLG 1023

- Gas from SoCalGas Distribution System at the Engineering Analysis Center (EAC) in Pico Rivera, CA on 7/15/03.
- **HHV:** 1023 Btu/cf, **Wobbe Number:** 1339 Btu/cf.

PLG Analysis**				
100479-2 stream 1 on 3/05/03 11:30 AM	MolPct	Gal/1000	BTUGross	RelDens
C6 + 57/28/14	0.0619	0.0272	3.21	0.0020
NITROGEN	0.5069	0.0000	0.00	0.0049
METHANE	95.9097	0.0000	970.89	0.5313
CARBON DIOXIDE	1.1384	0.0000	0.00	0.0173
ETHANE	1.8556	0.4960	32.91	0.0193
PROPANE	0.3756	0.1034	9.47	0.0057
i-BUTANE	0.0513	0.0168	1.67	0.0010
n-BUTANE	0.0663	0.0209	2.17	0.0013
NEOPENTANE	0.0000	0.0000	0.00	0.0000
i-PENTANE	0.0194	0.0071	0.78	0.0005
n-PENTANE	0.0150	0.0054	0.60	0.0004
TOTAL	**100.0001**	**0.6768**	**1021.70**	**0.5837**
Compressibility Factor	1.00213			
Heating Value Gross BTU Dry	1023.89			
Heating Value Gross BTU Sat.	1006.08			
Relative Density Gas Corr.	0.5847			
Gallons/1000 SCF C2+	0.6768			
Gallons/1000 SCF C3+	0.1809			
Gallons/1000 SCF C4+	0.0774			
Gallons/1000 SCF C5+	0.0397			
Gallons/1000 SCF C6+	0.0272			
Total Unnormalized Conc.	99.701			
WOBBE Index	1339.04			
**Replacement PLG analysis taken on 03/05/03. Both HHV and Wobbe No. match values taken on 04/23/03.				

LNG 1105

- Blended and bottled by Matheson Tri-Gases located in Joliet, IL
- **HHV:** 1105 Btu/cf, **Wobbe Number:** 1409 Btu/cf.

LNG Analysis

100479-2 stream 1 on 4/24/03 6:22:10 AM	MolPct	Gal/1000	BTUGross	RelDens
C6 + 57/28/14	0.0000	0.0000	0.00	0.0000
NITROGEN	0.2046	0.0000	0.00	0.0020
METHANE	91.3845	0.0000	925.09	0.5062
CARBON DIOXIDE	0.0000	0.0000	0.00	0.0000
ETHANE	5.6057	1.4983	99.43	0.0582
PROPANE	1.7646	0.4859	44.50	0.0269
i-BUTANE	0.5260	0.1721	17.15	0.0106
n-BUTANE	0.5146	0.1622	16.83	0.0103
NEOPENTANE	0.0000	0.0000	0.00	0.0000
i-PENTANE	0.0000	0.0000	0.00	0.0000
n-PENTANE	0.0000	0.0000	0.00	0.0000
TOTAL	**100.0000**	**2.3185**	**1103.00**	**0.6142**

Compressibility Factor	1.0025
Heating Value Gross BTU Dry	1105.76
Heating Value Gross BTU Sat.	1086.52
Relative Density Gas Corr.	0.6154
Gallons/1000 SCF C2+	2.3185
Gallons/1000 SCF C3+	0.8202
Gallons/1000 SCF C4+	0.3343
Gallons/1000 SCF C5+	0.0000
Gallons/1000 SCF C6+	0.0000
Total Unnormalized Conc.	99.849
WOBBE Index	1409.54

Zero & Span Averages

Span and Zero Average Datafile
Site Name: EAC 04/23/2003 7:08:40 AM
Data file name: C:\Das\Cart Das\Logfiles\eac042303_average.csv

			Raw Emissions				
	Time	Avg. Time	O_2	CO_2	CO (ppm)	HC (ppm)	NO_x (ppm)
Zero (Start)	7:19:35	2	0.07%	0.08%	0.02	-0.26	0.02
Span (Start)	7:35:52	2	9.12%	12.08%	79.93	91.45	18.17
Span (end)	11:40:13	2	9.12%	12.10%	80.13	91.25	18.26
Zero (end)	11:44:02	2	0.06%	0.11%	0.04	-1.09	0.03

* Corrected to 3% O_2