Ventura Engine

Results Summary

While operating on four different test gases and the line gas from our Ventura base the engine did not have any knocking or operational problems. In addition, the average CO and NOx were always below the requirements from Ventura Air Pollution Control District. With all the gases, there were some emissions spikes but we were unable to conclude how they were generated.

Equipment Selection Criteria

A rich burn engine was selected because they have to meet very stringent air pollution requirements in the Southern California Area and a lot of our customers are having difficulty meeting such requirements. Since engine that we tested was an existing engine in Ventura County, it has to meet less stringent air pollution requirements. The requirements by the Ventura Air Pollution Control District are:

NO_x: 25, CO: 4,500, ROG: 250 (all in ppm @ 15% O_2).

However, new engines in most of our territory have to meet the Best Available Control Technology (BACT), which is:

NO_x: 0.15, CO: 0.6, ROG: 0.15 (all in g/BHP-hr) or

NO_x: ~9.5, CO: ~64, ROG: ~28 (all in ppm @ 15% O_2)

Equipment Specifications:

Engine

- **Manufacturer:** Waukesha
- **Model:** F1197-GU
- **Serial No.:** 39885
- **Rating:** 186 BHP @1400 RPM
- **Bore:** 6.25 in.
- **Stroke:** 6.50 in.
- **Heat Rate Nominal (Btu/BHP-hr):** 8,500

Emissions Control System (NSCR)

- **Manufacturer of Air/ Fuel Controller:** Emission Control Systems, Inc.
- **Model:** FULARAC 2002 Air/Fuel Ratio Controller
- **Catalyst Manufacturer:** Miratech

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 2,000,000 CFH at low pressure (~80 PSIG). The test rig is illustrated in Figure 5.

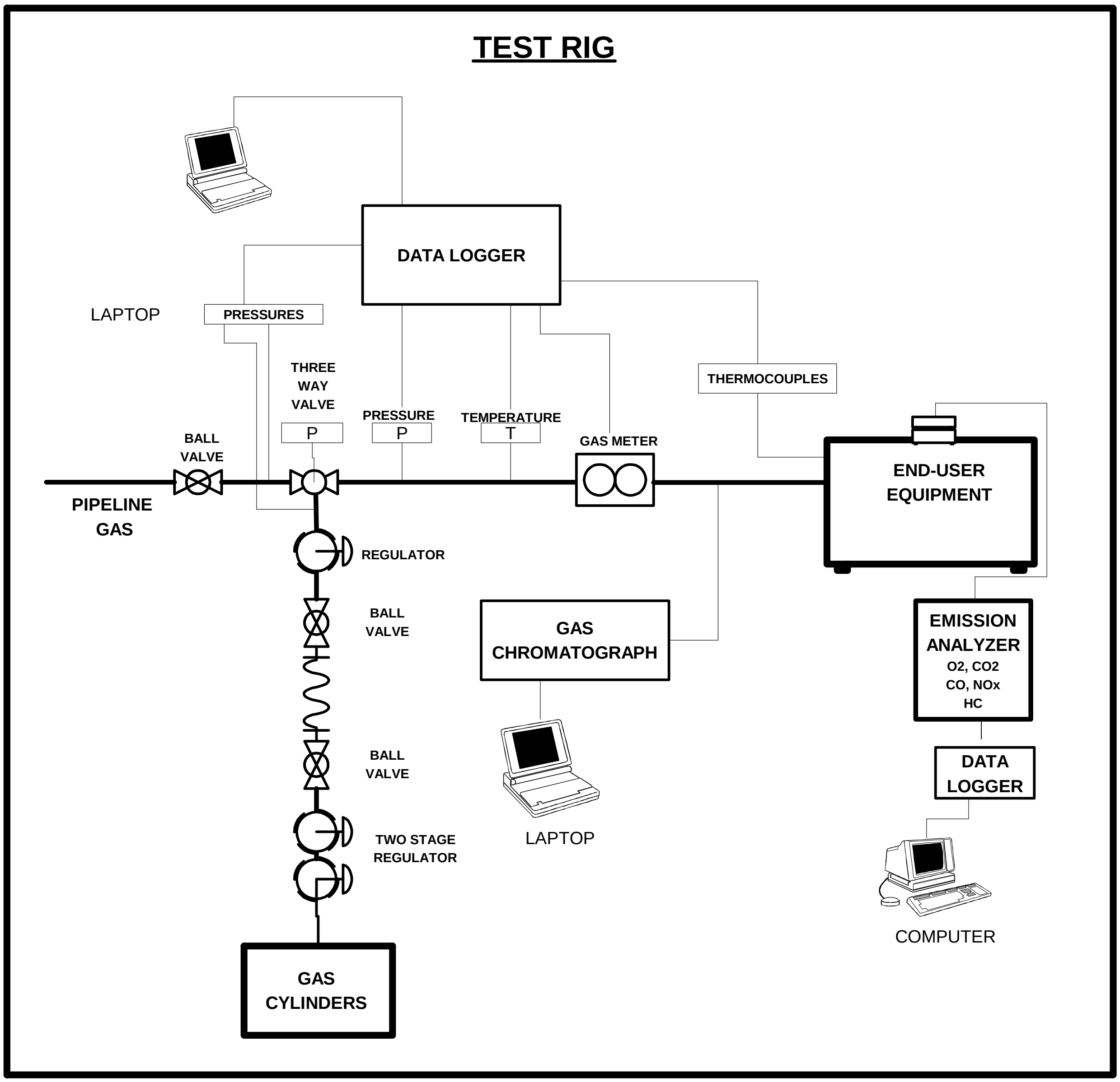

Figure 5

Emissions analyzers meet CARB and SCAQMD standards. Test gases are certified master class. Following is a list of the test equipment (Tables 1 & 2).

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**
GC	Agilent Technologies, Inc	G2890A	Micro Gas Chromatograph	± 1.0 BTU/ cu ft
Datalogger	Logic Beach Inc.	4.61	Data logging system	n/a

Table 1

Gas Meter & Pulser				
Equipment	**Manufacturer**	**Model**	**Type**	**Accuracy**
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
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°C or 0.75%
T	Omega Engineering Co.	TMQSS		2.2°C or 0.75%

Table 2

Calculations

Emission Concentrations (Corrected to 15% O_2)

$$\text{CO, HC \& NO}_x\text{ concentrations (corrected to 15\% O}_2\text{)} = ppm \times \left[\frac{20.9 - O_2\ Std.}{20.9 - \%O_2} \right]$$

Where:

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

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

% O_2 ……… Measured O_2 concentration

SCFH

$$SCFH = ACFH \times \left[\frac{(Fuel\ Press. + 14.62)}{14.62} \right] \times \left[\frac{520}{(Gas\ Temp + 460)} \right]$$

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)

$$Input\ Rate = SCFH \times HHV$$

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 1080 (Brea Gas)

- **GC Sample Time:** 1:49 PM
- Compressed and bottled from a producer located in Brea, CA.
- **HHV:** 1080 Btu/cf; **Wobbe Number:** 1354 Btu/cf.

Brea Gas Analysis (1:49 PM)				
c:\mti\ezchrom\200\chrom\vtest.21	Mole %	BTU	RD	GPM
NITROGEN	1.796	0.000	0.017	0.000
METHANE	89.330	904.320	0.495	0.000
CO_2	1.250	0.000	0.019	0.000
ETHANE	3.796	67.329	0.039	1.015
H_2S	0.000	0.000	0.000	0.000
PROPANE	2.709	68.319	0.041	0.746
i-BUTANE	0.449	14.635	0.009	0.147
n-BUTANE	0.549	17.951	0.011	0.173
NEOPENTANE	0.000	0.000	0.000	0.000
i-PENTANE	0.070	2.807	0.002	0.026
n-PENTANE	0.045	1.808	0.001	0.016
C6+	0.006	0.286	0.000	0.002
TOTAL	**100.000**	**1077.456**	**0.635**	**2.126**
Compressibility Factor	0.9975			
Heating Value Gross BTU Dry	1080.173			
Heating Value Gross BTU Sat.	1062.615			
Relative Density Gas Corr.	0.6362			
Total Unnormalized Conc.	99.402			
WOBBE Index	1354.243			

PLG 1060 (Ventura Line Gas)

- **GC Sample Time:** 11:00 AM
- Gas delivered to Ventura Base in Ventura, CA.
- **HHV:** 1077 Btu/cf; **Wobbe Number:** 1364 Btu/cf

Ventura Line Gas Analysis (11:00 AM)				
c:\mti\ezchrom\200\chrom\vtest.4	Mole %	BTU	RD	GPM
NITROGEN	0.574	0.000	0.006	0.000
METHANE	90.996	921.186	0.504	0.000
CO_2	1.380	0.000	0.021	0.000
ETHANE	4.289	76.074	0.045	1.147
H_2S	0.000	0.000	0.000	0.000
PROPANE	1.938	48.875	0.030	0.534
i-BUTANE	0.234	7.627	0.005	0.077
n-BUTANE	0.424	13.864	0.009	0.134
NEOPENTANE	0.000	0.000	0.000	0.000
i-PENTANE	0.082	3.288	0.002	0.030
n-PENTANE	0.066	2.652	0.002	0.024
C6+	0.017	0.810	0.001	0.007
TOTAL	**100.000**	**1074.376**	**0.622**	**1.952**
Compressibility Factor	0.9975			
Heating Value Gross BTU Dry	1077.040			
Heating Value Gross BTU Sat.	1059.533			
Relative Density Gas Corr.	0.6233			
Total Unnormalized Conc.	99.358			
Wobbe Number	1364.216			

PLG 1060 (Ventura Line Gas)

- **GC Sample Time:** 12:21 PM
- Gas delivered to Ventura Base in Ventura, CA.
- **HHV:** 1060 Btu/cf; **Wobbe Number:** 1360 Btu/cf

Ventura Line Gas Analysis (12:21 PM)				
c:\mti\ezchrom\200\chrom\vtest.34	Mole %	BTU	RD	GPM
NITROGEN	0.651	0.000	0.006	0.000
METHANE	92.544	936.857	0.513	0.000
CO_2	1.016	0.000	0.015	0.000
ETHANE	4.042	71.693	0.042	1.081
H_2S	0.000	0.000	0.000	0.000
PROPANE	1.217	30.692	0.019	0.335
i-BUTANE	0.164	5.345	0.003	0.054
n-BUTANE	0.252	8.240	0.005	0.079
NEOPENTANE	0.000	0.000	0.000	0.000
i-PENTANE	0.056	2.246	0.001	0.020
n-PENTANE	0.044	1.768	0.001	0.016
C6+	0.014	0.667	0.000	0.006
TOTAL	**100.000**	**1057.508**	**0.606**	**1.592**
Compressibility Factor	0.9977			
Heating Value Gross BTU Dry	1059.993			
Heating Value Gross BTU Sat.	1042.770			
Relative Density Gas Corr.	0.6073			
Total Unnormalized Conc.	99.121			
Wobbe Number	1360.196			

PLG 1055 (Ventura Line Gas)

- **GC Sample Time:** 1:19 PM
- Gas delivered to Ventura Base in Ventura, CA.
- **HHV:** 1055 Btu/cf; **Wobbe Number:** 1359 Btu/cf

Ventura Line Gas Analysis (1:19 PM)				
c:\mti\ezchrom\200\chrom\vtest.50	Mole %	BTU	RD	GPM
NITROGEN	0.653	0.000	0.006	0.000
METHANE	92.899	940.451	0.515	0.000
CO_2	0.952	0.000	0.014	0.000
ETHANE	4.029	71.462	0.042	1.078
H_2S	0.000	0.000	0.000	0.000
PROPANE	1.028	25.925	0.016	0.283
i-BUTANE	0.142	4.628	0.003	0.046
n-BUTANE	0.199	6.507	0.004	0.063
NEOPENTANE	0.000	0.000	0.000	0.000
i-PENTANE	0.048	1.925	0.001	0.018
n-PENTANE	0.037	1.487	0.001	0.013
C6+	0.013	0.620	0.000	0.005
TOTAL	**100.000**	**1053.005**	**0.602**	**1.506**
Compressibility Factor	0.9977			
Heating Value Gross BTU Dry	1055.446			
Heating Value Gross BTU Sat.	1038.299			
Relative Density Gas Corr.	0.6033			
Total Unnormalized Conc.	99.147			
Wobbe Number	1358.843			

PLG 1055 (Ventura Line Gas)

- **GC Sample Time:** 1:55 PM
- Gas delivered to Ventura Base in Ventura, CA.
- **HHV:** 1055 Btu/cf; **Wobbe Number:** 1359 Btu/cf

Ventura Line Gas Analysis (1:55 PM)				
c:\mti\ezchrom\200\chrom\vtest.62	Mole %	BTU	RD	GPM
NITROGEN	0.643	0.000	0.006	0.000
METHANE	92.978	941.250	0.515	0.000
CO_2	0.946	0.000	0.014	0.000
ETHANE	3.996	70.877	0.041	1.069
H_2S	0.000	0.000	0.000	0.000
PROPANE	1.005	25.345	0.015	0.277
i-BUTANE	0.141	4.596	0.003	0.046
n-BUTANE	0.195	6.376	0.004	0.061
NEOPENTANE	0.000	0.000	0.000	0.000
i-PENTANE	0.047	1.885	0.001	0.017
n-PENTANE	0.036	1.447	0.001	0.013
C6+	0.013	0.620	0.000	0.005
TOTAL	**100.000**	**1052.396**	**0.602**	**1.489**
Compressibility Factor	0.9977			
Heating Value Gross BTU Dry	1054.831			
Heating Value Gross BTU Sat.	1037.694			
Relative Density Gas Corr.	0.6027			
Total Unnormalized Conc.	98.825			
Wobbe Number	1358.727			

PLG 1130 (Seal Beach Gas)

- **GC Sample Time:** 12:07 PM
- Compressed and bottled from a producer located in Seal Beach, CA
- **HHV:** 1131 Btu/cf, **Wobbe Number:** 1367 Btu/cf

Seal Beach Gas Analysis (12:07 PM)				
c:\mti\ezchrom\200\chrom\vtest.26	Mole %	BTU	RD	GPM
NITROGEN	1.165	0.000	0.011	0.000
METHANE	84.602	856.457	0.469	0.000
CO_2	2.618	0.000	0.040	0.000
ETHANE	4.983	88.383	0.052	1.333
H_2S	0.000	0.000	0.000	0.000
PROPANE	4.781	120.573	0.073	1.317
i-BUTANE	0.668	21.773	0.013	0.219
n-BUTANE	0.964	31.521	0.019	0.304
NEOPENTANE	0.000	0.000	0.000	0.000
i-PENTANE	0.126	5.053	0.003	0.046
n-PENTANE	0.080	3.215	0.002	0.029
C6+	0.013	0.620	0.000	0.005
TOTAL	**100.000**	**1127.595**	**0.682**	**3.253**
Compressibility Factor	0.9971			
Heating Value Gross BTU Dry	1130.915			
Heating Value Gross BTU Sat.	1112.511			
Relative Density Gas Corr.	0.6842			
Total Unnormalized Conc.	99.596			
WOBBE Index	1367.220			

PLG 1130 (Seal Beach Gas)

- **GC Sample Time:** 1:49 PM
- Compressed and bottled from a producer located in Seal Beach, CA
- **HHV:** 1126 Btu/cf, **Wobbe Number:** 1365 Btu/cf

Seal Beach Gas Analysis (1:49 PM)				
c:\mti\ezchrom\200\chrom\vtest.60	Mole %	BTU	RD	GPM
NITROGEN	1.167	0.000	0.011	0.000
METHANE	84.964	860.122	0.471	0.000
CO_2	2.579	0.000	0.039	0.000
ETHANE	4.896	86.840	0.051	1.309
H_2S	0.000	0.000	0.000	0.000
PROPANE	4.691	118.303	0.071	1.293
i-BUTANE	0.636	20.730	0.013	0.208
n-BUTANE	0.892	29.167	0.018	0.281
NEOPENTANE	0.000	0.000	0.000	0.000
i-PENTANE	0.104	4.171	0.003	0.038
n-PENTANE	0.062	2.491	0.002	0.022
C6+	0.009	0.429	0.000	0.004
TOTAL	**100.000**	**1122.253**	**0.678**	**3.156**
Compressibility Factor	0.9971			
Heating Value Gross BTU Dry	1125.513			
Heating Value Gross BTU Sat.	1107.200			
Relative Density Gas Corr.	0.6801			
Total Unnormalized Conc.	99.347			
WOBBE Index	1364.785			

PLG 1008 (Pico Gas)

- **GC Sample Time:** 11:21 AM
- Compressed and bottled at the Engineering Analysis Center (EAC) in Pico Rivera, CA
- **HHV:** 1008 Btu/cf, **Wobbe Number:** 1319 Btu/cf

Pico (POD) Gas Analysis (11:21 AM)				
c:\mti\ezchrom\200\chrom\vtest.11	Mole %	BTU	RD	GPM
NITROGEN	1.041	0.000	0.010	0.000
METHANE	95.724	969.049	0.530	0.000
CO_2	1.354	0.000	0.021	0.000
ETHANE	1.520	26.960	0.016	0.407
H_2S	0.000	0.000	0.000	0.000
PROPANE	0.250	6.305	0.004	0.069
i-BUTANE	0.042	1.369	0.001	0.014
n-BUTANE	0.044	1.439	0.001	0.014
NEOPENTANE	0.000	0.000	0.000	0.000
i-PENTANE	0.013	0.521	0.000	0.005
n-PENTANE	0.009	0.362	0.000	0.003
C6+	0.003	0.143	0.000	0.001
TOTAL	**100.000**	**1006.148**	**0.583**	**0.512**
Compressibility Factor	0.9979			
Heating Value Gross BTU Dry	1008.259			
Heating Value Gross BTU Sat.	991.906			
Relative Density Gas Corr.	0.5838			
Total Unnormalized Conc.	99.166			
WOBBE Index	1319.593			

PLG 1008 (Pico Gas)

- **GC Sample Time:** 1:43 PM
- Compressed and bottled at the Engineering Analysis Center (EAC) in Pico Rivera, CA
- **HHV:** 1008 Btu/cf, **Wobbe Number:** 1320 Btu/cf

Pico (POD) Gas Analysis (1:43 PM)				
c:\mti\ezchrom\200\chrom\vtest.58	**Mole %**	**BTU**	**RD**	**GPM**
NITROGEN	1.041	0.000	0.010	0.000
METHANE	95.722	969.029	0.530	0.000
CO_2	1.352	0.000	0.021	0.000
ETHANE	1.520	26.960	0.016	0.407
H_2S	0.000	0.000	0.000	0.000
PROPANE	0.250	6.305	0.004	0.069
i-BUTANE	0.042	1.369	0.001	0.014
n-BUTANE	0.045	1.471	0.001	0.014
NEOPENTANE	0.000	0.000	0.000	0.000
i-PENTANE	0.014	0.561	0.000	0.005
n-PENTANE	0.010	0.402	0.000	0.004
C6+	0.004	0.191	0.000	0.002
TOTAL	**100.000**	**1006.288**	**0.583**	**0.514**
Compressibility Factor	0.9979			
Heating Value Gross BTU Dry	1008.400			
Heating Value Gross BTU Sat.	992.045			
Relative Density Gas Corr.	0.5839			
Total Unnormalized Conc.	98.796			
WOBBE Index	1319.665			

LNG 1105

- **Sample Time:** 11:46 AM
- Blended and bottled by Matheson Tri-Gases located in Joliet, IL.
- **HHV:** 1106 Btu/cf, **Wobbe Number:** 1410 Btu/cf.

LNG Analysis (11:46 AM)				
c:\mti\ezchrom\200\chrom\vtest.16	**Mole %**	**BTU**	**RD**	**GPM**
NITROGEN	0.118	0.000	0.001	0.000
METHANE	91.555	926.845	0.507	0.000
CO_2	0.005	0.000	0.000	0.000
ETHANE	5.503	97.606	0.057	1.472
H_2S	0.000	0.000	0.000	0.000
PROPANE	1.772	44.688	0.027	0.488
i-BUTANE	0.522	17.014	0.010	0.171
n-BUTANE	0.523	17.101	0.010	0.165
NEOPENTANE	0.000	0.000	0.000	0.000
i-PENTANE	0.000	0.000	0.000	0.000
n-PENTANE	0.001	0.040	0.000	0.000
C6+	0.001	0.048	0.000	0.000
TOTAL	**100.000**	**1103.343**	**0.613**	**2.297**
Compressibility Factor	0.9975			
Heating Value Gross BTU Dry	1106.114			
Heating Value Gross BTU Sat.	1088.113			
Relative Density Gas Corr.	0.6148			
Total Unnormalized Conc.	99.541			
Wobbe Number	1410.694			

Zero & Span Averages

Span and Zero Average Datafile (Before Catalyst)							
Site Name: LNG-Ventura-100203 10/02/2003 7:34:16 AM							
Data file name: C:\Das\Cart Das\Logfiles\LNG-Ventura-100203100203tensec.csv							
			Raw Emissions				
	Time	Avg. Time (min)	O_2 (%)	CO_2 (%)	CO (ppm)	HC (ppm)	NO_x (ppm)
Zero (Start)	9:43:46	1	0.00	0.00	0.00	0.00	0.00
Span (Start)	9:47:32	1	3.95	15.96	8600.00	2800.00	452.50
Span (end)	1:58:41	1	3.99	15.96	8626.00	2790.00	452.50
Zero (end)	2:01:28	1	0.00	0.00	0.00	0.00	0.00
* Corrected to 15% O_2							

Span and Zero Average Datafile (After Catalyst)							
Site Name: LNG-Ventura-100203 10/02/2003 7:34:16 AM							
Data file name: C:\Das\Cart Das\Logfiles\LNG-Ventura-100203100203tensec.csv							
			Raw Emissions				
	Time	Avg. Time (min)	O_2 (%)	CO_2 (%)	CO (ppm)	HC (ppm)	NO_x (ppm)
Zero (Start)	7:37:50	1	0.74	0.04	0.04	-0.08	-0.09
Span (Start)	7:44:43	1	1.00	12.21	77.56	434.82	18.64
Zero (Start)	9:43:46	1	0.05	0.03	0.51	-0.97	-0.22
Span (Start)	9:47:32	1	1.00	12.23	79.24	431.25	19.04
Span (Start)	1:13:49	1	0.97	12.24	7.97	433.87	18.49
Zero (Start)	1:16:27	1	0.05	0.07	0.00	-0.4	0.67
Span (end)	1:58:41	1	1.01	12.28	7.94	435.18	18.27
Zero (end)	2:01:28	1	0.04	0.07	-0.12	-0.49	-0.08
* Corrected to 15% O_2							

Compressor

- **Manufacturer:** Ariel
- **Type:** Reciprocating
- **Number of Cylinders:** 2

Engine History

This engine is one out of three engines used to compress natural gas. These engines are no longer needed and are scheduled to be decommissioned. Following is a table with the yearly fuel consumption, run hours and pounds of NO_x.

Fuel Consumption (mmscf)					
1997	**1998**	**1999**	**2000**	**2001**	**2002**
0.73	n/a	n/a	0.1083	0.0979	0.2914
Run Hours					
1997	**1998**	**1999**	**2000**	**2001**	**2002**
829	444	3027	138	72	326
NO_X lb/yr					
1997	**1998**	**1999**	**2000**	**2001**	**2002**
0.42	0.22	1.51	0.07	0.04	0.16

Installation

The engine was installed following the manufacturer's directions for installation. The engine was operated at an output of 168 BHP at 1400 RPM. The horsepower was calculated using the manufacturer's performance tables. The air/fuel controller set points were 744 mV – 780 mV. The vacuum pressure was maintained at 8.5 in w.c. For the compressor, the suction and discharge pressures were set to 148 psig and 340 psig. Thermocouples were installed to measure ambient, gas, inlet catalyst and outlet catalyst temperatures. A gas meter was installed to measure the gas flow. Pressure transducers were installed to measure gas pressure and skid pressure. An emissions probe was installed in the exhaust system before and after the catalyst.

Test Method

1. All emissions analyzers were calibrated.
2. The engine was turned "on" and allowed to warm up on PLG 1061 (Ventura Line Gas) while emission, pressure, and temperature readings were monitored.
3. The data logger was turned on and the engine-net was loaded. Temperatures, pressures, and gas flow readings were verified to ensure that all probes were working properly.
4. Engine operating parameters including air/full controller set points, temperatures before and after catalyst, suction, discharge, and vacuum manifold pressures were verified to ensure that the pollution control system and engine were working properly.
5. Tests were conducted for at least 15 minutes or until the test gas run out. During the morning tests the gases were introduced in the following order:

   PLG 1061 — Ventura Line Gas
   PLG 1008 — Pico Gas
   LNG 1107 — Liquid Natural Gas
   PLG 1080 —Brea Gas
   PLG 1128 —Seal Beach Gas
   PLG 1061 — Ventura Line Gas

6. Drift inspections were performed on all emissions analyzers.
7. During the afternoon tests the gases were introduced in the following order:

   PLG 1061 — Ventura Line Gas
   LNG 1107 — Liquid Natural Gas
   PLG 1008 — Pico Gas
   PLG 1128 —Seal Beach Gas

8. Drift inspections were performed on all emissions analyzers.

Results

Emissions Data After the Catalyst [1]— While operating on all the different test gases the engine met the CO and NOx emissions requirements from the Ventura Air Quality Management District VAQMD. The CO, NOx emission limits in this district are 25 and 4,500. We were unable to draw any conclusion because there were large variations in the emissions concentrations even while running on one gas. Often emissions concentrations of all the different constituents fluctuated up or down when the gases were switched, however there were not consistent patterns and therefore we were not able to draw any conclusions. These fluctuations also occurred in the middle of a run and they are common in these types of systems. There are different theories that explain these fluctuations such us: a) changes in load, b) variations in the gas supply pressure, and c) air/fuel controller over correcting. However, we are not sure why they occurred during our tests. Emissions data after the catalyst are depicted below in Figure 1.

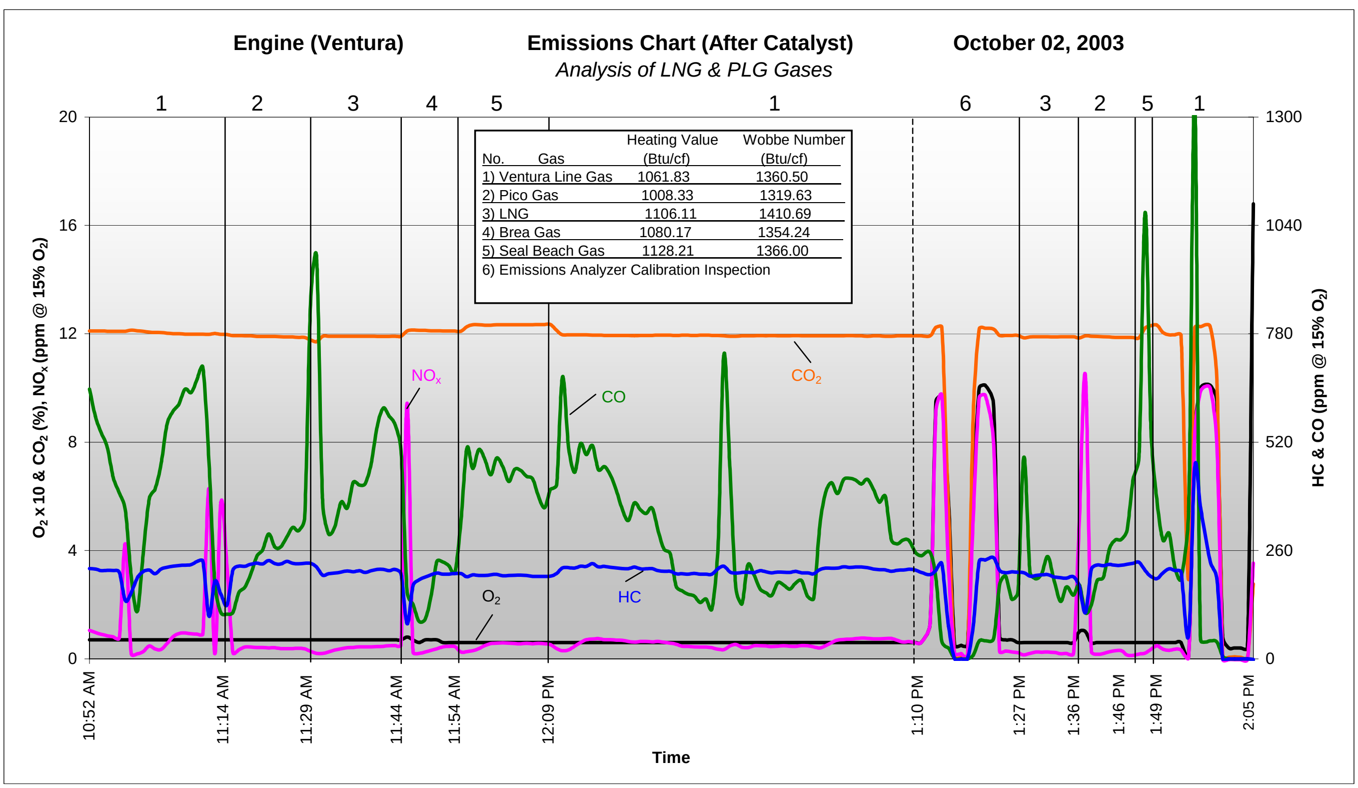

Figure 1

[1] Emissions data is reported as follows: O_2, CO_2 in percentage (%) and NO_x, CO and HC, in ppm @ 15% O_2.

Emissions Data Before the Catalyst — The emissions before the catalyst follow almost the same pattern as the emissions after the catalyst. Again, we were unable to draw any conclusion because of the reasons described above. Emissions data before the catalyst are depicted below in Figure 2.

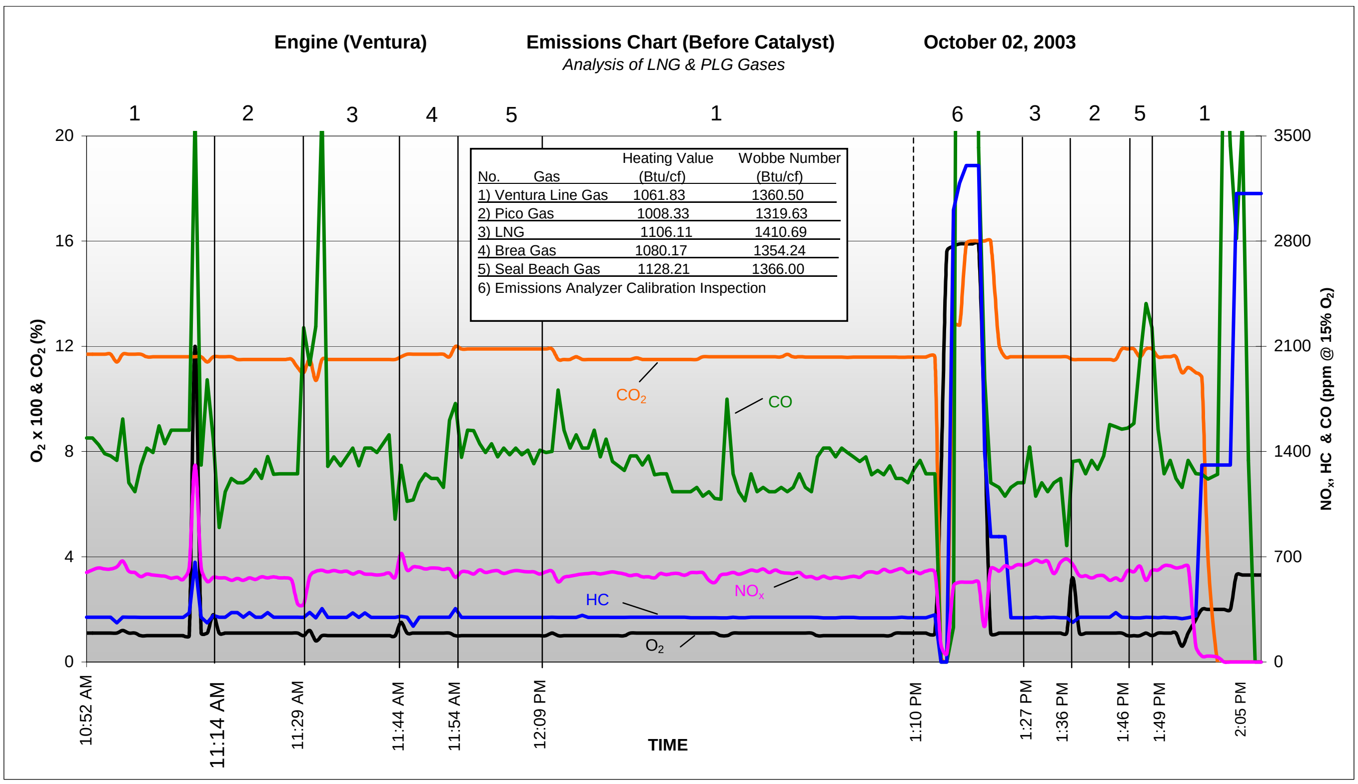

Figure 2

Temperature Data **–** The data from the temperatures before and after the catalyst demonstrate that these temperatures increase as the heating value and Wobbe number decreases. In the following graph we can observe that the highest temperatures before and after the catalyst were when the PLG 1008 was utilized. This is the gas with the lowest heating value and Wobbe number. Also, the lowest temperatures are observed when LNG 1107 and PLG 1128 were utilized which are the gases with the highest heating values and Wobbe numbers. The changes in temperatures before and after the catalyst are because the engine is running leaner with the lower heating value gases and richer with the higher heating value gases. The gas temperature changed due to the pressure drop in the two-stage regulator system. When utilizing Ventura gas line the temperature changes were very minimal because this gas did not go through the two-stage regulator system. Temperature results are depicted in Figure 3.

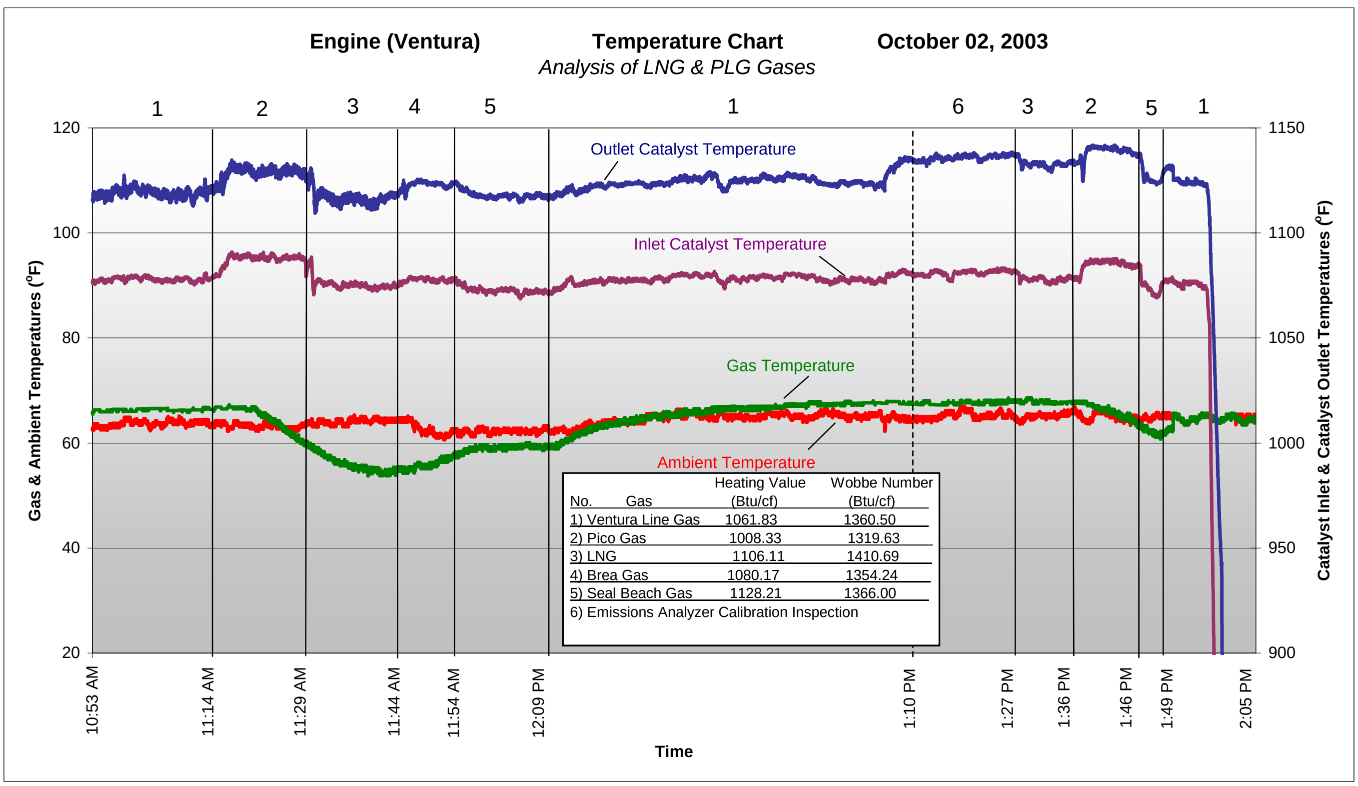

Figure 3

Input Data **–** Throughout the tests we tried to maintain the supply pressure constant but when the test gases were introduced and bottles were switched there were some changes in the supply pressure. We concluded that the supply pressure was not the main cause of the emissions spiking because when we ran the line gas, which had very little pressure changes, the emissions continued to have fluctuations. Input data results are depicted below in Figure 4.

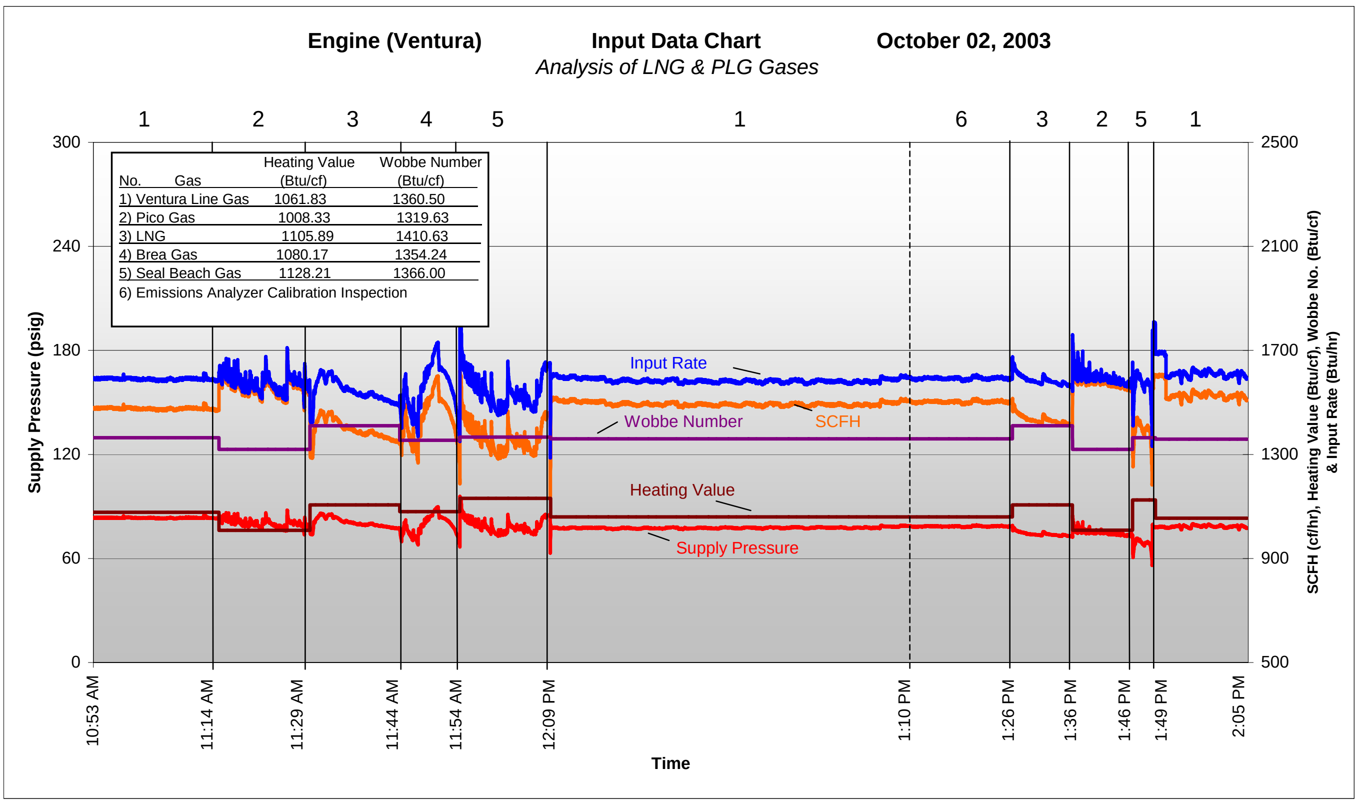

Figure 4