LNG RESEARCH STUDY - PHASE 1

TESTING OF A HIGH EFFICIENCY DUAL SPEED CONDENSING RESIDENTIAL FORCED AIR UNIT (FAU)

The Southern California Gas Company

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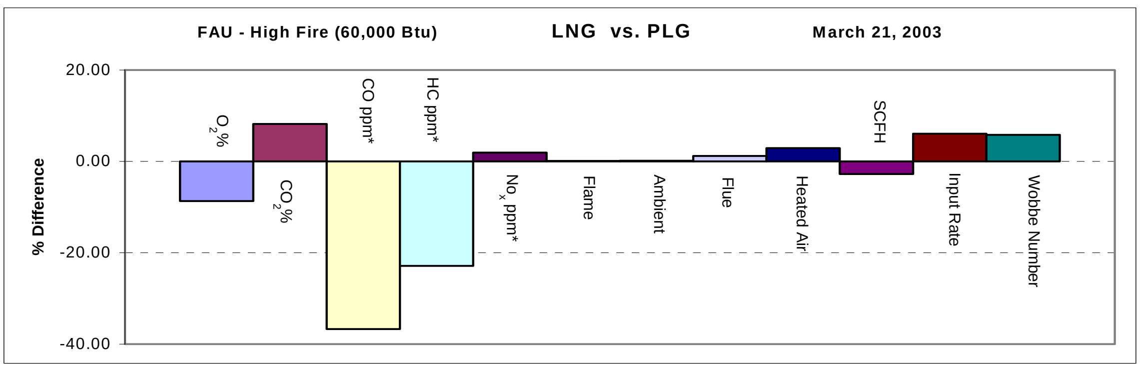
Results Summary

A forced air unit (FAU) was tested at low and high fire settings using PLG 1014 and LNG 1106. Switching to LNG did not result in significant change to the combustion characteristics of the FAU but flame, ambient, flue and heated air temperatures increased slightly. However, these changes did not cause unsafe or unstable conditions. Results obtained from the tests conducted revealed that:

1) On high fire, CO and HC emissions decreased by 37% and 23% and NO_x emissions increased by 1.9%. Even though the NO_x emissions only increased slightly, this may be a concern because rule 1111 from the SCAQMD is difficult to meet.
2) On low fire, CO and HC emissions decreased by 23% and 12.6% and NO_x emissions increased by 1.1%. Also, on low fire the flame became a little yellow.

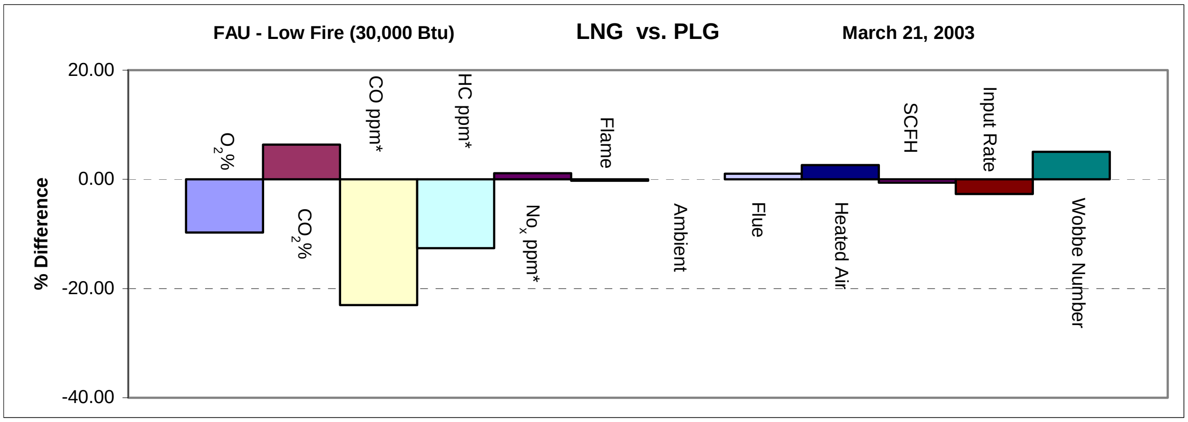
Figure 1 and Table 1 depict summary results for high fire testing while Figure 2 and Table 2 show summary results for low fire testing.



High Fire Data for FAU (March 21, 2003)	EMISSIONS					TEMPERATURES (°F)				GAS INPUT		
	O_2%	CO_2%	CO* ppm	HC* ppm	NO_x* ppm	Flame	Ambient	Flue	Heated Air	SCFH	Input Rate (Btu/cf)	Wobbe Number (Btu/cf)
LNG 1:00 - 1:29 PM	8.8	6.9	7.7	268.7	71.2	1684	74.0	111.9	136.0	55.05	61093	1410
PLG 1:29 - 1:59 PM	9.7	6.4	12.1	359.4	69.8	1682	74.8	111.1	132.8	56.44	57500	1333
LNG 1:59 - 2:29 PM	8.9	7.0	7.7	271.8	72.0	1684	74.9	112.5	136.6	54.78	60950	1410
PLG 2:29 - 3:01 PM	9.8	6.4	12.0	343.7	70.4	1683	74.8	111.2	132.8	56.45	57563	1332
LNG 3:01 - 3:30 PM	8.9	7.0	7.7	273.5	72.3	1685	74.8	112.4	136.6	54.91	61128	1410
PLG 3:30 - 4:00 PM	9.8	6.4	12.3	352.6	71.2	1683	73.8	110.5	131.9	56.56	57628	1331
% Difference	-8.70	8.23	-36.70	-22.90	1.92	0.11	0.17	1.20	2.94	-2.78	6.07	5.83

* Corrected to 0% O_2

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



Low Fire Data for FAU (March 21, 2003)												
	EMISSIONS					TEMPERATURES (°F)				GAS INPUT		
	O_2%	CO_2%	CO* ppm	HC* ppm	NO_x* ppm	Flame	Ambient	Flue	Heated Air	SCFH	Input Rate	Wobbe Number
PLG 8:30 - 8:59 AM	7.9	7.5	1.8	259.3	69.2	1631	71.4	106.6	159.2	1.61	36597	1342
LNG 8:59 - 9:29 AM	7.1	8.0	1.3	226.2	70.2	1628	71.4	108.0	163.7	1.60	35655	1410
PLG 9:29 - 10:00 PM	7.8	7.5	1.8	241.8	69.7	1631	71.2	106.7	159.4	1.61	36700	1342
LNG 10:00 - 10:30 AM	7.1	8.0	1.4	212.7	70.4	1628	71.2	107.7	163.1	1.60	35658	1410
PLG 10:30 - 10:59 AM	7.9	7.5	1.8	242.3	70.0	1632	71.4	106.4	158.5	1.61	36724	1340
LNG 10:59 - 11:29 AM	7.1	7.9	1.5	211.0	70.6	1627	71.3	107.4	162.6	1.60	35786	1410
% Difference	-9.72	6.39	-23.03	-12.59	1.13	-0.24	0.00	1.03	2.59	-0.59	-2.66	5.08

*** Corrected to 0% O_2**

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

Equipment Selection Criteria

This unit was selected due the following concerns by manufacturers and industry experts:

- Potential for the heat exchangers to crack due to over firing.
- Complexity of the unit — high efficiency dual speed condensing residential FAU with an induced combustion system.
- Complexity in meeting SCAQMD Rule 1111 while adhering to the Gas-Fired Central Furnace standards (ANSI Z21.47) when operating on rich gases. Rule 1111 controls the NO_x from natural gas fired FAUs to 40 nanograms per joule of useful heat delivered to the living space. The ANSI Z21.47 standard covers safety, construction and performance. Under the performance section, it has a combustion test that limits the CO emissions to 400 ppm air free.

Installation

The FAU was installed following the manufacturer's directions for installation in a typical residence. Thermocouples were installed to measure ambient air, FAU air discharge, flame temperature, supplied gas, and flue gases. A gas meter was installed to measure the gas flow. Pressure transducers were installed to measure manifold gas pressure and skid pressure. An emissions probe was installed in the flue vent.

Test Method for Low and High Fire

1. All emissions analyzers were calibrated.
2. The furnace was turned "on" and allowed to reach a steady state condition while running on PLG.
3. Emissions probe was installed.
4. Data loggers were synchronized and temperatures, pressures and gas flow readings were inspected.
5. Data recording was started while running with PLG.
6. Test was run for 30 minutes on PLG.
7. Furnace was switched to LNG and run for 30 minutes.
8. Steps 6 and 7 were repeated twice.
9. Drift inspections were performed on all emissions analyzers.

Results

High Fire (60,000 Btu)

Emissions Data

Switching from PLG 1014/1025 to LNG 1107 did not affect the combustion characteristics of the FAU. On low fire, the average CO and HC emissions values for each 30-minute run decreased by 37% and 23% respectively while the average NO_x emissions increased by 1.9%. Even though the NO_x emissions only increased slightly, this may be a concern because currently it is difficult for manufacturers to meet Rule 1111 from the SCAQMD. This rule controls the NO_x from natural gas fired FAUs to 40 nanograms per joule of useful heat delivered to the living space, thus, controlling the NO_x emissions and the thermal efficiency of the unit. The figure below depicts the tests results.

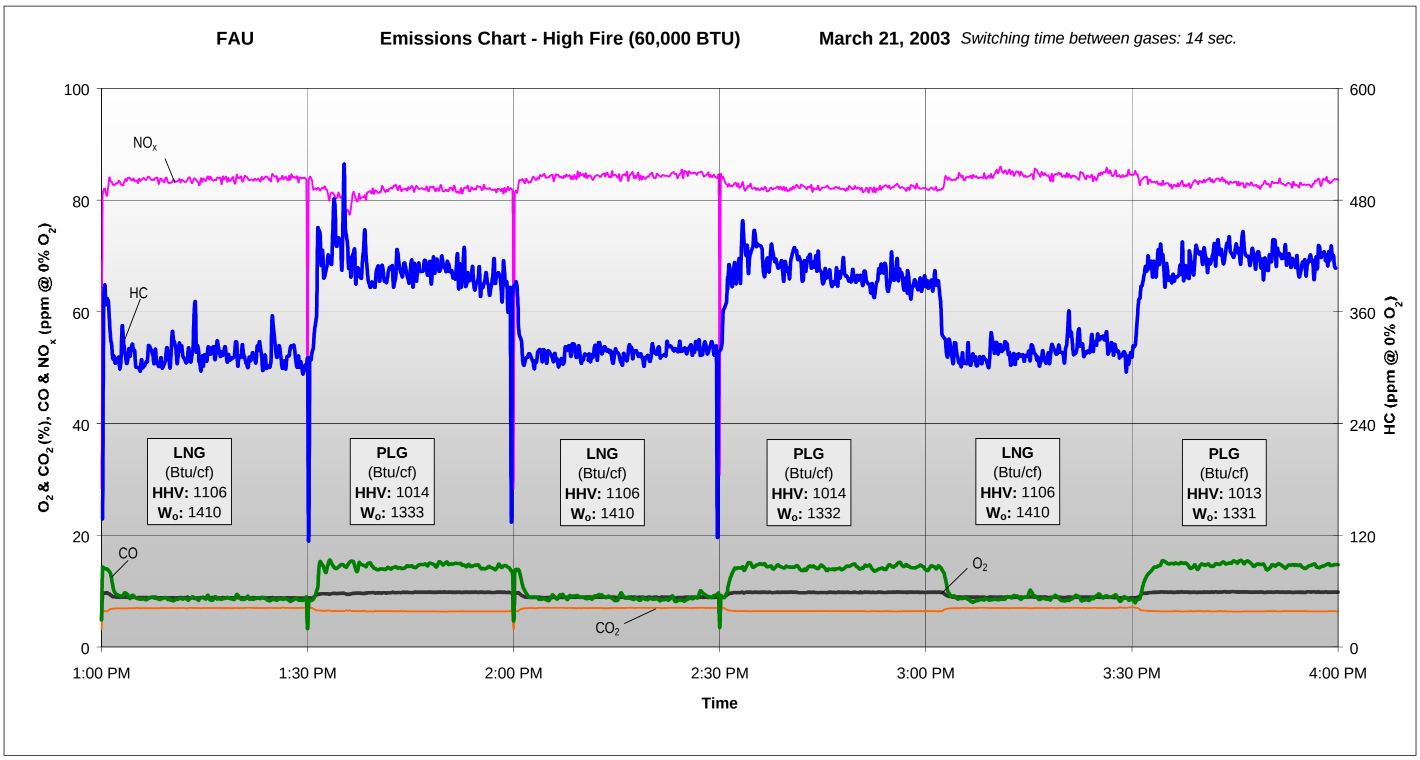


Figure 3

Temperature Data

The flame, ambient, flue and heated air temperatures increased slightly but a long-term test should be conducted to determine if this could create a problem with the heat exchanger (Figure 4).

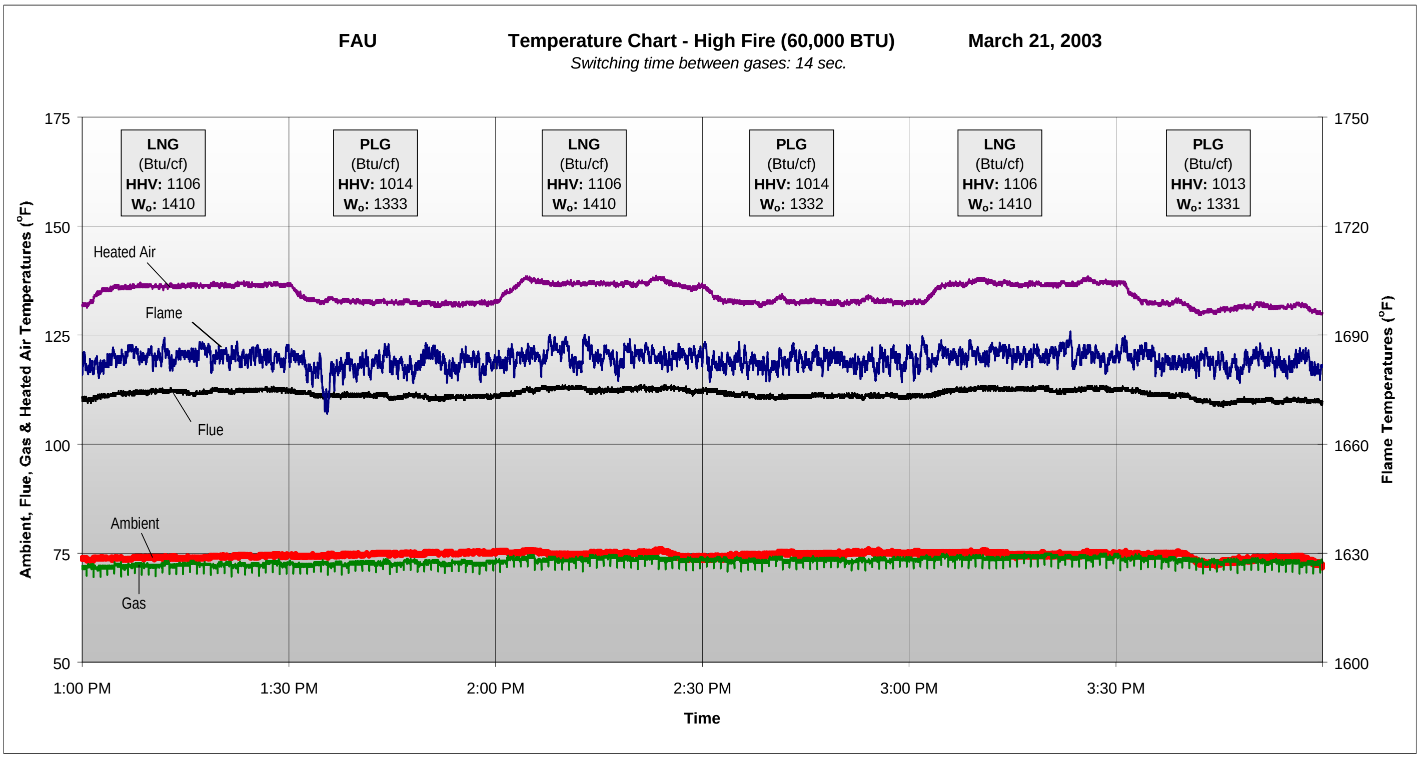


Figure 4

Input Data

On LNG the average SCFH decreased by 2.8% but the average input increased by 6.1%. The highest input while running on LNG was 61,128 Btu/cf that is within ± 2% of the rated input (60,000 Btu/cf at high fire) as specified by the ANSI Z21.47 (Figure 5).

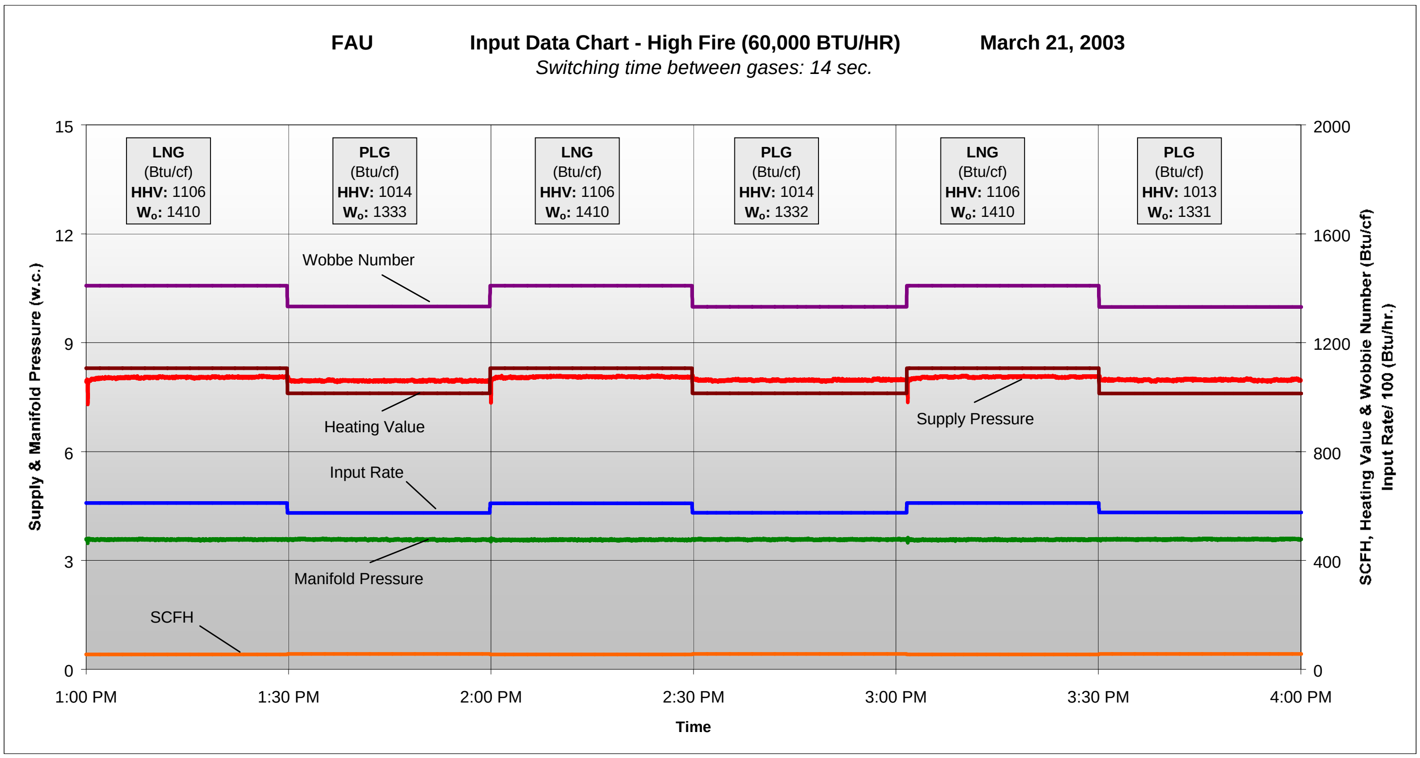


Figure 5

Low Fire (30,000 Btu)

Emissions Data

On low fire the average CO and HC emissions values for each 30-minute run decreased by 23% and 12.6% respectively while the average NO_x emissions increase by 1.1% (Figure 6). Similar to high fire conditions, the slight increase in NO_x emissions may be a concern for manufacturers due Rule 1111 from the SCAQMD.

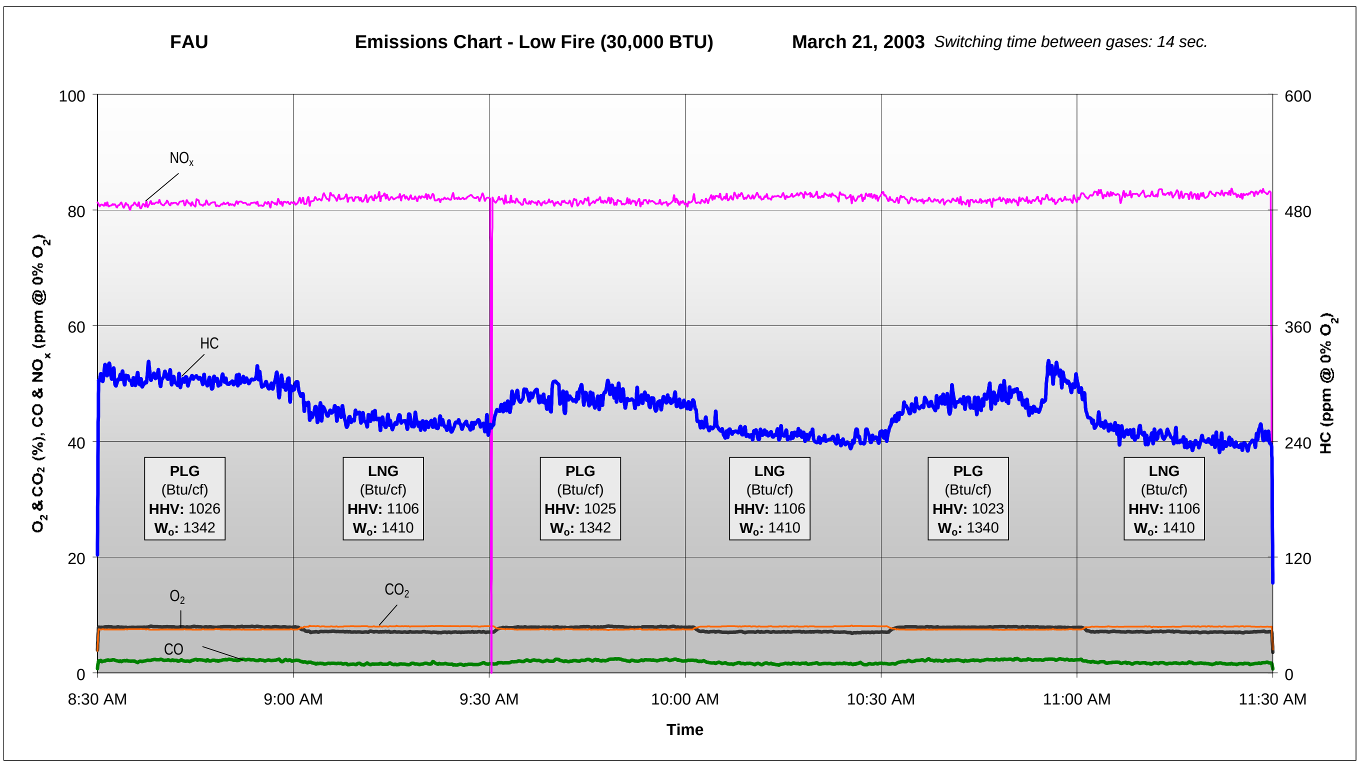


Figure 6

Temperature Data

The flame temperature decreased slightly, the ambient temperature did not change and the flue and heated air temperatures increased slightly but none of these changes were significant enough to be of concern since the FAU is running on low fire (Figure 7).

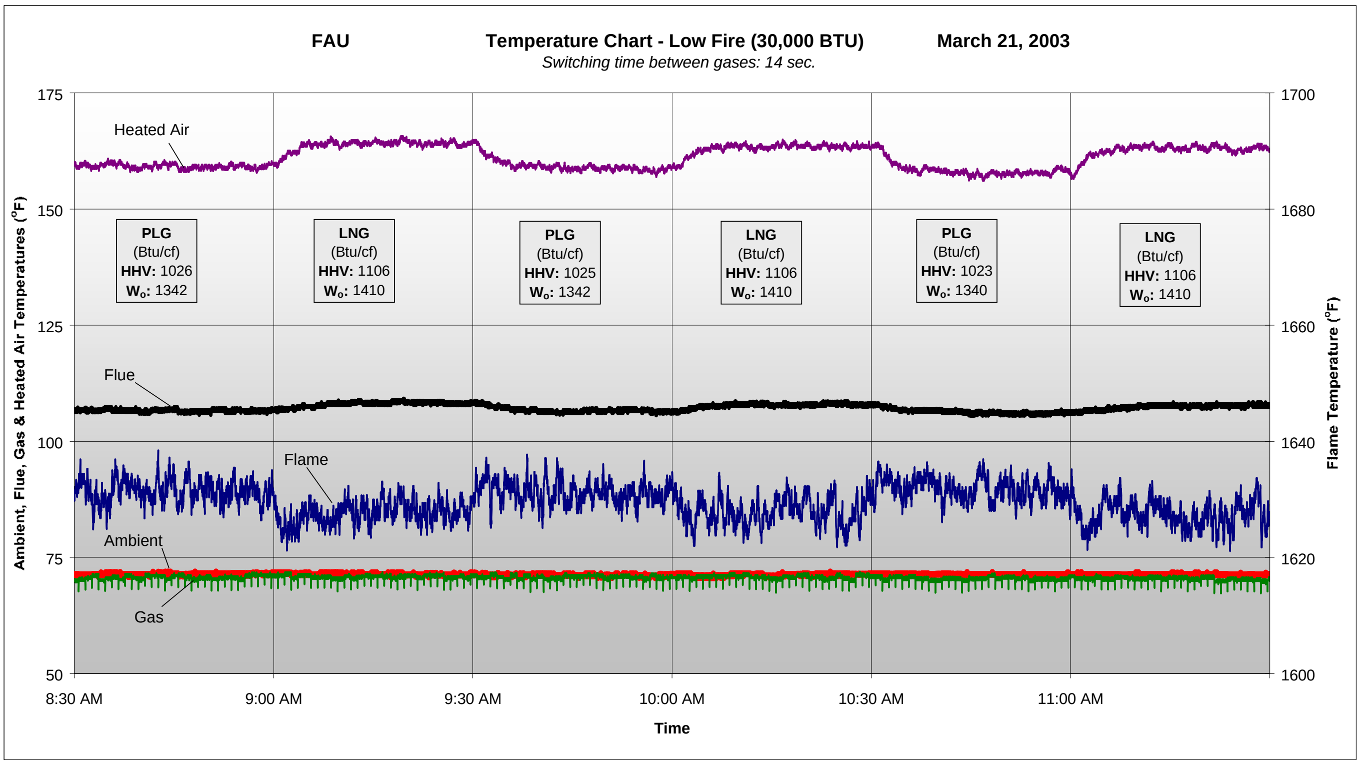


Figure 7

Input Data

On LNG, the average SCFH and the average input rate decreased by 0.6% and 2.7%, respectively (Figure 8).

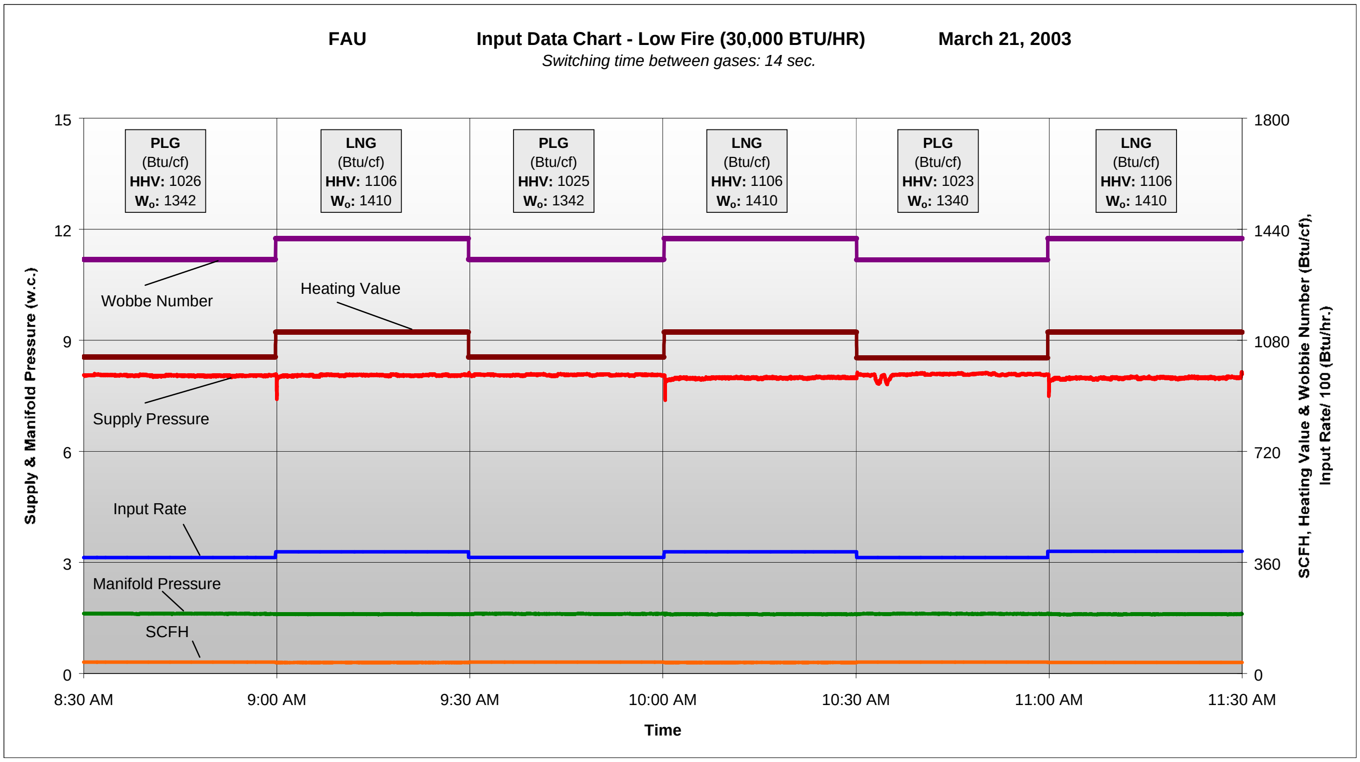


Figure 8

In low fire, the flame became a little yellow (Figure 9) when LNG was introduced, but it did not seem to affect flame stability or combustion characteristics.

Figure 9

Test Equipment

Equipment utilized for testing adheres to industry standards for testing laboratories. 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 2,200,000 CFH at low pressure (~8" w.c.). The test rig is illustrated in Figure 10.

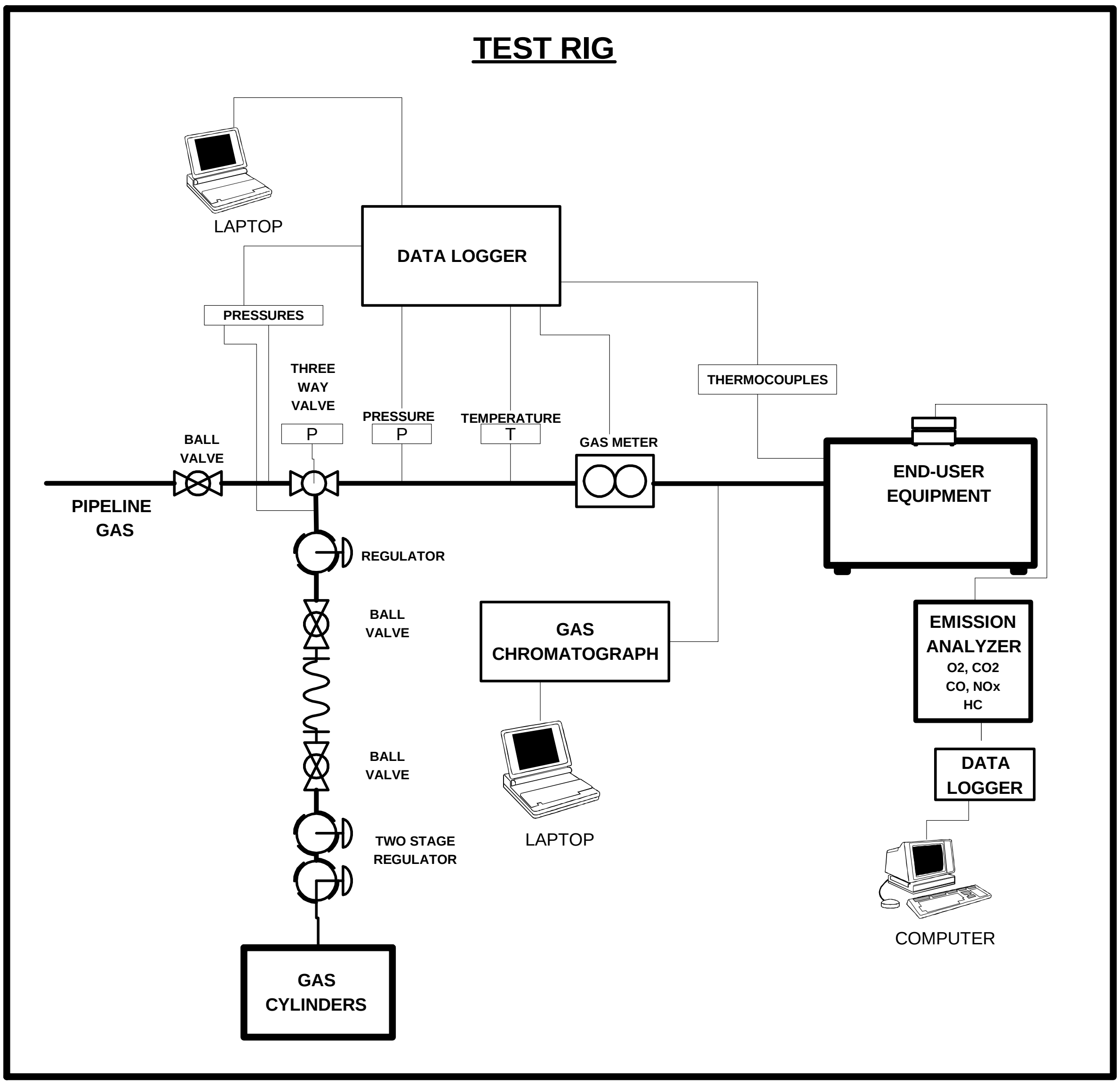


Figure 10

Emissions analyzers meet CARB and SCAQMD standards. Test gases are certified master class. The following is a list of the test equipment (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
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	@ 200cfh 100.1% @ 60cfh 99.9%
Pulser	Rio Tronics	4008468	2 pulses per 1/10 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: 1107, 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%

Table 4

Calculations

Emission Concentrations (Corrected to 0% O_2)

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

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)

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

Where:

W_0 ………. Wobbe Number (Btu/cf)

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

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

Attachment A

Gases

PLG 1012 (High Fire)

- Gas delivered to the Engineering Analysis Center (EAC) in Pico Rivera, CA
- **HHV:** 1012 Btu/cf, **Wobbe Number:** 1331 Btu/cf.

PLG Analysis**				
100479-2 stream 1 on 5/30/03 10:29:19 AM	**MolPct**	**Gal/1000**	**BTUGross**	**RelDens**
C6 + 57/28/14	0.0220	0.0097	1.14	0.0007
NITROGEN	0.3266	0.0000	0.00	0.0032
METHANE	96.8644	0.0000	980.56	0.5366
CARBON DIOXIDE	1.3269	0.0000	0.00	0.0202
ETHANE	1.1659	0.3116	20.68	0.0121
PROPANE	0.2025	0.0557	5.11	0.0031
i-BUTANE	0.0342	0.0112	1.11	0.0007
n-BUTANE	0.0366	0.0115	1.20	0.0007
NEOPENTANE	0.0000	0.0000	0.00	0.0000
i-PENTANE	0.0128	0.0047	0.51	0.0003
n-PENTANE	0.0082	0.0030	0.33	0.0002
TOTAL	**100.0001**	**0.4074**	**1010.64**	**0.5778**
Compressibility Factor	1.0021			
Heating Value Gross BTU Dry	1012.74			
Heating Value Gross BTU Sat.	955.11			
Relative Density Gas Corr.	0.5787			
Gallons/1000 SCF C2+	0.4074			
Gallons/1000 SCF C3+	0.0958			
Gallons/1000 SCF C4+	0.0400			
Gallons/1000 SCF C5+	0.0173			
Gallons/1000 SCF C6+	0.0097			
Total Unnormalized Conc.	99.408			
WOBBE Index	1331.30			
**Replacement PLG analysis taken on 05/30/03. Both HHV and Wobbe No. match values taken on 03/21/03.				

PLG 1025 (Low Fire)

- Gas delivered to the Engineering Analysis Center (EAC) in Pico Rivera, CA
- **HHV:** 1025 Btu/cf, **Wobbe Number:** 1343 Btu/cf

PLG Analysis**				
100479-2 stream 1 on 3/05/03 7:54 AM	**MolPct**	**Gal/1000**	**BTUGross**	**RelDens**
C6 + 57/28/14	0.0428	0.0188	2.22	0.0014
NITROGEN	0.6309	0.0000	0.00	0.0061
METHANE	95.9902	0.0000	971.71	0.5317
CARBON DIOXIDE	0.8684	0.0000	0.00	0.0132
ETHANE	1.9301	0.5159	34.24	0.0200
PROPANE	0.3754	0.1034	9.47	0.0057
i-BUTANE	0.0603	0.0197	1.96	0.0012
n-BUTANE	0.0652	0.0206	2.13	0.0013
NEOPENTANE	0.0000	0.0000	0.00	0.0000
i-PENTANE	0.0214	0.0078	0.86	0.0005
n-PENTANE	0.0152	0.0055	0.61	0.0004
TOTAL	**99.9999**	**0.6917**	**1023.20**	**0.5815**
Compressibility Factor	1.0021			
Heating Value Gross BTU Dry	1025.37			
Heating Value Gross BTU Sat.	1007.53			
Relative Density Gas Corr.	0.5826			
Gallons/1000 SCF C2+	0.6917			
Gallons/1000 SCF C3+	0.1758			
Gallons/1000 SCF C4+	0.0724			
Gallons/1000 SCF C5+	0.0322			
Gallons/1000 SCF C6+	0.0188			
Total Unnormalized Conc.	99.445			
WOBBE Index	1343.40			
**Replacement PLG analysis taken on 03/05/03. Both HHV and Wobbe No. match values taken on 03/21/03.				

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 3/05/03 2:07 PM	**MolPct**	**Gal/1000**	**BTUGross**	**RelDens**
C6 + 57/28/14	0.0000	0.0000	0.00	0.0000
NITROGEN	0.2211	0.0000	0.00	0.0021
METHANE	91.3485	0.0000	924.72	0.5060
CARBON DIOXIDE	0.0000	0.0000	0.00	0.0000
ETHANE	5.6089	1.4992	99.49	0.0582
PROPANE	1.7733	0.4883	44.72	0.0270
i-BUTANE	0.5278	0.1726	17.20	0.0106
n-BUTANE	0.5204	0.1641	17.02	0.0104
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**	**2.3242**	**1103.15**	**0.6143**
Compressibility Factor	1.00251			
Heating Value Gross BTU Dry	1105.92			
Heating Value Gross BTU Sat.	1086.68			
Relative Density Gas Corr.	0.6157			
Gallons/1000 SCF C2+	2.3242			
Gallons/1000 SCF C3+	0.8250			
Gallons/1000 SCF C4+	0.3367			
Gallons/1000 SCF C5+	0.0000			
Gallons/1000 SCF C6+	0.0000			
Total Unnormalized Conc.	100.119			
WOBBE Index	1409.43			
**Replacement LNG analysis taken on 03/05/03. Both HHV and Wobbe No. match values taken on 03/21/03.				

Zero & Span Averages

Span and Zero Average Datafile
Site Name: EAC 03/21/2003 7:31:35 AM
Data file name: C:\Das\Cart Das\Logfiles\eac032103 average.csv

			Raw Emissions				
	Time	Avg. Time	O_2	CO_2	CO (ppm)	HC (ppm)	NO_x (ppm)
Span (Start)	7:56:19	2	9.09%	12.05%	79.98	426.01	18.6
Zero (Start)	8:06:55	2	0.05%	0.05%	0.02	-0.12	0
Zero (end)	16:44:07	2	0.03%	0.05%	0.11	-0.31	0
Span (end)	16:51:55	2	9.06%	12.02%	79.81	418.92	18.22

* Corrected to 3% O_2