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Testing of a 4-Stroke Lean Burn Gas-fired Reciprocating Internal Combustion Engine to Determine the Effectiveness of an Oxidation Reduction Catalyst System for Reduction of Hazardous Air Pollutant Emissions

FINAL REPORT

TESTING OF A 4-STROKE LEAN BURN GAS-FIRED RECIPROCATING INTERNAL COMBUSTION ENGINE TO DETERMINE THE EFFECTIVENESS OF AN OXIDATION CATALYST SYSTEM FOR REDUCTION OF HAZARDOUS AIR POLLUTANT EMISSIONS

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Appendix A presents the 4SLB report issued by CSU EECL on April 28, 2000. Appendix B contains example calculations used by PES to calculate results, and background correspondence pertaining to the Waukesha test program.

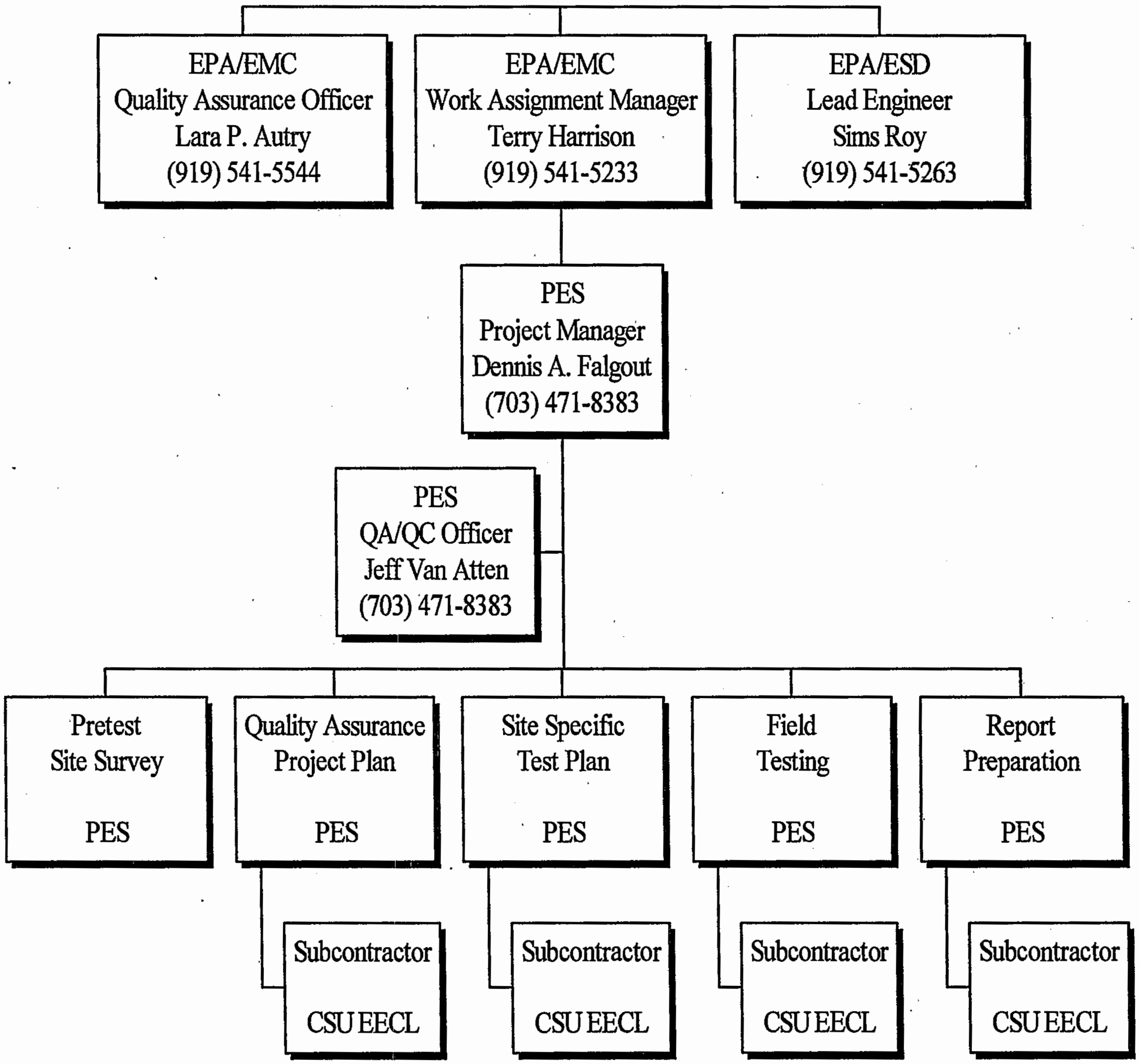

Figure 1.1 Test Program Organization and Major Lines of Communication

2.0 SUMMARY OF RESULTS

This section provides summaries of the stack gas parameters and HAP emissions measured during the test program. Testing of the Waukesha 3521GL engine was conducted August 4 through August 6, 1999 at CSU's Engines and Energy Conversion Laboratory in Fort Collins, Colorado. The following sub-sections present the test times and durations, engine and stack gas parameters, and HAP concentrations and mass flow rates before and after the oxidation catalyst. The end of this section contains a discussion of the efficiencies at which the catalyst removed HAP.

CSU submitted a report documenting the results of the test program to PES. This report is reproduced in its entirety in Appendix A. PES discovered errors in the combustion products (F_d) factors calculated by CSU, which resulted in errors in the calculations of pollutant mass flow rates. PES requested that CSU correct the errors and re-submit the emissions calculations so that the final report could be completed. The corrected results submitted by CSU showed that only 9 of the sixteen runs used the correct F_d values. Slight errors still exist in CSU's calculated results for Runs 2, 4, 7, 8, 10, 11, and 12. In the tables that follow, the correct F_d values are used for each run. PES believes that the values expressed in these tables are correct representations of pollutant mass flow rates during the test program.

2.1 EMISSIONS TEST LOG

During the test period, the test team conducted thirty-four test runs using FTIRS and CEMS. These test runs consisted of sixteen 5-minute Quality Control (QC) runs, sixteen 33-minute sampling runs for collection of FTIRS and CEMS data, and two 5-minute baseline runs. Table 2.1 presents the emissions test log. The test log summarizes the date and time that each run was conducted. Additional discussions regarding the engine operating parameters may be found in Section 3.0 of this document.

In Table 2.1, the sampling runs are presented in the order that they were conducted. In the tables that follow Table 2.1, the sampling runs are presented in numerical order. During the test program, engine conditions were set by making small changes in engine operation from run to run rather than large changes. The purpose of this approach was to reduce both the times between test runs to change an engine condition and the time required for the engine to stabilize after each change. The effect on the test program was that the engine load conditions for which emissions data were sought were not conducted in the same

TABLE 2.3

EMISSION RATES OF DETECTED FTIRS AND CEMS COMPOUNDS

Run ID		Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8
Catalyst Inlet									
Formaldehyde	mg/bhp-hr	308	346	327	282	394	308	354	318
	mlb/hr	501	394	311	384	641	501	403	433
Acetaldehyde	mg/bhp-hr	ND	ND	ND	ND	ND	ND	ND	ND
	mlb/hr	ND	ND	ND	ND	ND	ND	ND	ND
Acrolein	mg/bhp-hr	ND	ND	ND	ND	ND	ND	ND	ND
	mlb/hr	ND	ND	ND	ND	ND	ND	ND	ND
Nitrogen Oxides (as NO_2)	g/bhp-hr	0.824	0.588	0.554	0.742	0.588	1.43	1.05	0.453
	lb/hr	1.34	0.669	0.527	1.01	0.955	2.33	1.20	0.617
Carbon Monoxide	g/bhp-hr	2.78	2.77	2.66	2.48	3.70	2.84	2.81	2.91
	lb/hr	4.52	3.15	2.53	3.37	6.01	4.62	3.20	3.95
Methane	g/bhp-hr	3.69	4.44	5.01	4.08	5.33	3.08	3.61	5.17
	lb/hr	6.00	5.05	4.77	5.54	8.66	5.01	4.11	7.03
Non-methane Hydrocarbons	g/bhp-hr	1.19	1.34	1.53	0.98	1.64	0.89	1.15	1.35
	lb/hr	1.94	1.52	1.45	1.33	2.67	1.45	1.30	1.83
Total Hydrocarbons	g/bhp-hr	4.57	5.71	6.42	5.19	7.01	3.89	4.57	6.51
	lb/hr	7.43	6.49	6.11	7.05	11.39	6.33	5.20	8.84
Catalyst Outlet									
Formaldehyde	mg/bhp-hr	99	87.7	60.1	83.1	133	74.6	69.7	110
	mlb/hr	160	100	57.1	113	216	121	79.2	150
Acetaldehyde	mg/bhp-hr	ND	ND	ND	ND	ND	ND	ND	ND
	mlb/hr	ND	ND	ND	ND	ND	ND	ND	ND
Acrolein	mg/bhp-hr	ND	ND	ND	ND	ND	ND	ND	ND
	mlb/hr	ND	ND	ND	ND	ND	ND	ND	ND
Nitrogen Oxides (as NO_2)	g/bhp-hr	0.876	0.637	0.622	0.780	0.637	1.48	1.10	0.489
	lb/hr	1.42	0.724	0.592	1.06	1.03	2.41	1.25	0.665
Carbon Monoxide	g/bhp-hr	0.185	0.126	0.101	0.127	0.266	0.167	0.115	0.163
	lb/hr	0.301	0.143	0.097	0.172	0.433	0.271	0.131	0.221
Methane	g/bhp-hr	3.22	4.04	4.20	3.71	4.75	2.72	3.20	3.46
	lb/hr	5.23	4.59	4.00	5.04	7.72	4.42	3.64	4.70
Non-methane Hydrocarbons	g/bhp-hr	0.95	1.10	1.22	0.849	1.37	0.692	0.862	1.25
	lb/hr	1.54	1.25	1.16	1.15	2.22	1.13	0.98	1.70
Total Hydrocarbons	g/bhp-hr	4.79	5.83	6.51	5.19	7.02	3.84	4.59	6.74
	lb/hr	7.78	6.63	6.20	7.05	11.4	6.24	5.22	9.16

g/bhp-hr - grams per brake horsepower hour
lb/hr - pounds per hour
mg/bhp-hr - milligrams per brake horsepower hour
mlb/bhp-hr - millipounds per brake horsepower hour
ND - Not Detected. Refer to Table 6.1 for run-by-run summary of detection limits.

NOTES: The methane/NMHC analyzer at the catalyst outlet malfunctioned during Run No. 8. Emission Rates for methane and NMHC were calculated using QC Run No. 8 values.
Different analyzer models were used to measure THC and the catalyst inlet and outlet locations. This may have led to small measurement errors due to variability in FID responses.
F_d values for Runs 2,4,7,8,10,11, and 12 differ from F_d values reported by CSU. See text on page 2-1 for discussion.

TABLE 2.3 (CONCLUDED)

EMISSION RATES OF DETECTED FTIRS AND CEMS COMPOUNDS

Run ID		Run 9	Run 10	Run 11	Run 12	Run 13	Run 14	Run 15	Run 16
Catalyst Inlet									
Formaldehyde	mg/bhp-hr	307	297	294	306	356	301	326	319
	mlb/hr	498	483	478	497	579	489	531	519
Acetaldehyde	mg/bhp-hr	ND	ND	ND	ND	ND	ND	ND	ND
	mlb/hr	ND	ND	ND	ND	ND	ND	ND	ND
Acrolein	mg/bhp-hr	ND	ND	ND	ND	ND	ND	ND	ND
	mlb/hr	ND	ND	ND	ND	ND	ND	ND	ND
Nitrogen Oxides (as NO_2)	g/bhp-hr	0.784	0.93	0.774	0.800	0.542	1.26	0.720	0.811
	lb/hr	1.27	1.51	1.26	1.30	0.880	2.05	1.17	1.32
Carbon Monoxide	g/bhp-hr	2.76	2.68	2.67	2.68	3.16	2.88	2.91	2.85
	lb/hr	4.48	4.36	4.34	4.36	5.14	4.69	4.73	4.64
Methane	g/bhp-hr	3.74	3.06	3.30	3.48	4.57	3.57	4.02	3.87
	lb/hr	6.07	4.97	5.37	5.65	7.43	5.80	6.54	6.29
Non-methane Hydrocarbons	g/bhp-hr	1.17	0.96	1.08	0.99	1.52	1.05	1.33	1.22
	lb/hr	1.91	1.56	1.76	1.61	2.47	1.70	2.16	1.99
Total Hydrocarbons	g/bhp-hr	4.62	4.19	4.52	4.40	5.55	4.46	4.92	4.84
	lb/hr	7.50	6.82	7.35	7.15	9.02	7.24	8.00	7.86
Catalyst Outlet									
Formaldehyde	mg/bhp-hr	96	94.8	94.4	93.9	91.3	101	98.2	97.0
	mlb/hr	155	154	154	153	148	164	160	158
Acetaldehyde	mg/bhp-hr	ND	ND	ND	ND	ND	ND	ND	ND
	mlb/hr	ND	ND	ND	ND	ND	ND	ND	ND
Acrolein	mg/bhp-hr	ND	ND	ND	ND	ND	ND	ND	ND
	mlb/hr	ND	ND	ND	ND	ND	ND	ND	ND
Nitrogen Oxides (as NO_2)	g/bhp-hr	0.862	0.96	0.832	0.845	0.561	1.34	0.775	0.873
	lb/hr	1.401	1.56	1.35	1.37	0.91	2.17	1.26	1.42
Carbon Monoxide	g/bhp-hr	0.181	0.179	0.179	0.179	0.214	0.187	0.197	0.191
	lb/hr	0.294	0.291	0.291	0.291	0.348	0.304	0.320	0.311
Methane	g/bhp-hr	3.30	2.99	3.18	3.26	3.91	3.14	3.58	3.45
	lb/hr	5.36	4.86	5.17	5.30	6.35	5.11	5.83	5.61
Non-methane Hydrocarbons	g/bhp-hr	0.92	0.85	1.00	0.836	0.942	0.863	0.951	0.961
	lb/hr	1.50	1.38	1.62	1.36	1.53	1.40	1.55	1.56
Total Hydrocarbons	g/bhp-hr	4.76	4.37	4.64	4.71	5.51	4.60	5.19	4.96
	lb/hr	7.73	7.11	7.55	7.65	8.95	7.48	8.43	8.06

g/bhp-hr - grams per brake horsepower hour
mlb/bhp-hr - millipounds per brake horsepower hour
lb/hr - pounds per hour
ND - Not Detected. Refer to Table 6.1 for run-by-run summary of detection limits.
mg/bhp-hr - milligrams per brake horsepower hour

NOTES: The methane/NMHC analyzer at the catalyst outlet malfunctioned during Run No. 8. Emission Rates for methane and NMHC were calculated using QC Run No. 8 values.
Different analyzer models were used to measure THC and the catalyst inlet and outlet locations. This may have led to small measurement errors due to variability in FID responses.
F_d values for Runs 2,4,7,8,10,11, and 12 differ from F_d values reported by CSU. See text on page 2-1 for discussion.

Formaldehyde was detected at the upstream and downstream locations during every sampling run. Neither acetaldehyde nor acrolein were detected on any sampling run either before or after the catalyst. Run by run detection limits for the FTIRS compounds are presented in Table 6.1.

EECL personnel operated two CEMS sampling and analysis systems. Engine exhaust gas samples were extracted from locations before and after the catalyst, conditioned, and transported to the CEMS analyzer racks. Moisture was removed from the gas sample before introduction to the O_2, CO_2, CO, and NO_X analyzers. All of the CEMS target compounds were detected at the catalyst inlet and catalyst outlet.

The reported concentration of NMHC at the catalyst outlet for Run No. 8 was 284 ppmv as methane. The reported concentration at the catalyst inlet was 171 parts per million by volume (ppmv) as methane. CSU examine the NMHC data and invalidated the data for this run. At the direction of the WAM, the NMHC values obtained during the 5-minute QC run conducted just prior to Run No. 8 were substituted at both locations. The NMHC concentrations were 168 ppmv as methane and 155 ppmv as methane at the catalyst inlet and outlet locations, respectively. These values are presented in Appendix C of the CSU test report.

2.4 DESTRUCTION OF HAP BY THE CATALYST

There are five possible HAP mass flow rate combinations that can occur across the oxidation catalyst. Table 2.4 presents these combinations, and notes whether a destruction efficiency is reported. Out of the five possible combinations, there are two instances where the destruction efficiency of the target pollutant is reported. If the mass flow rate of a pollutant into the catalyst (Q_{in}) is greater than the mass flow rate exiting the catalyst (Q_{out}), %DE is calculated. If the pollutant is detected entering the catalyst, but is not detected exiting the catalyst, %DE is estimated using the measured mass flow rate at the inlet, and the mass flow rate corresponding to the analytical detection limit at the outlet.

The removal efficiency of HAP for various target compounds is presented in Table 2.5. Formaldehyde was detected on every run that was attempted. In every case, the mass flow rate of formaldehyde into the catalyst was greater than the mass flow rate of formaldehyde leaving the catalyst. Therefore sixteen formaldehyde removal efficiencies were reported. Neither acetaldehyde nor acrolein were detected on any run at either location. There are no removal efficiency data to present for either of these compounds.

The removal efficiency of NO_X is not presented for any run. In every case, the measured concentration of NO_X at the catalyst exit was greater than the measured concentration of NO_X at the catalyst inlet. The difference between the outlet and the inlet

TABLE 2.4

MASS FLOW SCENARIOS

Scenario No.	Result	DE Reported?
1	$Q_{in} > 0$; $Q_{out} > 0$; $Q_{in} > Q_{out}$	YES
2	$Q_{in} > 0$; $Q_{out} = ND$	YES
3	$Q_{in} < Q_{out}$	NO
4	$Q_{in} = ND$; $Q_{out} > 0$	NO
5	$Q_{in} = ND$; $Q_{out} = ND$	NO

values ranged from 5 parts per million by volume, dry basis (ppmvd) to 11 ppmvd, which is 1.0 to 2.2% of the measurement range (0 - 500 ppmvd) of the NO_X analyzers. The apparent increase in NO_X across the catalyst may be due to uncertainty inherent in using two analyzers, and not due to any increase in the mass flow rate of NO_X. Carbon monoxide was detected at the catalyst inlet and outlet on every run. The mass flow rate of carbon monoxide showed a marked decrease across the catalyst. Carbon monoxide destruction efficiencies are presented for every run.

Methane and NMHC were detected by each methane/NMHC analyzer at both locations for every run. There are sixteen removal efficiencies calculated. The difference in methane concentrations across the catalyst averaged approximately 160 ppm for all of the runs. This corresponds to about 3% of the methane analytical range of 0 - 5,000 ppmv. The small difference makes it difficult to determine if there was a reduction in methane across the catalyst, or if the differences are due to uncertainty inherent in using two analyzers. The difference between the NMHC concentrations measured at the catalyst inlet and the catalyst outlet averaged about 30 ppm for all of the runs. This difference is about 6% of the NMHC analytical range of 0 - 500 ppmv. The data indicates that some NMHC was probably removed by the catalyst.

There are no destruction efficiencies presented for total hydocarbons. In fifteen of sixteen cases, the mass flow rate of THC exiting the catalyst was greater than the mass flow rate of THC entering the catalyst. The difference in the concentration measurements at these locations approached 1% of the THC analytical range of 0 - 5,000 ppmv. Therefore, there was most likely no removal of THC across the catalyst. Since THC is made up mostly of methane, this seems to indicate that the difference in methane values was most likely due to inherent measurement errors.

TABLE 2.5

CATALYST HAP REMOVAL EFFICIENCIES

Run ID	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8
Formaldehyde	68%	75%	82%	71%	66%	76%	80%	65%
Carbon Monoxide	93%	95%	96%	95%	93%	94%	96%	94%
Methane	13%	9%	16%	9%	11%	12%	12%	33%
Non-methane Hydrocarbons	20%	18%	20%	13%	17%	23%	25%	7%

Run ID	Run 9	Run 10	Run 11	Run 12	Run 13	Run 14	Run 15	Run 16
Formaldehyde	69%	68%	68%	69%	74%	66%	70%	70%
Carbon Monoxide	93%	93%	93%	93%	93%	94%	93%	93%
Methane	12%	2%	4%	6%	14%	12%	11%	11%
Non-methane Hydrocarbons	21%	12%	8%	16%	38%	18%	29%	21%

3.0 SOURCE DESCRIPTION AND OPERATION

This section presents discussions of the candidate engine and the catalyst used for the test program. The sections that follow describe the engine and the operation of the engine during testing.

3.1 ENGINE DESCRIPTION

The Waukesha 3521GL is a 4-stroke stationary internal combustion engine. The engine has six inline cylinders; the total piston displacement is 3520 cubic inches. Each cylinder is 9.375 inches in diameter, and has an 8.5-inch stroke. The compression ratio is 10.5:1. Air is delivered to the engine via the EECL's pressurized air delivery system; air manifold pressures are controlled by the EECL process control system. Engine loading is controlled by a computer-controlled water brake dynamometer. Before the test program EECL installed an oxidation catalyst, manufactured by MiraTech Corporation, on the engine. EECL aged the catalyst under its normal operating condition (i.e., burned in the catalyst) before the test program. This procedure ensured that the catalyst's HAP destruction efficiency approximated the HAP destruction efficiency of mature catalysts installed on 4-stroke engines in industry. Table 3.1 presents specifications of the engine and the catalyst. Table 3.2 presents nominal engine operating parameters.

The 4-stroke cycle requires two revolutions of the engine crankshaft for each power stroke. During the intake stroke, the piston moves down the cylinder and an air/fuel mixture is injected into the piston chamber. On the compression stroke, the piston moves back up the chamber, and the mixture is compressed and ignited. The expanding gas generated upon combustion forces the piston back down the chamber. This stroke is the power stroke. The last stroke of the 4-stroke cycle is the exhaust stroke. The piston travels back up the chamber and the combustion products are vented through the exhaust manifold.

The 3521GL engine was outfitted with lean-burn technology, which controls NO_X emissions. The lean-burn system uses pre-combustion chambers to ignite a lean air/fuel mixture in the main combustion chambers. A rich mixture of air and fuel is drawn into the pre-combustion chamber and is ignited by a spark plug. The resulting flame is then directed into the main combustion chamber, which contains a lean mixture of air and fuel. The flame jet from the pre-combustion chamber ignites the air/fuel mixture in the main chamber.

TABLE 3.1

ENGINE AND CATALYST SPECIFICATIONS

Engine Classification	Four-stroke, lean burn, natural-gas-fired
Manufacturer and Type	Waukesha 3521 GL
Number of Cylinders	6
Bore and Stroke	9.375" x 8.5"
Nominal Engine Speed	1200 RPM
Ignition System Classification	Spark Ignited Pre-combustion Chamber
Ignition System	Altronic
Pre-combustion Chamber Type	Standard OEM Product
Number of Pre-combustion Chambers	1 Per Cylinder
Catalyst Classification	Oxidation Type
Manufacturer	Miratech Corporation
Date of Manufacture:	May 1999
Model Number: Serial Number: Item Number:	None. Custom-designed unit None. Custom-designed unit CSU-RE-12160
Catalyst Material:	Platinum/Palladium on Stainless Steel Substrate. Manufactured in Finland by Kemira
Element Size: Effective Area:	12" x 16" x 3" 11" x 14 7/8"
Number of Elements	2

TABLE 3.2

SUMMARY OF NOMINAL ENGINE PARAMETERS

Parameter	Nominal Value	Acceptable Deviation	Designation
Torque	3236 ft-lb	± 2% of value	Primary
Speed	1200 rpm	± 5% of value	Primary
Jacket Water Temp (Outlet)	180 °F	± 5% of value	Primary
Oil Temperature	185 °F	± 5% of value	Primary
Air Manifold Temperature	100 °F	± 5% of value	Primary
Air Manifold Pressure	5 inches Hg over ambient pressure (i.e., sea level)	± 5% of value	Primary
Exhaust Manifold Pressure	5 inches Hg less than Air Manifold Pressure	± 5% of value	Primary
Ignition Timing	10° BTDC	± 5% of value	Primary
Overall Air/Fuel Ratio	28/1	± 5% of value	Primary
Inlet Air Humidity-Absolute	0.015 lb H_2O/lb Air	± 10% of value	Primary
Fuel Flow	5460 scfh	± 5% of value	Primary
Oil Pressure Inlet	52 psig	± 10% of value	Secondary
Inlet Air Flow	1730 scfm	± 5% of value	Secondary
Average Exhaust Temp	700 °F	± 5% of value	Secondary

ft-lb - foot-pounds
rpm - revolutions per minute
°F - degrees Fahrenheit
BTDC - Before Top Dead Center
lb H_2O/ lb Air - pounds water vapor per pound of air
scfh - standard cubic feet per hour
psig - pounds per square inch, gauge
scfm - standard cubic feet per minute

3.2 ENGINE OPERATION DURING TESTING

As stated in Section 2 of this document, three types of test runs were conducted during the test program: quality control runs, sampling runs for FTIRS and CEMS, and baseline runs. The operation of the engine during these various runs is discussed in the following pages and tables. The four-stroke engine test matrix described in the QAPP was based upon estimated operating parameters for a candidate engine to be installed and operated at the EECL. When the engine was received and first operated by EECL the actual operating parameters differed from the estimates. Table 3.3 presents the test matrix for the Waukesha engine based upon the actual engine parameters. During the test program, the six engine operating parameters expected to have the greatest impact on pollutant formation were varied from their baseline values. These parameters were: engine speed (measured in revolutions per minute or rpm), engine torque (measured in foot-pounds or ft-lb), air-to-fuel ratio (calculated as an equivalence factor), engine timing (the location of the piston, relative to top dead center, at the time of spark in the pre-combustion chamber, measured in degrees), air manifold temperature (measured in degrees Fahrenheit), and jacket water outlet temperature (measured in degrees Fahrenheit).

Table 3.4 presents engine parameters recorded during each test run and their percent deviation from the target values. Sixteen sampling runs were conducted on the engine during the two-day period. Except for air/fuel ratios, the actual parameters agreed with the target parameters to within 5%. Although the calculated air/fuel ratios were not within 5% of the target air/fuel ratios, testing was conducted while operating at rich air/fuel ratios (Runs 5 and 8) and at lean air/fuel ratios (Runs 6 and 7). The air/fuel ratio was varied to simulate the range of air/fuel ratios that typcial in field applications.

Before starting Run 7, the humidity control system failed. The humidity system could not be repaired quickly so the run was conducted without inlet air humidity control. Run 2 was also conducted without inlet air humidity control. The set point for the humidity ratio for all test points was 0.015 lb. water / lb. air. The actual humidity ratios for Runs 2 and 7 were 0.0126 and 0.0127 lb. water / lb. air respectively. The engine emissions for Runs 2 and 7 should be similar to engine emissions at the specified humidity ratio. The most dramatic effect will be on NO_x emissions as can be seen from the data and the graphs presented in Appendix S of the CSU test report. At a constant humidity ratio, it would be expected that formaldehyde emissions would either remain constant or increase slightly with similar changes in CO and THC emissions.

TABLE 3.3

TARGET ENGINE OPERATING CONDITIONS DURING TESTING

Operating Conditions Tested:	Speed (rpm)	Torque (% of maximum)	Equivalence Ratio (ϕ)	Timing (° BTDC)	Intercooler Water Temperature (°F)	Jacket Water Temperature (°F)
Condition 1	H	H	N	S	S	S
Condition 2	H	L	N	S	S	S
Condition 3	L	L	N	S	S	S
Condition 4	L	H	N	S	S	S
Condition 5	H	H	L	S	S	S
Condition 6	H	H	H	S	S	S
Condition 7	H	L	H	S	S	S
Condition 8	L	H	L	S	S	S
Condition 9	H	H	N	S	L	S
Condition 10	H	H	N	S	H	S
Condition 11	H	H	N	S	S	L
Condition 12	H	H	N	S	S	H
Condition 13	H	H	N	L	S	S
Condition 14	H	H	N	H	S	S
Condition 15	H	H	N	S	S	S
Condition 16	H	H	N	S	S	S
	L = 1000 H = 1200	L = 70 H = 100	N = 0.61 L = 0.56 H = 0.62	N = 10 L = 6 H = 14	N = 130 L = 120 H = 140	N = 180 L = 170 H = 190

N = Normal Value
L = Low Value
H = High Value
S = Set-point Value

TABLE 3.4

SUMMARY OF ENGINE PARAMETERS - WAUKESHA 3521 GL

Run ID		Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Run 11	Run 12	Run 13	Run 14	Run 15	Run 16
Engine Speed, rpm	Actual	1197	1197	1002	1002	1197	1197	1197	1001	1197	1197	1197	1197	1197	1197	1197	1197
	Target	1200	1200	1000	1000	1200	1200	1200	1000	1200	1200	1200	1200	1200	1200	1200	1200
	% diff	-0.29%	-0.25%	0.16%	0.15%	-0.28%	-0.26%	-0.26%	0.15%	-0.28%	-0.26%	-0.26%	-0.26%	-0.26%	-0.29%	-0.26%	-0.26%
Engine Torque ft-lb	Actual	3236	2263	2264	3234	3235	3234	2263	3234	3234	3237	3238	3236	3236	3235	3236	3235
	Target	3236	2265	2265	3236	3236	3236	2265	3236	3236	3236	3236	3236	3236	3236	3236	3236
	% diff	0.0%	-0.1%	-0.1%	-0.1%	0.0%	0.0%	-0.1%	-0.1%	-0.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
Equivalence Ratio, ϕ	Actual	0.56	0.56	0.56	0.56	0.52	0.59	0.59	0.53	0.56	0.56	0.56	0.55	0.53	0.56	0.55	0.56
	Target	0.61	0.61	0.61	0.61	0.56	0.62	0.62	0.56	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
	% diff	-8.4%	-8.6%	-8.6%	-8.4%	-6.3%	-4.6%	-5.4%	-6.2%	-7.6%	-8.5%	-8.5%	-9.3%	-13.7%	-8.5%	-9.2%	-8.6%
Ignition Timing, °BTDC	Actual	10	10	10	10	10	10	10	10	10	10	10	10	6	14	10	10
	Target	10	10	10	10	10	10	10	10	10	10	10	10	6	14	10	10
	% diff	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Intercooler Water Temperature, °F	Actual	132	128	130	129	130	128	129	129	119	141	129	130	128	132	128	130
	Target	130	130	130	130	130	130	130	130	120	140	130	130	130	130	130	130
	% diff	0.3%	-0.4%	0.1%	-0.3%	0.1%	-0.3%	-0.2%	-0.2%	-0.1%	0.2%	-0.2%	0.0%	-0.3%	0.3%	-0.3%	0.0%
Jacket Water Temperature, °F	Actual	179	179	179	179	179	180	179	179	179	180	170	190	183	179	179	180
	Target	180	180	180	180	180	180	180	180	180	180	170	190	180	180	180	180
	% diff	-0.3%	-0.5%	-0.6%	-0.3%	-0.3%	0.2%	-0.5%	-0.7%	-0.6%	0.3%	0.0%	0.1%	1.7%	-0.5%	-0.7%	0.1%
Horsepower	bhp	737	516	432	617	737	737	516	617	737	738	738	738	737	737	737	737
Fuel Flow Rate	scfh	5378	4083	3205	4368	5523	5337	4040	4424	5389	5341	5353	5411	5683	5272	5452	5372
Lower Heating Value	Btu/cf	1024	1040	1040	1040	1040	1040	1040	1040	1024	1040	1040	1040	1040	1024	1040	1040
Heat Rate	MMBtu/hr	5.51	4.24	3.33	4.54	5.74	5.55	4.20	4.60	5.52	5.55	5.56	5.63	5.91	5.40	5.67	5.58
Dry Fuel Factor, F_d	dscf/MMBtu	8654	8645	8655	8645	8655	8655	8645	8645	8654	8645	8645	8645	8655	8654	8655	8655

rpm - revolutions per minute
ft-lb - foot pounds
°BTDC - degrees Before Top Dead Center
°F - degrees Fahrenheit
bhp - brake horsepower
scfh - standard cubic feet per hour
Btu/cf - British Thermal Units per cubic foot of natural gas
MMBtu/hr - million Btu per hour

Table 3.5 presents engine parameters measured during two baseline test runs. There were two testing periods. On August 4, testing was conducted over a six-hour period. The engine was shut down and testing resumed on August 5. The testing was completed over the next 26 hours of continuous engine operation. Test accuracy required that the overall engine operation did not change. The stability of the engine over this period was demonstrated by operating the engine at the baseline condition for one 5-minute period early in the 26-hour period and a second 5-minute period at the end of the testing. Changes to the baseline parameters would have indicated a change in the overall operating characteristics of the engine. It would not have been possible to distinguish between emission rate changes attributable to changes in the independent variables and emission rate changes attributable to random changes in the performance of the engine. Table 3.5 compares the values of 13 engine parameters measured during the baseline runs to the manufacturer's recommended settings that were presented in Table 3.2. Deviations are calculated in percent. Temperatures were converted to degrees Rankine, then the percent deviation was calculated.

TABLE 3.5

SUMMARY OF ENGINE PARAMETERS DURING BASELINE RUNS

Run ID		Baseline 1	Baseline 2
Engine Speed, rpm	Actual	1197	1197
	Deviation	-0.26%	-0.26%
Engine Torque, ft-lb	Actual	3236	3238
	Deviation	-0.01%	0.07%
Air/Fuel Ratio, lb air / lb fuel	Actual	32.70	28.60
	Deviation	16.8%	2.1%
Ignition Timing, °BTDC	Actual	10.0	10.0
	Deviation	0.0%	0.0%
Jacket Water Temperature, °F	Actual	180	180
	Deviation	0.18%	-0.11%
Oil Temperature, °F	Actual	186	187
	Deviation	3.37%	3.78%
Air Manifold Pressure, in. Hg	Actual	5.01	5.00
	Deviation	0.2%	0.0%
Exhaust Manifold Pressure, in. Hg	Actual	5.06	4.91
	Deviation	1.20%	-1.80%
Inlet Air Humidity, lb H_2O/lb air	Actual	0.01561	0.01585
	Deviation	4.07%	5.67%
Fuel Flow, scfh	Actual	5474	5358
	Deviation	0.3%	-1.9%
Oil Pressure, psig	Actual	52.19	52.03
	Deviation	0.4%	0.1%
Inlet Air Flow, scfh	Actual	1747	1712
	Deviation	1.0%	-1.0%
Exhaust Temperature, °F	Actual	699	705
	Deviation	-0.09%	0.66%

rpm - revolutions per minute
ft-lb - foot-pounds
lb air / lb fuel - pounds air per pound of fuel
°BTDC - degrees Before Top Dead Center
°F - degrees Fahrenheit
in. Hg - inches of mercury
lb H2O / lb air - pounds water vapor per pound of air
scfh - standard cubic feet per hour
psig - pounds per square inch, gauge
scfm - standard cubic feet per minute

4.0 SAMPLING LOCATIONS

A schematic drawing of the exhaust gas piping on the Waukesha 3521GL engine is shown in Figure 4.1. The engine exhaust manifold was connected to the inlet of the catalyst with an 8-inch internal diameter (ID) pipe. The pipe extended vertically from the exhaust manifold, made a 90° bend, and was connected to the inlet of the catalyst. A 12-inch diameter pipe connected the outlet of the catalyst to a back pressure valve, and then to the exhaust header. EECL personnel used two sampling ports to extract samples for analysis by FTIRS and CEMS. One port was located before the catalyst and one port was located after the catalyst.

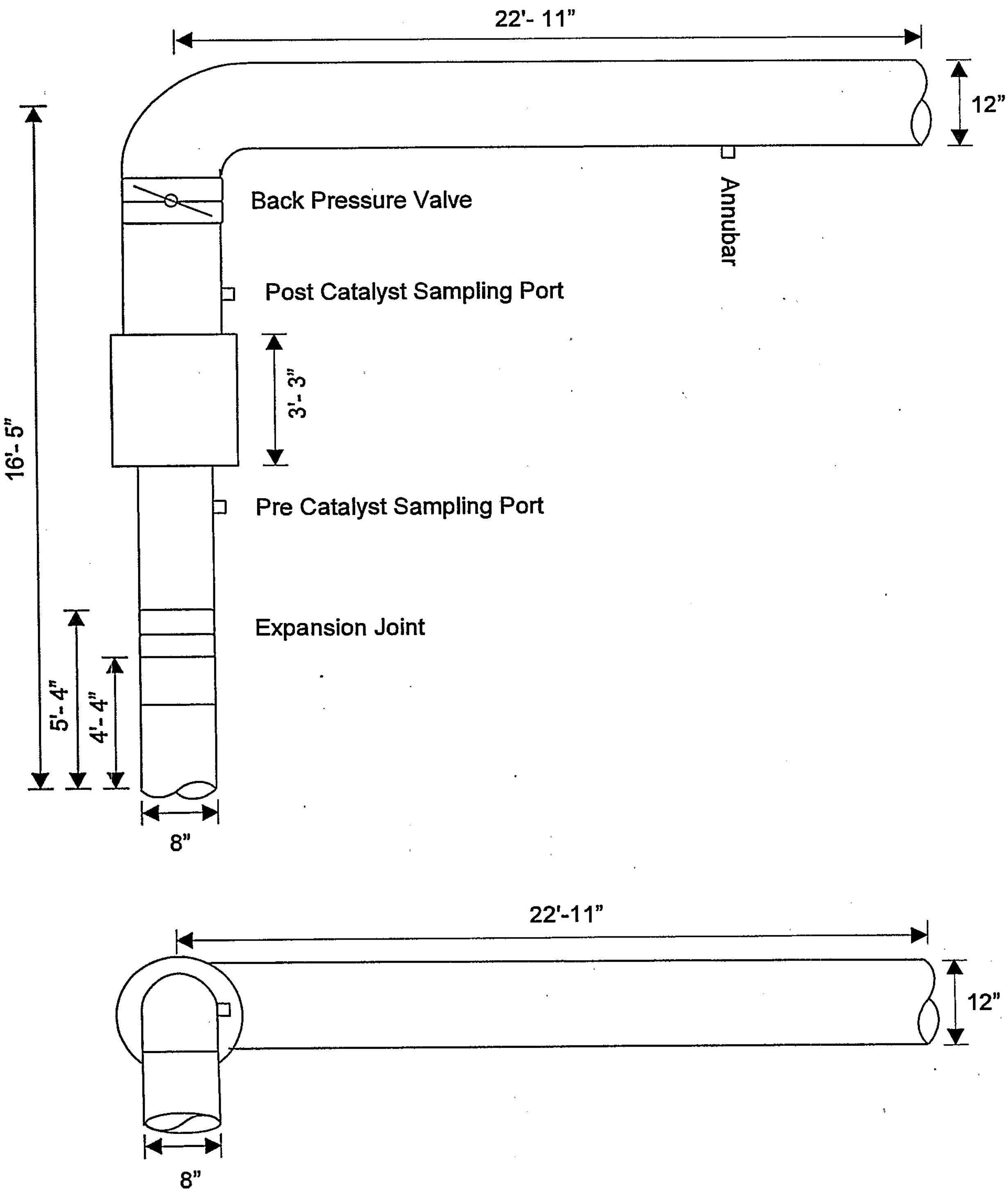

Figure 4.1 Exhaust Piping Schematic

5.0 SAMPLING AND ANALYSIS METHODS

This section discusses the various sampling and analysis methods employed by PES and EECL to quantify the HAP emission rates upstream and downstream of the oxidation catalyst. PES selected the sampling and analysis procedures that would provide the information required during the planning stages of the project. The methods were selected to provide the required data in the most economical fashion, while providing the quality required by EPA's Emissions Standards Division (ESD).

Table 5.1 summarizes the parameters measured, the sampling methods, and measurement principle. The text that follows presents brief descriptions of the sampling and analysis procedures used.

PES and EECL used QA and calibration procedures described in 40 CFR 60, Appendix A (or other references as appropriate) as a guideline for instrument calibrations and drift checks. The instrumental methods as written in 40 CFR 60 Appendix A are designed by EPA to be portable, field test procedures. Because these instruments are maintained in a laboratory-type environment (the control room at EECL), fewer QA activities and calibrations are required to adequately show their continuing accuracy. The only significant change to the quality assurance activities was that fewer instrument calibrations were done to quantify instrument drift. Historical calibration data for the instruments shows their stable operation over extended, e.g., 24-hour, periods. Multipoint calibrations were conducted (including the sampling system bias checks) on these instruments once at the beginning of each engine test series.

5.1 DETERMINATION OF STACK GAS VOLUMETRIC FLOW RATE

PES used EPA Method 19 to calculate the volumetric flow rate of the exhaust gases for Runs 1 through 16. The mass flow rates of pollutants measured by FTIRS and CEMS were calculated using the Method 19 flow data. EPA Method 19, *Determination of Sulfur Dioxide Removal Efficiency and Particulate Matter, Sulfur Dioxide, and Nitrogen Oxides Emissions Rates*, uses a fuel factor to calculate the volume of combustion products generated upon combustion of specific fuel types. EECL personnel analyzed a sample of the natural gas fuel during each day of testing. The results of the compositional analysis were used to calculate the upper heating value and oxygen-based F-factor, F_d. The EECL Engine Control and Monitoring System recorded stack gas O_2 concentrations and the fuel consumption rate during testing. These data were used to calculate the exhaust gas flow rates by multiplying the fuel consumption by the fuel factor, and correcting for excess air. Exhaust gas flow rates were calculated upstream and downstream of the catalyst for each run.

TABLE 5.1

SUMMARY OF SAMPLING AND ANALYSIS METHODS

Parameter	Test Method	Measurement Principle
Volumetric Flow	EPA Method 19	Stoichiometry
Oxygen and Carbon Dioxide	EPA Method 3A	Paramagnetic and Non-dispersive Infrared Analyzers
Moisture	GRI Protocol[1]	FTIR Analyzer
	Carbon Balance[2]	Stoichiometry
Nitrogen Oxides	EPA Method 7E	Chemiluminescent Analyzer
Carbon Monoxide	EPA Method 10	GFC/NDIR Analyzer
Formaldehyde, Acetaldehyde, Acrolein	GRI Protocol	FTIR Analyzer
Methane	EPA Method 25A (modified)	GC-FID Analyzer
Non-methane hydrocarbons	EPA Method 25A (modified)	GC-FID Analyzer
Total Hydrocarbons	EPA Method 25A	FID Analyzer

[1] Measurement of Select Hazardous Air Pollutants, Criteria Pollutants, and Moisture Using Fourier Transform Infrared (FTIR) Spectroscopy. Presented as an Appendix to Fourier Transform Infrared (FTIR) Method Validation at a Natural Gas-Fired Internal Combustion Engine (GRI-95/0271), Gas Research Institute, December 1995.

[2] Derivation of General Equation for Obtaining Engine Exhaust Emissions on a Mass Basis Using the "Total Carbon" Method.

5.2 DETERMINATION OF STACK GAS OXYGEN AND CARBON DIOXIDE CONTENT

EECL used EPA Method 3A, *Determination of Oxygen and Carbon Dioxide Concentrations in Emissions from Stationary Sources (Instrumental Analyzer Procedure)*, to measure oxygen and carbon dioxide content of the exhaust gas during testing. EECL's sample gas extraction and transport system extracted a gas sample from locations upstream and downstream of the catalyst. Each sample was conditioned to remove moisture and entrained particulate matter and directed to the CEMS.. Oxygen was measured using the paramagnetic detection principle. Carbon dioxide was measured using non-dispersive infrared (NDIR) analyzers. The oxygen and carbon dioxide monitors were calibrated with a pre-purified zero gas and three upscale gas standards corresponding to approximately 30, 55 and 85 percent of the instruments' analytical ranges. EECL used only EPA Protocol gas standards certified by the gas manufacturer. The calibration gases that were used and the calibration responses of the instruments are discussed in Section 6.0 of this document. A schematic diagram of the FTIRS/CEMS sampling and analysis system is presented in Figure 5.1.

5.3 DETERMINATION OF STACK GAS MOISTURE CONTENT

EECL used two methods to determine the moisture concentration in the exhaust gas upstream and downstream of the catalyst. Moisture content downstream of the catalyst was calculated using a carbon balance method. This method is summarized in the EECL test report, which may be found in Appendix A. During the testing, EECL personnel determined that the moisture concentrations downstream of the catalyst, as measured by the Nicolet Magna 560 FTIR analyzer, were about 6 percent higher than actual. Therefore the carbon balance method was used to calculate moisture content at this location.

EECL used methodology described in the document *Measurement of Select Hazardous Air Pollutants, Criteria Pollutants, and Moisture Using Fourier Transform Infrared (FTIR) Spectroscopy* to measure moisture concentrations upstream of the catalyst. This document, called the GRI Protocol in this report, is presented as Appendix B of a report published by the Gas Research Institute: *Fourier Transform Infrared (FTIR) Method Validation at a Natural Gas-Fired Internal Combustion Engine*. A sample of the gas was extracted from the exhaust, filtered and directed to a Nicolet Rega 7000 FTIR analyzer to measure the moisture concentration. The gas sample was transported to the analyzer via a heated Teflon® sample line. Further discussion of the FTIRS sampling and analysis method may be found in the report generated by the EECL.

5.4 DETERMINATION OF NITROGEN OXIDES

EPA Method 7E, *Determination of Nitrogen Oxide Emissions from Stationary Sources (Instrumental Analyzer Procedure)*, determined nitrogen oxide content of the exhaust gases.

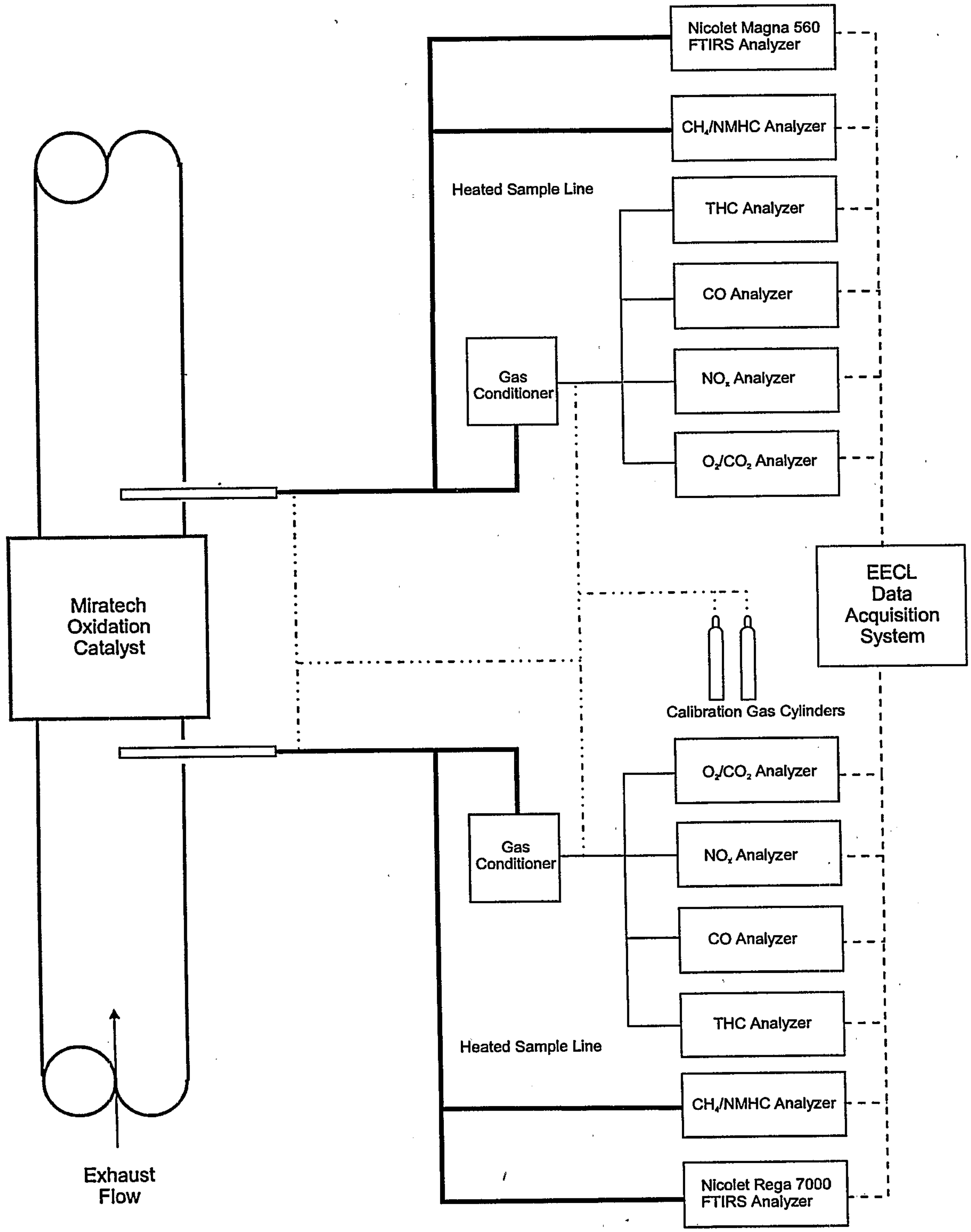

Figure 5.1. Schematic Diagram of EECL FTIRS/CEMS Sampling and Analysis System

These tests also provided the data needed to do the EPA Method 301 validation of the FTIRS for NO_x emissions from this source. Gas samples were extracted from locations upstream and downstream of the catalyst, conditioned to remove moisture, and the nitrogen oxide concentration determined by chemiluminescence analyzers. The NO_x monitors were calibrated with a pre-purified zero gas, and two upscale gas standards corresponding to approximately 55 and 85 percent of the instruments analytical ranges. EECL used EPA Protocol gas standards certified by the gas manufacturer. The calibration gases that were used and the calibration responses of the instruments are discussed in Section 6.0 of this document. A schematic diagram of the FTIRS/CEMS sampling and analysis system is presented in Figure 5.1.

5.5 DETERMINATION OF CARBON MONOXIDE

EPA Method 10, *"Determination of Carbon Monoxide Emissions from Stationary Sources,"* measured CO concentration of the exhaust gas during the testing. These tests also provided the data needed to do the EPA Method 301 validation of the FTIRS sampling and analysis system for CO emissions from this source. Gas samples were extracted from the exhaust gas streams, conditioned to remove moisture, and the carbon monoxide concentration determined by instrumental analyzers. The measurement principle for carbon monoxide is GFC/NDIR. The CO monitor was calibrated using a pre-purified zero gas and three upscale gas standards corresponding to approximately 30, 55 and 85 percent of the instrument's analytical range. All gas standards used for calibrations were prepared according to EPA Protocol and certified by the gas manufacturer. The calibration gases that were used and the calibration responses of the instruments are discussed in Section 6.0 of this document. A schematic diagram of the FTIRS/CEMS sampling and analysis system is presented in Figure 5.1.

5.6 DETERMINATION OF TOTAL HYDROCARBONS

EPA Method 25A, *Determination of Total Gaseous Organic Concentration Using a Flame Ionization Analyzer*, determined the total hydrocarbon concentrations at the inlet and the outlet of the catalyst. At the catalyst inlet, EECL used a Thermo Environmental Instruments (TECO) Model 51 Total Hydrocarbon Analyzer. The analyzer consisted of a heated compartment to prevent condensation of organic compounds, and a Flame Ionization Detector (FID) to measure THC concentrations. At the catalyst outlet, EECL used a Rosemount Analytical NGA-2000 FID Hydrocarbon Analyzer. This analyzer also used an FID to measure the concentrations of THC in the gas stream. The FID detector consists of a burner in which a regulated flow of a sample gas passes through a flame sustained by regulated flows of a fuel gas and air. The hydrocarbon components of the sample stream ionize in the flame. The positive ions that are produced are collected by an electrode causing current to flow through a measuring circuit. The ionization current is proportional to the rate at which carbon atoms enter the burner, and is therefore a measure of the concentration of hydrocarbons in the sample.

5.7 DETERMINATION OF METHANE AND NON-METHANE HYDROCARBONS

A modification of EPA Method 25A determined the methane and non-methane concentrations at the inlet and the outlet of the catalyst. Gas samples extracted from each gas stream were transported to Questar Baseline 1030H Methane/Non-Methane Analyzers. These analyzers are single-purpose gas chromatographs that separate methane from the other organic compounds in the sample by passing the sample through a separation column. The methane elutes from the column first and is directed to the flame ionization detector. Then, the analyzer reverses the flow through the column and the remaining organic compounds are back flushed to the same detector. The analyzer sums the two fractions to yield the concentration of total organic compounds. Because this unit is a gas chromatograph, it cannot measure methane and non-methane concentrations continuously. During testing, each analyzer determined concentrations once every five minutes. This frequency is sufficient for testing on RICE, because the operating conditions were maintained within close constraints. Each analyzer was calibrated before each week of testing using methane and propane calibration standards corresponding to approximately 30, 50, and 85 percent of the instrument span. The calibration gases that were used and the calibration responses of the instruments are discussed in Section 6.0 of this document. A schematic diagram of the CEMS/FTIRS sampling and analysis system is presented in Figure 5.1.

5.8 DETERMINATION OF GASEOUS ORGANIC HAPS USING FTIRS

EECL used two FTIRS systems that met the sampling and analysis requirements set forth in the GRI Protocol. Table 5.2 summarizes the specifications of each FTIRS analyzer. GRI validated extractive FTIRS systems successfully for an analysis of emissions from natural gas-fired RICE. The extractive FTIRS continuously extracts a sample gas from the stack, transports the sample to the FTIRS system, and does spectral analysis of the sample gas. The computer system analyzes sample gas spectra for target analytes continuously and archives them for possible later re-analysis.

The sampling and measurement system consists of the following components:

- heated probe;
- heated filter;
- heat-traced Teflon® sample line;
- Teflon® coated, heated-head sample pump;
- FTIRS spectrometer; and
- QA/QC apparatus.

TABLE 5.2

FTIRS ANALYZER SPECIFICATIONS

Parameter	Pre-catalyst	Post-catalyst
Manufacturer and Type	Nicolet Rega 7000	Nicolet Magna 560
Spectral Resolution	0.5 cm^{-1}	0.5 cm^{-1}
Detector Type	MCT-A	MCT-A
Cell Type	4.2 Meter - Fixed Path Length	2.0 Meter - Fixed Path Length
Cell Temperature	185 °C	165 °C
Cell Pressure	600 Torr	600 Torr
Cell Window Material	Zinc Cellinide	KBr

EECL validated each sample extraction and analysis system for formaldehyde, acetaldehyde, and acrolein before testing. The results of the FTIRS validation are discussed in Section 6. The basic sampling procedure consisted of EECL taking an initial interferogram of the stack gas with the FTIRS measurement and analysis system before each test to describe the sample matrix. This measured the concentrations of moisture and the target pollutants and allowed for adjustments to the cell pathlength and the spectral analysis regions if the concentrations differ from expectations. Sample conditioning was not necessary at the EECL test site.

After QA/QC procedures and initial adjustments were completed for a given test day, a gas sample was drawn continuously through the heated FTIRS cell while the system collected spectral data. The spectrometer collected one complete spectrum of the sample, as an interferogram, per second and averaged interferograms over 1-minute periods. The FTIRS computer converted these time-integrated interferogram into conventional wave number spectra, analyzed for the target compounds and archived the data. Sample collection was 33 minutes in duration, coinciding with the test runs.

5.9 DETERMINATION OF NATURAL GAS COMPOSITION

The composition of the fuel gas combusted in the engine was determined daily using a dedicated Daniels Industries gas chromatograph (GC). The GC was calibrated each day using a known standard. From the results of the daily analyses, the specific gravity, mole fractions, and BTU content of the fuel were calculated. Fuel flow measurements were determined using an American Gas Association (AGA) specified orifice meter run equipped with high accuracy pressure and temperature transmitters. All fuel flow calculations were in accordance with AGA Report #3. Stoichiometric air to fuel ratio calculations were also made using the results of the fuel gas analysis. The results of fuel gas calibrations and analysis are presented in the EECL report, which is attached in Appendix A.

6.0 QUALITY ASSURANCE/QUALITY CONTROL PROCEDURES AND RESULTS

Summarized in this section are the specific QA/QC procedures that PES and EECL personnel employed during the performance of this source testing program. PES' quality assurance program was based upon the procedures and guidelines contained in the "Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III, Stationary Source Specific Methods," EPA/600/R-94/038c, as well as in the test methods. These procedures ensure the collection, analysis, and reporting of reliable source test data.

6.1 FTIRS QA/QC PROCEDURES

EECL calibrated the FTIRS instruments before each engine test series and at the beginning and end of each test day. The calibration procedures employed were consistent with procedures found in the following documents:

> Gas Research Institute Report Number GRI-95/0271 entitled, "Fourier Transform Infrared (FTIRS) Method Validation at a Natural Gas-Fired Internal Combustion Engine."

This report was prepared for the Gas Research Institute by Radian Corporation. Included as appendices are two additional documents, which also have relevance in the test program:

> "Measurement of Select Hazardous Air Pollutants, Criteria Pollutants, and Moisture Using Fourier Transform Infrared (FTIRS) Spectroscopy" – Prepared by Radian Corporation for the Gas Research Institute.

> "Protocol for Performing Extractive FTIRS Measurements to Characterize Various Gas Industry Sources for Air Toxics" – Prepared by Radian Corporation for the Gas Research Institute.

6.1.1 FTIRS System Preparation

Both FTIRS sampling systems (before and after the catalyst) were subjected to an EPA Method 301 validation process for formaldehyde, acetaldehyde, and acrolein. The validation process quantified the precision and accuracy of each FTIRS analyzer for these compounds. Besides the validation program, EECL personnel performed the following calibration procedures before each engine test series.

1. Source Evaluation - Initial source data were acquired to verify concentration ranges of target compounds and possible interferences. This was completed before and during the Method 301 validation process for formaldehyde, acetaldehyde, and acrolein, and during the test program for moisture.

2. Sample System Leak Check – A leak check was done on the portions of the system between the sample filter and the pump outlet. A rotameter was connected to the discharge side of the sample pump. The indicated sample flow rate was recorded with the sample system operating at typical temperatures and pressures (the sample pump pulled a slight vacuum on the suction side). The inlet was closed off just downstream of the sample probe. The rotameter monitored the flow rate. If the leakage rate is found to be no greater than 500 ml/min or 4% of the average sampling rate (whichever is less) the system is considered to be acceptable for use. The leak checks conducted by EECL personnel indicated that the system was acceptable for use.

3. Analyzer Leak Check – Both FTIRS analyzers were checked to ensure that they were operating at normal operating temperatures and pressures. The operating pressures were recorded. The automatic pressure control device was disabled and the inlet to the FTIRS was closed. The cell was evacuated to 20% or less of the normal operating pressure. After the cell was evacuated, it was isolated and the cell pressure was monitored with a dedicated pressure sensor. The leakage rate of the measurement cell is acceptable if it is less than 10 Torr per minute. All analyzer leak checks performed by EECL were within the acceptable range.

4. Cell Pathlength Determination - The FTIRS cell pathlengths were to be determined using the procedure outlined in the Field Procedure Section the document entitled "*Protocol for Performing Extractive FTIRS Measurements to Characterize Various Gas Industry Sources for Air Toxics.*" Because each FTIRS was a fixed pathlength unit (i.e., the pathlengths were not adjustable) measurements of the cell pathlengths were deemed unnecessary. The cell pathlengths specified by the manufacturer were used in the measurement algorithms.

6.1.2 FTIRS Daily Calibrations and QA Procedures

Before each day of testing, EECL personnel calibrated each FTIRS system following the procedures outlined below.

1. Instrument Stabilization – Each of the following components were checked for proper operation to ensure the stability of the operation of the FTIRS instruments:

    a) Instrument heaters and temperature controllers.

    b) Pressure sensors and pressure controllers.

    c) Sample system (pump, filters, flow meters, and water knockouts).

2. The FTIRS analyzers were purged with conditioned air for a minimum of 30 minutes before conducting background spectrum analysis. During periods when the instruments were in stand-by mode (i.e., between sampling runs or between test days), they were maintained at normal operating temperatures and purged with conditioned air.

3. Background Spectrum Procedures – Each instrument was allowed to stabilize while being purged with Ultrahigh Purity (UHP) nitrogen for 10 minutes. The FTIRS spectra were monitored during this time, until CO and H_2O concentrations reached a steady state. The following procedures were then done:

    a) The interferogram signal was checked using signal alignment software.

    b) A single beam spectrum was collected and inspected for irregularities.

    c) Using the single beam spectrum, the detector was checked for non-linearity and corrected if necessary.

    d) The instrument alignment procedure was done.

    e) A background spectrum consisting of 256 scans was collected.

4. Analyzer Diagnostics – Analyzer diagnostics were done by analyzing a diagnostic standard. The standard was a 109 ppm CO EPA Protocol gas standard. EECL uses CO because it has distinct spectral features that are sensitive to variations in system operation and performance. The standard was introduced directly into each instrument, and instrument readings were allowed to stabilize for 5 minutes. The accuracy and precision of each instrument were calculated. The pass/fail criterion for accuracy and precision was 10% of the concentration of the standard

gas. A second diagnostic standard consisting of a blend of CO_2, CO, CH_4, and NO_X was analyzed using the same procedure. Each instrument met the precision and accuracy requirements. Analyzer diagnostic data are presented in the report generated by EECL.

5. Indicator Check & Sample Integrity Check - An indicator check was done by analyzing an indicator standard. A 10.66 ppm formaldehyde standard was introduced directly into each instrument. The instrument readings were allowed to stabilize and a 5-minute data set was collected. The indicator standard was then introduced into the sample system at the sample probe, just upstream of the filter. The instrument readings were allowed to stabilize and a 5-minute set of data was collected. The accuracy, precision, and recovery were calculated based on equations in the document entitled "Protocol for Performing Extractive FTIRS Measurements to Characterize Various Gas Industry Sources for Air Toxics", prepared by Radian Corporation for the Gas Research Institute. The pass/fail criterion for accuracy, precision, and recovery is 100 ± 10% of the known standard (recovery shall be 100 ± 10% of the instrument reading when the indicator gas is introduced directly into the instrument.) Each instrument met these criteria. Indicator check and sample integrity data sheets are included with the EECL report.

6.1.3 Background Assessment

During data acquisition procedures, the baseline absorbance was continually monitored. If at any time the baseline spectrum changed by more than 0.1 absorbance units, the instrument's interferometer was realigned and a new background spectrum collected.

6.1.4 Post Test Checks

Upon completion of the daily test program steps 4 and 5 of the pre-test calibration procedures were repeated. Both of the FTIRS analyzers met all of the acceptance criteria for the calibration and QA procedures. Post test calibration data sheets are included in the EECL report.

6.1.5 FTIRS Validation

Before the test program, both FTIRS sampling and analysis systems were validated for formaldehyde, acrolein, and acetaldehyde. The validation was conducted by personnel from ERG, using procedures outlined in EPA Method 301 "Field Validation of Pollutant Measurement Methods from Various Waste Media." The validation was conducted by spiking the sample gas with known concentrations of formaldehyde, acrolein, and acetaldehyde. The carrier gas was a mixture of acrolein and acetaldehyde and was introduced into the spiking system from a compressed gas cylinder. Formaldehyde was added to the carrier gas by injecting a stock formalin solution onto a heated block at a fixed rate. The acrolein/acetaldehyde gas standard was used as a carrier gas for the vaporized formaldehyde. The three-component mixture was injected into each FTIRS sampling system at a point upstream of each system's filter. Further discussions of the validation procedures employed may be found in the report generated by EECL.

6.1.6 FTIRS Detection Limits

Table 6.1 presents the in-stack detection limits for formaldehyde, acetaldehyde, and acrolein as reported by CSU EECL. These detection limits have been used to calculate the run-by-run mass detection limits for each of the target pollutants.

6.2 CEMS QA/QC PROCEDURES

The following paragraphs describe the CEMS quality assurance procedures that EECL personnel used during the test program. The calibration and QC frequencies far exceeded those required for permanently-installed, compliance analyzers, but are less than those specified for compliance tests by EPA (40 CFR 60, Appendix A). EECL operates their CEMS in a way that is more similar to permanently-installed analyzers.

6.2.1 Analyzer Calibration Gases

EECL used EPA Protocol calibration gases. The calibration gases were manufactured by Scott Specialty Gases. For this program, EPA Protocol 1 calibration gases (RATA Class) were used. Formaldehyde and acetaldehyde/acrolein standards with concentration ranges between 5 - 20 ppm were obtained for FTIRS calibrations. These gases are not available as EPA Protocol Gases, so EECL specified the highest quality available. Scott supplied certification sheets, which may be found in the Appendices of EECL's test report.

6.2.2 Response Time Tests

Response time tests were done on each sample system before initiation of the engine test program. The response time tests were performed before the FTIRS validation process for each sampling system. The response time of the slowest responding analyzer (Questar Baseline Methane/Non-methane hydrocarbon GC) was determined. Response time tests conducted at the EECL indicated sampling system response times of 1:10 minutes. This is the time for the Rosemount Oxygen analyzer (the slowest responding continuous analyzer) to stabilize to response output of the analyzer. The Questar Baseline analyzers have a minimum cycle time of 4:50 minutes. The overall response time for these analyzers when their cycle is started 1:10 minutes after a sample source change is 5:50 minutes.

TABLE 6.1

DETECTION LIMITS OF FTIRS AND CEMS COMPOUNDS

Run ID		Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Run 11	Run 12	Run 13	Run 14	Run 15	Run 16
Catalyst Inlet																	
Formaldehyde	mg/bhp-hr	4.32	4.72	4.65	3.88	5.42	4.06	4.65	4.48	4.21	4.04	4.08	4.12	4.82	4.18	4.42	4.32
	mlb/hr	7.02	5.37	4.42	5.27	8.81	6.59	5.29	6.09	6.85	6.57	6.64	6.70	7.83	6.80	7.19	7.03
Acetaldehyde	mg/bhp-hr	20.1	21.9	21.6	18.1	25.0	18.9	21.4	20.8	19.7	18.8	19.1	19.2	22.5	19.5	20.6	20.1
	mlb/hr	32.7	24.9	20.6	24.6	40.6	30.6	24.3	28.3	32.0	30.6	31.0	31.2	36.5	31.7	33.5	32.7
Acrolein	mg/bhp-hr	15.5	16.3	16.6	14.2	17.4	15.7	16.4	14.9	15.8	15.3	15.5	15.4	18.9	15.3	16.6	16.3
	mlb/hr	25.2	18.5	15.8	19.3	28.3	25.5	18.7	20.3	25.7	24.9	25.3	25.1	30.7	24.9	27.1	26.4
Nitrogen Oxides (as NO2)	g/bhp-hr	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	lb/hr	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Carbon Monoxide	g/bhp-hr	0.04	0.05	0.05	0.04	0.05	0.04	0.04	0.05	0.04	0.04	0.04	0.04	0.05	0.04	0.05	0.05
	lb/hr	0.07	0.05	0.04	0.06	0.08	0.07	0.05	0.06	0.07	0.07	0.07	0.07	0.08	0.07	0.08	0.07
Methane	g/bhp-hr	0.1	0.2	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.1
	lb/hr	0.2	0.2	0.1	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2
Non-methane Hydocarbons	g/bhp-hr	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.04	0.04	0.04
	lb/hr	0.07	0.05	0.04	0.05	0.07	0.06	0.04	0.05	0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07
Total Hydrocarbons	g/bhp-hr	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	lb/hr	0.0002	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Catalyst Outlet																	
Formaldehyde	mg/bhp-hr	3.04	3.14	3.33	2.91	3.42	2.80	2.88	3.20	3.03	2.86	2.86	2.85	3.19	2.99	3.11	3.04
	mlb/hr	4.94	3.57	3.17	3.95	5.57	4.56	3.28	4.36	4.92	4.64	4.66	4.63	5.19	4.86	5.05	4.95
Acetaldehyde	mg/bhp-hr	12.6	12.9	13.7	12.0	14.2	11.6	11.9	13.2	12.5	11.8	11.8	11.8	13.2	12.3	12.8	12.6
	mlb/hr	20.4	14.7	13.1	16.3	23.0	18.8	13.5	18.0	20.3	19.2	19.3	19.1	21.4	20.0	20.8	20.4
Acrolein	mg/bhp-hr	59.7	52.4	54.0	49.0	56.1	51.0	50.6	50.7	52.1	50.8	50.0	50.2	56.4	52.3	54.3	53.4
	mlb/hr	97	59.6	51.4	66.6	91.1	82.8	57.6	68.9	84.6	82.6	81.4	81.6	91.7	85.0	88.3	86.8
Nitrogen Oxides (as NO2)	g/bhp-hr	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	lb/hr	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Carbon Monoxide	g/bhp-hr	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	lb/hr	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01
Methane	g/bhp-hr	0.15	0.15	0.15	0.14	0.16	0.14	0.14	0.15	0.15	0.14	0.14	0.14	0.16	0.14	0.15	0.15
	lb/hr	0.24	0.17	0.14	0.19	0.26	0.22	0.16	0.20	0.24	0.23	0.23	0.23	0.25	0.23	0.24	0.24
Non-methane Hydocarbons	g/bhp-hr	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	lb/hr	0.07	0.05	0.04	0.05	0.07	0.06	0.04	0.05	0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07
Total Hydrocarbons	g/bhp-hr	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	lb/hr	0.0002	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002

mg/bhp-hr - milligrams per brake horsepower hour
mlb/bhp-hr - millipounds per brake horsepower hour
g/bhp-hr - grams per brake horsepower hour
lb/hr - pounds per hour

6.2.3 Analyzer Calibrations

Zero and mid-level span calibration procedures were done on the CO, CO_2, O_2, NO_x, THC, and methane/non-methane analyzers before each test day. Zero and span drift checks were performed upon completion of each data point and upon completion of each test day. A zero and mid-level gas was introduced directly to the analyzers before testing for carbon monoxide, carbon dioxide, oxygen, total hydrocarbons, methane/non-methane, and oxides of nitrogen. The analyzers' output response was set to the appropriate levels. Each analyzer's stable response was recorded. From this data a linear fit was developed for each analyzer. The voltages for each analyzer were recorded and used in the following formula:

$$Y = MX + B$$

where:

B = Intercept
M = Slope
X = Analyzer or transducer voltage
Y = Engineering Units

After each test point and upon completion of a test day, calibrations were conducted by reintroducing the zero and span gases directly to the back of the analyzers. The analyzers' stabilized responses were recorded. No adjustments were made during testing or during the final calibration check. Initial calibration values and all calibration checks were recorded for each analyzer during the daily test program.

The before and after calibrations checks were used to determine zero and span drift for each test point for the CO, CO_2, O_2, NO_x, THC, and methane/non-methane, and analyzers. The zero and span drift checks for all test points and all test days were less than ±2.0% of the span value of each analyzer used during the daily test program. The calibration data sheets are presented in the test report generated by EECL. Table 6.2 presents the types and frequencies of the analyzer calibrations conducted by EECL.

TABLE 6.2

TYPES AND FREQUENCIES OF CEMS ANALYZER CALIBRATIONS

Calibration Type	Gas	Calibration Gas Concentration (units of % of span (1))	Frequency	Calibrant Injection Point	Validation Criterion
ACE (2)	O_2, CO_2, CO, NO_x	0 to 0.25, 40 to 60, 80 to 100	Before each engine test	Directly into the analyzer	<2% of analyzer span for each gas
	Methane/Non-Methane Hydrocarbons	0 to 0.1, 25 to 35, 45 to 55, 80 to 90			<5% of respective cal. gas value
ZSD (3)	O_2, CO_2, CO, NO_x	0 to 0.25, 40 to 60 or 80 to 100 (5)	Before and after each test run	Directly into the analyzer	All errors <3% of span
	Methane/Non-Methane Hydrocarbons	25 to 35, 45 to 55			All errors <3% of span
SSB (4)	NO_x	0 to 0.25, 40 to 60 or 80 to 90 (5)	Before and after each test day	Both directly into the analyzer and into the inlet of the sample line	Both errors <5% of analyzer span
	Methane/Non-Methane Hydrocarbons	0 to 0.25, 25 to 35, 45 to 55 or 80 to 90 (5)	Before and after each test day		

(1) - The span must be 1.5 to 2.5 the concentration expected for each pollutant
(2) - Analyzer calibration error check
(3) - Zero and span drift check
(4) - Sampling system bias check
(5) - Whichever is closer to the exhaust gas concentration

6.2.4 Analyzer Linearity Check

Analyzer linearity checks were done before beginning the test program. The oxygen, carbon monoxide, total hydrocarbon, methane/non-methane, and oxides of nitrogen analyzers were "zeroed" using either zero grade nitrogen or hydrocarbon free air. The analyzers were allowed to stabilize and their output recorded. The analyzers were then "spanned" using the mid-level calibration gases. The analyzers were allowed to stabilize and their output recorded. From this data a linear fit was developed for each analyzer. The voltage for each analyzer was recorded and used in the following formula:

$$Y = MX + B$$

where:

B = Intercept
M = Slope
X = Analyzer or transducer voltage
Y = Engineering Units

Using the linear fit, the linear response of the analyzer was calculated. Low-level and high-level calibration gases were individually introduced to the analyzers. For each calibration gas, the analyzers were allowed to stabilize and their outputs were recorded. Each analyzer's linearity was acceptable. The predicted values of a linear curve determined from the zero and mid-level calibration gas responses agreed with the actual responses of the low-level and high-level calibration gases within ±2.0% of the analyzer span value. The methane/non-methane analyzers' linearity was acceptable as the predicted valued agreed with the actual response of the low-level and high-level calibration gases within ±5.0% of the actual calibration gas value. This procedure was done for one range setting for each analyzer. The Linearity Check data sheets are presented the test report generated by EECL.

6.2.5 NO_2 Converter Check

EECL did NO_2 converter checks before the test program began. A calibration gas mixture of known concentration between 240 and 270 ppm nitrogen dioxide (NO_2) and 160 to 190 ppm nitric oxide (NO) with a balance of nitrogen was used. The calibration gas mixture was introduced to the oxides of nitrogen (NO_X) analyzer until a stable response was recorded. The converter was considered acceptable if the instrument response indicated a 90 percent or greater NO_2 to NO conversion. The NO_2 Converter Check data sheets are presented in the test report generated by EECL.

6.2.6 Sample Line Leak Check

The sample lines were leak-checked before the engine test program. The leak check procedure was performed for both pre-catalyst and post-catalyst sample trains. The procedure was to close the valve on the inlet to the sample filter found just downstream of the exhaust stack probe. With the sample pump operating, a vacuum was pulled on the exhaust sample train. Once the maximum vacuum was reached, the valve on the pressure side of the pump was closed, thus sealing off the vacuum section of the sampling system. The pump was turned off and the pressure in the sample system was monitored. The leak test was acceptable as the vacuum gauge reading dropped by an amount less than 1 inch of mercury over a period of 1 minute. The Sample Line Leak Check data sheets are presented the test report generated by EECL.

6.2.7 <u>Sample Line Integrity Check</u>

A sample line integrity check was done before and upon completion of each test day. The analyzers' response was tested by first introducing a mid-level calibration gas directly to the NO_x analyzer. The analyzer was allowed to stabilize and the response recorded. The same mid-level calibration gas was then introduced to the analyzer through the sampling system. The calibration gas was introduced into the sample line at the stack, upstream of the inlet sample filter. The analyzer was allowed to stabilize and the response recorded. The analyzer response values were compared and the percent difference did not to exceed ±5% of the analyzer span value.

The sample line integrity check was to be done for both the NO_x and methane/non-methane analyzers. Due to time constraints, EECL performed the integrity check for the NO_x analyzers only. The SSB procedure was performed for the methane/non-methane analyzers before and upon completion of the test program. The Sample Line Integrity Check data sheets are presented in the test report generated by EECL.

6.2.8 <u>Carbon Balance Check</u>

One of the methods used to calculate mass emissions was a carbon balance calculation developed by Southwest Research Institute specifically for the American Gas Association. The calculations consist of a theoretical O_2 calculation based upon measured exhaust stack constituents and fuel gas composition. The theoretical exhaust O_2 is then compared to the measured exhaust O_2. The percent difference between the actual and theoretical O_2 measurements was within ±5 % of the measured O_2 reading. The O_2 balance was performed for every 1-minute average and the 33-minute averaged valued for each test point.

6.2.9 <u>Fuel Factor Quality Assurance Checks</u>

Besides the CEMS calibration and QC checks, carbon dioxide and oxygen measurements were validated by calculating the fuel factor, F_o, using the following equation:

$$F_o = \frac{20.9 - \%O_2}{\%CO_2}$$

The values of F_o at the inlet and the outlet for each sampling run are presented in Table 6.3. From the fuel gas analysis, the calculated F_o was 1.69, 1.68, and 1.70 for August 4, 5, and 6 respectively. The F_o values were within 6% of the calculated F_o for all of the sampling runs conducted. Based upon the results, the integrity of the CEMS sample stream was not compromised due to leaks in the sampling system.

TABLE 6.3

SUMMARY OF FUEL FACTOR VALUES

Run Number	Inlet F_o	Outlet F_o	Run Number	Inlet F_o	Outlet F_o
1	1.76	1.72	9	1.77	1.72
2	1.78	1.72	10	1.75	1.72
3	1.71	1.73	11	1.76	1.72
4	1.78	1.73	12	1.75	1.72
5	1.77	1.76	13	1.67	1.74
6	1.77	1.74	14	1.78	1.72
7	1.76	1.74	15	1.77	1.74
8	1.77	1.74	16	1.78	1.75

6.2.10 CEMS Detection Limits

For each of the sample runs, the mass detection limits of the CEMS were presented previously in Table 6.1. For each run, the detection limit was calculated using analytical detection limit data supplied by EECL. Table 6.4 summarizes these values.

TABLE 6.4

SUMMARY OF CEMS ANALYTICAL DETECTION LIMITS

Parameter	Inlet Detection Limit	Outlet Detection Limit
Oxygen	0.01 % volume	0.01 % volume
Carbon Dioxide	0.25 % volume	0.1 % volume
Nitrogen Oxides	0.1 ppm	0.1 ppm
Carbon Monoxide	2 ppm	2 ppm
Methane	20 ppm	20 ppm
Non-methane Hydrocarbons	2 ppm	2 ppm
Total Hydrocarbons	0.04 ppm	0.04 ppm

6.3 DATA QUALITY ASSESSMENT

EPA used the Data Quality Objective (DQO) Process to plan the test program. The DQO Process consists of seven distinct steps.

1. State the problem.
2. Identify the decision.
3. Define inputs to the decision.
4. Define the study boundaries.
5. Develop the decision rule.
6. Specify tolerable limits on decision errors.
7. Optimize the design for obtaining data.

The DQO outputs for this test program were presented in the Quality Assurance Project Plan. The problem was defined in the QAPP and is restated below.

EPA believes that there is a need to conduct emission tests on a subset of engines of differing designs to evaluate the following issues:

- *the effectiveness of after-combustion control systems on HAP emissions, and*
- *the effectiveness of combustion modifications (engine operating parameters) on HAP emissions.*

EPA then developed a decision statement. The decision statement defined the process that would be used to answer the stated problem. The decision statement is restated below:

If EPA can identify a range of engine operating conditions for a defined set of engines with specified after-combustion treatment systems and a list of pollutants of interest, and EPA collects data to determine emissions of those pollutants for each engine operated at each engine operating condition, then EPA can make a determination of the control effectiveness of after-combustion and combustion modifications. In addition, EPA can obtain information on HAP emissions throughout the engine operating range.

PES and EECL conducted the test program on the Waukesha 3521GL, natural gas-fired, 4-stroke, lean-burn, reciprocating internal combustion engine. The MiraTech oxidation catalyst was designed to provide the information required by the decision statement. Based upon the inputs, EPA will make decisions that will be used to regulate this engine subcategory. Inputs to the decision were defined, agreed to, and documented in the QAPP. These inputs consisted of agreement on a finite list of engines to test, the after-combustion control systems to test, the range of engine operating conditions, the catalyst conditioning process, the target list of pollutants, and the sampling and analysis methods, and sample durations.

During conduct of the test program, there were deviations from the QAPP. These deviations are discussed in Section 3.0 for deviations in engine operation, and Section 5.0 for deviations in Sampling and Analysis procedures.

Table 6.5 presents a summary of engine and sample method performance compared to the QAPP requirements. Outlier and data validation issues have been discussed in previous sections. Based upon the engine and method performance, the data quality is evaluated on a run-by-run basis for suitability in the assessment of pollutant emissions and destruction efficiency of HAP by the catalyst.

Six engine parameters were varied over the course of the test program. The parameters were changed so that emissions data and HAP destruction efficiency could be evaluated at a range of engine operating conditions. These conditions are expected to simulate the range of engine operating conditions in industry. Table 6.5 identifies the number of engine parameters that were within the tolerances prescribed in the QAPP. The target engine operating conditions were estimates based upon manufacturer's recommendations. There are differences between these recommendations and the nominal engine operating parameters of the Waukesha 3521GL engine located at the EECL. When testing was conducted some of the prescribed engine parameters could not be met. The fact that a pre-set engine parameter could not be met is considered to be minor. The testing was conducted over a range of engine operating conditions, and these operating conditions are documented.

The remainder of the table assesses data quality using a three-tiered system. A (✓ +) indicates that all method performance parameters defined in the QAPP and/or the sampling method were met. A (✓) indicates that at least 90% of the method performance parameters were met. In the case of FTIRS and CEMS detection limits, there were no detection limits specified in the QAPP. The calculated detection limits are reasonable for this test program. A (✓ -) would indicate that fewer than 90% of the method performance parameters were met. There were no cases where less than 90% of the method performance parameters were met.

TABLE 6.5

SUMMARY OF ENGINE AND METHOD PERFORMANCE

Run ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Engine Parameters Met	5/6	5/6	5/6	5/6	5/6	5/6	5/6	5/6	5/6	5/6	5/6	5/6	5/6	5/6	5/6	5/6
Catalyst Inlet																
FTIR QA Requirements	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
FTIR Detection Limits [a]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CEMS QA Requirements	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+
CEMS Detection Limits [a]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Catalyst Outlet																
FTIR QA Requirements	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+
FTIR Detection Limits [a]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CEMS QA Requirements	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+
CEMS Detection Limits [a]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Assessment of Data Quality																
Catalyst Inlet Mass Flow	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+	✓+
Catalyst Outlet Mass Flow	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
HAP Destruction Efficienc	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

[a] Neither FTIRS nor CEMS detection limits were specified in the QAPP.

APPENDIX A

SUBCONTRACTOR TEST REPORT
COLORADO STATE UNIVERSITY
ENGINES AND ENERGY CONVERSION LABORATORY

EMISSIONS TESTING OF CONTROL DEVICES FOR RECIPROCATING INTERNAL COMBUSTION ENGINES IN SUPPORT OF REGULATORY DEVELOPMENT BY THE U.S. ENVIRONMENTAL PROTECTION AGENCY (EPA)

PHASE 2: FOUR-STROKE, LEAN BURN, NATURAL GAS FIRED INTERNAL COMBUSTION ENGINES

EMISSIONS TESTING OF CONTROL DEVICES FOR RECIPROCATING INTERNAL COMBUSTION ENGINES IN SUPPORT OF REGULATORY DEVELOPMENT BY THE U.S. ENVIRONMENTAL PROTECTION AGENCY (EPA)

PHASE 2: FOUR-STROKE, LEAN BURN, NATURAL GAS FIRED INTERNAL COMBUSTION ENGINES

Prepared for:

PACIFIC ENVIRONMENTAL SERVICES

Submitted by:

Engines & Energy Conversion Laboratory
Colorado State University
Mechanical Engineering Department

April 28, 2000

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APPENDIX

1.0 INTRODUCTION

1.1 OVERVIEW

Natural gas fueled and diesel fueled reciprocating engines represent a large portion of the horsepower in operation within the oil and gas industry and power generation markets. With stringent emissions regulations being required by federal, state, and local agencies, accurate data on current engine emission levels and development of new technologies to reduce and control emissions levels has become essential for federal agencies, engine manufacturers, and equipment operators. Criteria pollutants and Hazardous Air Pollutants (HAPS) issues are of major concern for operators of both two-stroke and four-stroke engines. Current Environmental Protection Agency (EPA) and natural gas industry funded test programs are directed toward evaluating emission levels from existing engines, determining formation mechanisms for the exhaust gas constituents of interest, and developing new technologies to reduce the emissions levels of these constituents.

The investigation of the application of commercially available techniques designed to address the HAPs emissions from reciprocating internal combustion engines (RICEs) will allow the EPA to quantify the effectiveness of current commercially available control devices. These devices have been identified as having the potential to reduce HAPs emissions from stationary RICE sources. Information gained through this program will assist the EPA in the regulatory development effort.

Accurate information on emission levels from operational facilities is difficult to obtain. Based upon a recommendation from the Internal Combustion Coordinating Rulemaking Committee (ICCR) to the EPA, a series of tests were conducted on industrial class engines at Colorado State University's Engines & Energy Conversion Laboratory. Testing was being conducted on both two-stroke and four-stroke natural gas engines and a four-stroke diesel engine. The test program for four-stroke, lean burn, natural gas fueled internal combustion engine was performed during Phase Two of this test program. The results of Phase Two testing are contained within this document.

1.2 BACKGROUND

The 1990 Amendments to the Clean Air Act include provisions that significantly impact the operation of stationary reciprocating internal combustion engines. Of the ten titles to these amendments, four have direct bearing. They are as follows:

Title I - Attainment of Air Quality Standards

Defines ambient air quality standards, defines non-attainment areas based, imposes emissions reductions to achieve attainment per specified timeline per reasonably available control technology (RACT).

Title III - Hazardous Air Pollutants

Defines 189 pollutants classified as hazardous air pollutants (HAPS), specifies thresholds in tons per year (TPY) for any one of these pollutants or a combination of these compounds, introduces maximum achievable control technology (MACT) for sources triggering thresholds.

Title V - Operating Permits

Imposes requirement to obtain federal operating permits for major sources, imposes requirement to provide annual certification of compliance, defines emissions fees based on actual emissions.

Title VII - Enforcement

Establish mechanisms to enhance and strengthen enforcement of CAA, establishes criminal penalties, gives authority to issue administrative orders (fines / penalties) without going to federal court for certain violations.

The EPA in conjunction with the RICE Work Group of the ICCR process determined that additional emissions data for HAPs exhaust gas constituents is required to support the regulatory development process. In a RICE Emissions Test Plan Document dated November 1997, a five component test plan to acquire additional HAPs emissions test data was set forth. The five components include the following:

Engines, Fuels, and Emissions Controls to be tested
Matrix of Operating Conditions to be tested
Pollutants to be Measured During Testing
Test Methods to Quantify Emissions
Prioritization

Eight HAPs pollutants are included in the test plan. These compounds are: formaldehyde, acetaldehyde, acrolein, the BTEX compounds (benzene, toluene, ethylbenzene, xylene) and 1-3 butadiene. Polyaromatic hydrocarbon (PAH) compounds were measured on the two-stroke lean burn gas engine, but were not measured during the test program for the four-stroke lean burn gas engine.

Insight gained through the test program will provide information on the engine operating conditions that affect the formation / reduction mechanisms of HAPs. The investigation of the application of commercially available techniques designed to address the HAPs emissions from RICEs will allow the EPA to quantify the effectiveness of current commercially available control devices. These devices have been identified as having the potential to reduce HAPs emissions from stationary RICE sources. Information gained through this program will assist the EPA in the regulatory development effort.

2.0 TEST PROGRAM

2.1 OBJECTIVE

The objective of this program is to evaluate commercially available catalyst technologies which have been identified as having the potential to control both formaldehyde and other Hazardous Air Pollutants (HAPS) as well as existing criteria pollutants from reciprocating internal combustion engines (RICE). The specific internal combustion engine class tested under the Phase Two test program was the four-stroke, lean burn, natural gas fueled internal combustion engines. The catalyst hardware was evaluated according to the 16-point test matrix developed by the EPA, and the Reciprocating Internal Combustion Engine (RICE) Work Group of the ICCR process. Investigation of catalyst performance during operation at various engine operating conditions provides insight into the effectiveness of catalysts at various conditions. The information gained through the test program will assist the EPA in regulatory development efforts for control of HAPs emissions and criteria pollutants from RICE sources.

2.2 INCENTIVES

Title III of the 1990 Clean Air Act Amendment requires the development of Maximum Achievable Control Technology (MACT) standards for major sources of Hazardous Air Pollutants (HAPs) emissions. A MACT major source is defined as one that emits greater than 10 tons per year of any single HAP or 25 tons per year for all HAPs. For most source categories (RICE included), the MACT standards will require existing major sources apply HAPs emissions control technologies that reduce emissions to a level achieved by the best performing existing sources. In some cases, depending upon the cost of the control technology and the amount and toxicity of the HAPs removed, more stringent standards may be set. The MACT standards for RICEs are scheduled to be promulgated by the year 2000.

Of the HAPs listed, the EPA in conjunction with the Internal Combustion Coordinating Rulemaking Committee (ICCR) have identified compounds which may be present in the exhaust of reciprocating internal combustion engines. Existing test data indicates that the only HAP present in the exhaust of RICEs at levels approaching 10 tons per year is formaldehyde. Commercially available after-treatment technologies (catalysts) for the control of organic compound emissions are currently in operation on RICEs. These technologies have demonstrated performance for control of volatile organic compounds (VOCs) and products of incomplete combustion. However, there is limited information on the effectiveness of these technologies for reducing organic HAPs emissions. Determining the effectiveness and longevity of exhaust catalyst will aid the EPA in evaluating current technologies for control of HAPs emissions from RICE sources as well as provide information in support of regulatory development by the EPA for these sources.

2.3 WORK PLAN

Pacific Environmental Services (PES) serves as the prime contractor responsible for providing information to the EPA. CSU is a subcontractor to PES. Testing was conducted at the Colorado State University 's Engines and Energy Conversion Laboratory. The engine and catalyst type tested is described in Table 1.

TABLE 1

ENGINE AND CATALYST TYPE

Engine Classification	Four-Stroke, Lean Burn, Natural Gas Fueled
Manufacturer and type	Waukesha 3521 GL
Number of Cylinders	6
Bore and Stroke	9.375" X 8.5"
Engine Speed	1200 RPM
Ignition System Classification	Spark Ignited Precombustion Chamber
Ignition System	Altronic
Precombustion Chamber Type	Standard OEM Product
Number of Precombustion Chambers	1 Per Cylinder
Catalyst Classification	Oxidation Type
Manufacturer	Miratech Corporation
Element Size	12"x16"x3"
Number of Elements	2
Substrate	Stainless steel, alternating corrugated & flat layers

The test matrix as originally defined is presented in Table 2, with engine baseline conditions shown in Table 3. Deviations from the described test conditions are detailed in Section 3 of this report. Each test point consisted of collecting thirty-three minutes of data. The raw data was averaged into thirty-three one-minute data points. The data points were then averaged to provide the results for the single test point. The results are presented in tabular form in Appendix A of this report.

TABLE 2

ENGINE OPERATING CONDITIONS DURING TESTING
WAUKESHA 3521 GL (4-STROKE LEAN BURN, NATURAL-GAS-FIRED)
US EPA ICCR RICE HAP EMISSIONS TESTING

Operating Conditions to be Tested:	Speed (rpm)	Torque (% of baseline)	Air-to-Fuel Ratio	Timing	Intercooler Water Temp.	Jacket Water Temp.
Run 1	H	H	N	S	S	S
Run 2	H	L	N	S	S	S
Run 3	L	L	N	S	S	S
Run 4	L	H	N	S	S	S
Run 5	H	H	L	S	S	S
Run 6	H	H	H	S	S	S
Run 7	H	L	H	S	S	S
Run 8	L	H	L	S	S	S
Run 9	H	H	N	S	L	S
Run 10	H	H	N	S	H	S
Run 11	H	H	N	S	S	L
Run 12	H	H	N	S	S	H
Run 13	H	H	N	L	S	S
Run 14	H	H	N	H	S	S
Run 15	H	H	N	S	S	S
Run 16	H	H	N	S	S	S
	L = 1000 H = 1200	L = 70 H = 100	N = 0.61 (9.8 % O_2) L = 0.56 (10.7 % O_2) H = 0.62 (8.9 % O_2)	S = 10 L = 6 H = 14	S = 130 L = 120 H = 140	S = 180 L = 170 H = 190

- Note: Air/fuel ratio calculations based on Appendix Q and Appendix R.

TABLE 3

WAUKESHA 3521GL BASELINE CONDITIONS

Engine Operating Parameters	Nominal Value	Acceptable Range	Designation
Engine Torque	3383 ft-lb. to 3230 ft-lb.	± 2% of value	Primary
Engine Speed	1000 RPM	± 5% of value	Primary
Jacket Water Temperature Outlet	180°F	± 5% of value	Primary
Engine Oil Temperature Header	180°F	± 5% of value	Primary
Air Manifold Temperature	85°F to 130°F	± 5% of value	Primary
Air Manifold Pressure	30.0" Hg above Atm.	± 5% of value	Primary
Exhaust Manifold Pressure	5.0" Hg below AMP	± 5% of value	Primary
Ignition Timing	10°BTDC	± 5% of value	Primary
Overall Air:Fuel Ratio	28:1	± 5% of value	Primary
Inlet Air Humidity-Absolute	.0015 lb H_2O/lb Air	± 10% of value	Primary
Engine Fuel Flow SCFH	4460 to 4360 SCFH	± 5% of value	Primary
Engine Oil Pressure Inlet	45 lb.	± 10% of value	Secondary
Inlet Air Flow	1400-1500 SCFM	± 5% of value	Secondary
Average Engine Exhaust Temperature	660° F	± 5% of value	Secondary

3.2 FTIR POST-CATALYST WATER ANALYSIS

Analysis method on the Nicolet Magna 560 FTIR analyzer gave water measurements that were excessively high for post-catalyst emissions measurements. The spectra for H_2O, provided by Nicolet, on the Magna 560 calculated water content to be approximately 6% higher than actual exhaust gas concentrations. Carbon balance calculations for each one-minute data point, at all test conditions, agreed with the H_2O readings from the Rega 7000 FTIR analyzer, pre-catalyst emissions measurement. The measurements agreed within ±0.5% to ±1% water content. The carbon balance calculations for the post-catalyst water content agreed with the pre-catalyst measurements within ±0.5% to ±1% water content at all test conditions. The carbon balance measurements are based upon the pre-catalyst and post-catalyst reference method analyzers. Since the pre-catalyst and post-catalyst measurements were made with separate analyzers, the variability in the H2O calculation could be caused by variability in emissions analyzers.

The changes in the water content were calculated by the carbon balance method and detected by the FTIR analyzer. Based on the agreement between the pre-catalyst FTIR measurements and the carbon balance calculation for water content at every test condition, and between the pre-catalyst and post-catalyst calculations, the water content from the post-catalyst FTIR measurements were used to convert the wet FTIR measurements to dry measurements. As both FTIR analyzers passed the validation process and passed all QC checks, the variation in water readings from the Nicolet Magna 560 analyzer has no impact on the results of the testing conducted during Phase Two of the overall test program.

3.3 BASELINE ENGINE OPERATING CONDITIONS

Baseline engine operating conditions as described in the Scope of Work are presented in Table 3 of this report. These conditions were estimates. After running the engines, these values were found to be inaccurate. Deviations from the Baseline engine operating conditions as presented are as follows:

TABLE 4

WAUKESHA 3521GL BASELINE CONDITIONS

Engine Operating Parameters	Nominal Value	Acceptable Range	Designation
Engine Torque	3236 ft-lb.	± 2% of value	Primary
Engine Speed	1200 RPM	± 5% of value	Primary
Jacket Water Temperature Outlet	180°F	± 5% of value	Primary
Engine Oil Temperature Header	185°F	± 5% of value	Primary
Air Manifold Temperature	100°F	±5% of value	Primary
Air Manifold Pressure	5.0" Hg above Atm.	± 5% of value	Primary
Exhaust Manifold Pressure	5.0" Hg below AMP	± 5% of value	Primary
Ignition Timing	10°BTDC	± 5% of value	Primary
Overall Air:Fuel Ratio	28:1	± 5% of value	Primary
Inlet Air Humidity-Absolute	.015 lb H_2O/lb Air	± 10% of value	Primary
Engine Fuel Flow SCFH	5460 SCFH	± 5% of value	Primary
Engine Oil Pressure Inlet	52 lb.	± 10% of value	Secondary
Inlet Air Flow	1730 SCFM	± 5% of value	Secondary
Average Engine Exhaust Temperature	700°F	± 5% of value	Secondary

Humidity Ratio:
Baseline humidity ratio is 0.015-lb. H_2O/lb. air. The baseline humidity ratio was stated as 0.0015-lb. H_2O/lb. air . This is a misprint. Documentation should be corrected to show 0.015-lb. H_2O/lb. air as baseline humidity ratio.

August 6, 1999 Baseline:
The air/fuel ratio appears to be wrong because it is calculated from the output of the pre-catalyst O_2 monitor. The monitor failed during this baseline. The air/fuel ratio is 28:1 when the O_2 is 9.8%. The catalyst outlet O_2 is 9.9%, so the air/fuel ratio is correct.

3.4 FOUR-STROKE ENGINE TEST MATRIX

The four-stroke engine sixteen point test matrix and associated engine operating conditions as described in the Scope of Work are presented in Table 2 of this report. During testing discrepancies between the CSU "Scope of Work" and the QAPP in relation to engine operating conditions were identified. The QAPP referenced engine operating data in relation to field engines originally proposed in the ICCR process and not the engines at Colorado State University. Deviations from the engine operating conditions described in the sixteen-point test matrix are referenced to the CSU "Scope of Work". Deviation from the described engine operating conditions are as follows:

Global Deviation in Engine Operating Conditions

Speed:
The baseline speed condition was changed to 1200 rpm as indicated. This value was used for the high speed points. The value used for the low speed points was 1000 rpm.

Air/Fuel Ratio:
The baseline air/fuel ratio condition is 28:1. This corresponds to an equivalence ratio of 0.57 and an oxygen concentration of 9.8% in the exhaust. This value was used for the normal points. The low condition corresponds to an equivalence ratio of 0.53 and an oxygen concentration of 10.7%. The high condition corresponds to an equivalence ratio of 0.62 and an oxygen concentration of 8.9%.

Test Point Specific Variances

Only deviations which were not previously described in the "Global Deviation" section will be described.

Test Point 3:
The air/fuel ratio on test point 3 appears to be wrong because it is calculated from the output of the pre-catalyst O_2 monitor. The monitor falied during this test point. The air/fuel ratio is 28:1 when the O_2 is 9.8%. The catalyst outlet O_2 is 9.81%, so the air/fuel ratio is correct.

Test Points 2 and 7:

The humidity system experienced a failure prior to initiation of the test point and it was determined to conduct the test points without inlet air humidity control. The set point for humidity ratio for all test points is 0.015 lbs. water / lbs. dry air. The actual humidity ratios for Test Point 2 and Test Point 7 were 0.0126 and 0.0127 lbs. water / lbs. dry air respectively.

Appendix S contains a paper entitled "An Investigation on Inlet Air Humidity Effects on a Large-Bore, Two-Stroke Natural Gas Fired Engine" presented at the 1998 Gas Machinery Conference. The paper presents work funded by the PRCI and GRI. The paper details the effects of variations in humidity on engine performance and emissions.
Results from investigation into the effects of humidity on engine emissions show the following (Appendix S: Figure 27 – Figure 30):

- With increasing humidity ratio, NO_x emissions decrease.
- With increasing humidity ratio formaldehyde production increases.
- With increasing humidity ratio, CO emissions decrease slightly while THC emissions remain fairly constant.
- With increasing humidity ratio exhaust temperatures increase slightly, approximately 5°F over the range of humidity ratios at the air manifold boost pressure for Test Points 2 and 7(Appendix S: Figure 9).

Over the range which the humidity ratio deviated from the test matrix for Test Points 2 and 7, the engine emissions should be similar to engine emissions at the specified humidity ratio. The most dramatic effect will be on NO_x emissions as can be seen from the data and the graphs presented in Appendix S. At reduced air manifold temperatures (with engine operating parameters remaining constant), reduction in NO_x emissions would be the most noticeable change. NO_x emissions would be reduced due to the lower inlet air temperature and increased inlet air density. At a constant humidity ratio, it would be expected that CH_2O emissions would either remain constant or increase slightly with similar changes in CO and THC emissions.

The data collected at Test Point 2 and Test Point 7 is indicative of engine field data under similar operating conditions. The variation in humidity ratio represents minimal impact on the overall emissions obtained for this data point. The most noticeable impact would be increased NO_x emissions due to changes in ambient conditions, which would result in elevated in-cylinder temperatures and reducde heat capacity of the inlet air charge.

3.4 OTHER DEVIATIONS

The Annubar mass flowmeter used for the exhaust flow measurement did not perform correctly during the test program. Analysis by the manufacturer showed the unit to be properly calibrated and the operation of the unit was confirmed in another location on our piping system. Although the flowmeter was installed well downstream from flow obstacles, the unit shows signs of operating in disturbed flow. The fuel flow measurement is the primary mass flow measurement on the system. The exhaust flow system was not required for the test program and was disconnected, showing a negative value on the data sheets.

4.0 TEST SAMPLING PROCEDURES
Engines & Energy Conversion Laboratory
Industrial Engine Test Facility
Colorado State University

To aid industrial engine research, Colorado State University was commissioned to design and install a dedicated test facility for industrial class, reciprocating internal combustion engines. The Industrial Engine Test Facility was installed at the Engines & Energy Conversion Laboratory to provide a mechanism by which environmental and technological issues related to industrial class engines could be evaluated in an independent, economical and efficient manner. The facility would also provide a level of expertise and understanding not obtainable from field-testing.

4.1 GENERAL TEST PROCEDURES

As with any viable testing program, a procedure has been established which affords accurate and repeatable results. The test program developed for the Industrial Engine Test Facility located at the Colorado State University's Engines & Energy Conversion Laboratory is no exception to this rule. Testing criteria established for the test facility ensures that the data collected has a high degree of accuracy and can be repeated if warranted. However, since the Industrial Engine Test Facility was designed to allow for several different industrial engine types to be tested in a laboratory environment, testing procedures differ somewhat from field test procedures and are unique to this facility. The sampling procedure and calibration procedures are described under their respective sections of the TEST SPECIFICS portion of this report.

4.2 TEST SPECIFICS –DATA COLLECTION

The data collection process has been standardized to afford accurate and repeatable results throughout a test program. The high degree of accuracy, which can be obtained at the Industrial Engine Test Facility, is due to the sophisticated level of instrumentation utilized at the facility. However, without proper implementation no amount of instrumentation can assure accurate or repeatable results. Therefore a specific outline of the data collection process has been developed for the Industrial Engine Test Facility.

Data Point Definition

A typical data point consisted of engine operating data taken over a specified time period and averaged. During normal field operations, engine-operating parameters will fluctuate. Variations in facility process conditions can effect engine speed and load. Minimal control equipment or equipment which is not specialized to provide precision control required for engine research, can also generate unstable operation. Changes in environmental conditions during the course of a test program will introduce additional unknowns into typical emissions field data. The Industrial Engine Test Facility was developed through an initiative to provide a facility which would provide accurate and repeatable data by reducing variations in engine operation. Under controlled conditions at the EECL, fluctuations of engine load, speed, environmental conditions, etc. have been minimized. This effort allows more accurate and repeatable engine data than possible with field research programs.

A standard data point collected at the EECL consists of engine operating data being gathered over either a three-minute or five-minute period and averaged. It has been determined, based on previous tests, that 3-5 minutes provides an acceptable time period required for an appropriate data set to be collected and an average for each parameter calculated.

The Large Bore Engine Testbed, which has been functional since 1993, was used as a reference for the other test beds at the EECL. A data point at the LBET consists of 101 engine-operating parameters, which are collected and averaged for each data point. The data point consists of 30 parameters which provide basic engine operating information, twenty parameters which are received from the emissions computer and the remaining 51 parameters are engine combustion parameters calculated with a combustion analysis system. For each data point an average value, minimum value, maximum value, and standard deviation are obtained for all engine operation and emissions parameters collected. The combustion analyses system was not used for this test due to the lack of sensor access ports on the Waukesha 3521 Engine.

For the work conducted under this test program, a test point consisted of a series of data points taken in succession and averaged. The data were gathered in 1-minute averages over a 33-minute test period. Using a data set consisting of thirty-three, one-minute data points would highlight any large fluctuations in load and other parameters that would have a significant effect on emissions data. No fluctuations in data occurred during any test points. This demonstrated that the engine was operating at a steady condition and the data recorded in the individual data points was repeatable.

Table 5 provides information on the nominal number of samples collected under each data point / test run scenario for the LBET.

TABLE 5

SAMPLING SPECIFICATIONS

Measured Parameters	Number of Samples Collected	
	1 Minute Data Point	30 Minute Test Run
Engine Operation	30– 60	900 – 1800
Emissions CEMS	30 – 60	900 – 1800
Emissions FTIR	45 – 50	1350 – 1500

4.3 TEST SPECIFICS - ENGINE STABILITY

For data taken during testing to be reliable, the engine was operated in a state of equilibrium at each test point. The engine control system allowed for engine operation data to be monitored so that engine stability could be easily recognized. The stability of each specific engine's operation was not only determined on a test point by test point basis, but also on a daily basis. Since combustion parameters for each engine type will vary, engine-operating parameters were used to determine engine stability. Procedures used for determining acceptable engine stability are as follows:

Engine Stability: Engine Start Up Procedures

Prior to the beginning of data collection each day, the engine was "warmed up" and a thermal equilibrium state established. This was nominally determined when the engine coolant water systems and lubricating oil reached a steady state temperature. Once steady state operation was achieved, a daily "baseline" data point was gathered. The length of time required to obtain steady state operation was highly dependent upon the ambient temperature and the temperature of the engine when started. Due to the dependence on these factors, there was no pre-determined warm-up time.

Engine Stability: Daily Baseline Data Point

The Scope of Work for the project required that a specified number of test points be collected on the engine. The data collection process encompassed multiple days of testing. To ensure that the engine was operating in a similar manner on each test day, a set of engine "baseline" data was collected. An initial set of engine "baseline" data (one five-minute data point) was collected prior to the first data point. On the ensuing test days, a "baseline" data point was collected to verify the data collection for that day. The primary engine operating parameters of the data point must compare to within a specified acceptable range of the values of the primary engine operating parameters on the original "baseline" data set for engine stability and to the baseline operating conditions specified in Table 4. If primary engine operating parameters did not compare to within the predetermined range, corrective measures were taken to isolate and correct the cause of the unacceptable values for the primary engine operating parameters. Both CSU and PES representatives initialized the daily "baseline" data set. All baseline data points were acceptable during the test program. The primary/secondary engine operating parameters, acceptable ranges, and their nominal values for a "baseline" data set are presented above in Table 4.

Engine Stability: Pre-Data Point Test Procedures

As with the daily engine "baseline" data point, the engine must maintain a stable mode of operation prior to and during a test run. Changing various operating parameters to achieve the desired test condition will cause the engine to operate in an unstable mode during the transition period from one condition to the next. The engine parameter which has the most effect on engine equilibrium is engine load. Fluctuations in load will result in erratic and inaccurate emissions data and for this reason load was closely monitored during testing. Changes in load will also affect the engine's thermal equilibrium and will require the longest time for the engine to return to a thermal equilibrium state.

Although the effects are not as significant as those of changing engine load, any changes in air manifold pressure, temperature, exhaust back-pressure, or ignition timing also affected the engine's equilibrium. As with load changes, the engine must be closely monitored for return to an equilibrium state after any changes are made. Typically, the engine will return to equilibrium, steady-state condition within 30-45 minutes. Prior to initiating a test run, a pre-test run data point was gathered. The data point was five-minutes in length. For each pre-test run data point, an average value, minimum value, maximum value, and standard deviation were obtained for all engine operation and emissions parameters collected. Primary engine operating parameters specified at a test condition must agree with the test condition value within +/- 2% to +/-10% of the requested value dependent upon the engine parameter. The relative standard deviations of the primary operating variables were below 1.0% for engine operating parameters and below 3.0% for the engine emissions parameters. The primary engine operating parameters and their nominal values for a "pre-test run" data point are presented below in Table 6.

If primary engine operating parameters did not agree with the requested test condition values within the predetermined range, corrective measures was taken to isolate and correct the cause of the unacceptable values for the primary engine operating parameters. All pre-test run data points were acceptable for the test program. Both CSU and PES representatives initialized each "pre-test run" data point.

Engine Stability: Test Run Stability

A test run consisted of a set of one-minute averaged data points taken consecutively over a 33-minute time period. For each data point, the average value for each primary engine operating parameter must compare to within the acceptable range of the specified target value at the test condition for engine stability and the data collection process to be valid for the specific test condition. If primary engine operating parameters did not compare to within the predetermined range, the data point was invalid, and corrective measures were taken to isolate and correct the cause of the unacceptable values for the primary engine operating parameters.

Engine stability was maintained throughout the data collection process for each test run. The relative standard deviation of the primary operating variables was below 1.0% for engine operating parameters and below 3.0% for the engine emissions parameters at each data point.

Both CSU and PES representatives initialized each data point of a test run. The tabular format of the primary engine operating parameters, designation, and the acceptance criteria is presented in Table 6:

TABLE 6

TEST POINT – ENGINE STABILITY

Engine Operating Parameters	Acceptable Range	Standard Deviation	Designation
Engine Torque	± 2% of value	≤ 1.0	Primary
Engine Speed	± 5% of value	≤ 1.0	Primary
Jacket Water Temperature Outlet	± 5% of value	≤ 1.0	Primary
Engine Oil Temperature Outlet	± 5% of value	≤ 1.0	Primary
Air Manifold Temperature	± 5% of value	≤ 1.0	Primary
Air Manifold Pressure	± 5% of value	≤ 1.0	Primary
Exhaust Manifold Pressure	±5% of value	≤ 1.0	Primary
Ignition Timing	± 5% of value	≤ 1.0	Primary
Overall Air/Fuel Ratio	± 5% of value	≤ 1.0	Primary
Inlet Air Humidity-Absolute	± 10% of value	≤ 1.0	Primary
Engine Fuel Flow SCFH / Gal./Hr.	± 5% of value	≤ 1.0	Primary
Engine Oil Pressure Inlet	± 5% of value	≤ 3.0	Secondary
Inlet Air Flow	± 5% of value	≤ 3.0	Secondary
Average Engine Exhaust Temperature	± 5% of value	≤ 3.0	Secondary
NO_x Emissions (PPM)	± 5% of value	≤ 3.0	Secondary
CO Emissions (PPM)	± 5% of value	≤ 3.0	Secondary
THC Emissions (PPM)	± 5% of value	≤ 3.0	Secondary
CO2 (%)	± 5% of value	≤ 3.0	Secondary
02 (%)	± 5% of value	≤ 3.0	Secondary
Exhaust Air Flow	± 5% of value	≤ 3.0	Secondary

4.4 TEST SPECIFICS – DATA COLLECTION HARDWARE

The design of the test facility provides a platform for accurate and versatile performance and emission research on industrial engines. Control and measurement systems installed on the Industrial Engine Test-Beds are as follows:

Waukesha 3521 GL: Two-Stroke Lean Burn

Engine Control and Monitoring:	Bristol Babcock Control and Monitoring System
Emission Analysis Systems: Pre-catalyst Emissions	Rosemount NGA-2000 Five Gas Analyzer Rack for NO_x, CO, CO_2, O_2, & THC
Emission Analysis System: Pre-catalyst Emissions	Nicolet Rega 7000 Fourier Transform Infrared (FTIR) Exhaust Gas Analyzer
Emission Analysis Systems: Post-catalyst Emissions	Five Gas Analyzer Rack TECO NO_x, CO, & THC Servomex CO_2 & O_2
Emission Analysis System: Post-catalyst Emissions	Nicolet Magna 560 Fourier Transform Infrared (FTIR) Exhaust Gas Analyzer
Ignition Analysis System:	Altronic Diagnostic Module

4.5 TEST SPECIFICS – DATA COLLECTION PROCESS

The data collection process consisted of acquiring information from the various control and monitoring systems. The engine control and monitoring system (ECMS) collected all engine operating and emissions parameters (criteria pollutants only). All engine operating parameters were direct measurements of the ECMS, while emissions parameters (criteria pollutants) were passed by communication link from a computer dedicated to emissions hardware control and monitoring. All emissions parameters measured with an FTIR were collected and stored on a computer dedicated to individual FTIR operation.

After engine stability had been confirmed, the data collection process for a test run condition commenced. The data collection process was performed as follows:

Data Collection Process:

1.) Verification of engine stability confirmed, accepted, and initialized by PES and CSU representatives.
2.) Proper file names are assigned to all data acquisition hardware.
3.) Commence acquisition of data point for specified test condition
4.) At completion of data point, electronic files are saved and hard copies are printed out.
5.) PES and CSU representatives initialize hard copies verifying acceptable data point.
6.) Move engine operation to next test condition.

4.6 TEST SPECIFICS - EMISSION ANALYZER GENERAL TEST PROCEDURES

Introduction

The following general test procedures and calibration checks guaranteed the integrity of our sampling system and the accuracy of our data. The testing was conducted in basic accordance with approved Environmental Protection Agency (EPA) test methods as described in the Code of Federal Regulations, Title 40, Part 60, Appendix A.

General Procedure

Exhaust oxygen and oxides of nitrogen concentrations from the engine were determined in basic compliance with EPA Method 20, "Determination of Nitrogen Oxides, Sulfur Dioxide, and Diluent Emissions From Stationary Gas Turbines"and EPA Method 7E, "Determination of Nitrogen Oxides Emissions From Stationary Sources (Instrumental Analyzer Procedure)". The sampling procedure for CO concentrations was based on EPA Method 10, "Determination of Carbon Monoxide Emissions from Stationary Sources." EPA Method 25A, "Determination of Total Gaseous Organic Concentration Using a Flame Ionization Analyzer" was the sample procedure used to determine THC emission concentrations. A modified EPA Method 18A was used for the sampling procedures for Methane/Non-Methane Analysis. The method for calculating mass emissions levels was based upon an EPA Method 19 "Determination of Sulfur Dioxide Removal Efficiency and Particulate Matter, Sulfur Dioxide, and Nitrogen Oxides Emission Rates" calculation. Mass emissions were also calculated using carbon balance calculations developed by Southwest Research Institute specifically for the American Gas Association. Calibration and test procedures are detailed under their respective sections of the TEST SPECIFICS portion of this report.

Sampling System

Dedicated analyzers were used to determine the NO_X, CO, THC, CO_2, and O_2 emissions level on a dry basis for both pre and post-catalyst emissions. Dedicated analyzers were used to determine the Methane/Non-Methane emissions on a wet basis for both pre- and post-catalyst emissions. FTIR analyzers were used to determine aldehyde emissions on a wet basis for both pre and post-catalyst emissions. Refer to Table 7 for the analyzers and the methods of analysis.

Exhaust gas entered the system through a 3/8" stainless steel multi-point probe. Sample points were located in accordance with procedures described in Method 1. Exhaust gas then passed through a heated 3-way sample valve and glass wool filter assembly. The sample was transported via a heat-traced Teflon sample lines and heated sample distribution manifold. Sample for the "dry" gas analyzers then passed through a 4-pass minimum contact condenser specifically designed to dry the sample. The "dry" sample then entered a stainless steel sample pump. The discharge of the pump passed through 3/8" Teflon tubing to a Balston Microfibre coalescing filter, moisture sensor, and then to the sample manifold. The sample manifold was maintained at a constant pressure by means of a pressure bypass regulator. A flow meter, placed in line at the exhaust of each analyzer, monitored exact sample flows. Heated sample flow for all "wet" measurement analyzers will be provided by means of a heated sample distribution manifold prior to sample gas entering the "dry" gas analyzer platform. Each heated analyzer had a dedicated sample pump and heat traced line from the main sample train to the analyzer.

TABLE 7

CURRENT INSTRUMENTATION

Post-catalyst Emissions			
Manufacturer and Model	Parameters	Detection Principle	Range
Rosemount NGA-2000 CLD Analyzer	NO or NO_x	Thermal reduction of NO_2 to NO. Chemiluminescent reaction NO with O_3.	Variable to 10000 PPM
Rosemount NGA-2000 NDIR Analyzer	CO	NDIR with Gas Filter Correlation	Variable to 2000 PPM
Rosemount NGA-2000 NDIR Analyzer	CO_2	NDIR	Variable to 20%
Rosemount NGA-2000 FID Analyzer	THC	Flame Ionization	Variable to 10,000 PPM
Rosemount NGA-2000 PMD Analyzer	O_2	Paramagnetic	Variable to 100%
Questar Baseline 1030H HeatedGC / FID	CH4 Non-CH4	Gas Chromatograph Flame Ionization	Variable to 5000 PPM
Nicolet Magna 560	Multiple See Attached	FTIR analysis utilizing a medium range IR source.	Variable
Pre-catalyst Emissions			
Manufacturer and Model	Parameters	Detection Principle	Range
TECO Model 42H CLD Analyzer	NO or NO_x	Thermal reduction of NO_2 to NO. Chemiluminescent reaction NO with O_3.	Variable to 5000 PPM
TECO Model 48H NDIR Analyzer	CO	NDIR with Gas Filter Correlation	Variable to 20000 PPM
Servomex NDIR Analyzer	CO_2	NDIR	0-25%
TECO Model 51 FID Analyzer	THC	Flame Ionization	Variable to 10000 PPM
Servomex PMD Analyzer	O_2	Paramagnetic	0-5% 0-25%
Questar Baseline 1030H HeatedGC / FID	CH4 Non-CH4	Gas Chromatograph Flame Ionization	Variable to 50000 PPM
Nicolet Rega-7000	Multiple See Attached	FTIR analysis utilizing a medium range IR source.	Variable

TABLE 8

COMPONENTS MEASURED BY NICOLET FTIR

Component Formula	Component Name
H_20	Water
CO	Carbon Monoxide
CO_2	Carbon Dioxide
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
N_2O	Nitrous Oxide
NH_3	Ammonia
NO_X	Oxides of Nitrogen
CH_4	Methane
C_2H_2	Acetylene
C_2H_4	Ethylene
C_2H_6	Ethane
C_3H_6	Propene
H_2CO	Formaldehyde
CH_3OH	Methanol
C_3H_8	Propane
I-C_4H_{10}	Iso-Butylene
N-C_4H_{10}	Normal-Butane
CH_3CHO	Acetaldehyde
SO_2	Sulfur Dioxide
THC	Total Hydrocarbons

4.7 TEST SPECIFICS - EMISSION ANALYZERS CHECKS AND CALIBRATIONS

The following instrument checks and calibrations guaranteed the integrity of our sampling system and the accuracy of our data.

Analyzer Calibration Gases

Standard calibration gases used at the facility are Scott Specialty Gases EPA Protocol Gas Standard calibration gases with a ±1.0% or ±2.0% accuracy. For this program, EPA Protocol 1 calibration gases (RATA Class) were used. Manufacturer supplied certification sheets were available during the testing procedure and copies of the current inventory of gases, which were used for calibration and integrity checks on the reference method and FTIR analyzers, are provided within this document.

EPA Protocol 1 gases (Rata Class) were used to calibrate the reference method analyzers and FTIR analyzers. Formaldehyde standards with a concentration range between 5 – 20 PPM were obtained. Acetylaldehyde/acrolein standards were also acquired. Any calibration standards which were not EPA Protocol 1 gases were the highest quality standard available.

Analyzer Specifications

Vendor instrument data concerning interference response and analyzer specifications are available if requested. Information supplied by the manufacturer on the factory specification sheets will be furnished if requested.

Response Time Tests (Prior to initiation of engine test program)

Response time tests were performed on each sample system. The response time tests were performed prior to the FTIR validation process for each sampling system. The response time of the slowest responding analyzer (Questar Baseline) was determined. Response time tests conducted at the EECL indicated sampling system response times of 1:10 minutes. This is the time for the Rosemount Oxygen Analyzer (slowest responding analyzer which continuously monitors) to stabilize to response output of the analyzer. The Questar Baseline Industries CH4/Non-CH4 analyzers have a minimum cycle time of 4:50 minutes. The overall response time for these analyzers when their cycle is started 1:10 minutes after a sample source change is 5:50 minutes. When the CH4/Non-CH4 analyzer cycle time was initiated at a sample source change, the overall response time is 9:00 minutes. The response time was tested to assure that the analyzers' response was for exhaust gas entering the sample system from each of the test point conditions.

Calibration (Daily)

Zero and mid-level span calibration procedures were performed on the reference method analyzer prior to each test day. Zero and span drift checks were performed upon completion of each data point and upon completion of each test day. This procedure is referenced as ZSD (zero and span drift check) in the CSU "Scope of Work". A zero and a mid-level gas was introduced individually directly to the back of the analyzers before testing for carbon monoxide, carbon dioxide, oxygen, total hydrocarbons, Methane/Non-Methane, and oxides of nitrogen. The analyzers' output response was set to the appropriate levels. Each analyzer's stable response was recorded. From this data a linear fit was developed for each analyzer. The voltage for each analyzer were recorded and used in the following formula:

$$Y = MX + B$$

Where: B = Intercept
M = Slope
X = Analyzer or transducer voltage
Y = Engineering Units

After each test point and upon completion of a test day, calibration checks were conducted by re-introducing the zero and span gases directly to the back of the analyzers. The analyzers' stabilized responses were recorded. No adjustments were made during testing or during the final calibration check. Initial calibration values and all calibration checks were recorded for each analyzer during the daily test program.

The before and after calibrations checks will be used to determine a zero and span drift for each test point for the CO, CO_2, O_2, THC, CH4/Non-CH4, and NO_X analyzers. The zero and span drift checks for each test point and each test day were less than ±2.0% of the span value (specific range setting) of each analyzer used during the daily test program. The calibration data sheets are presented in Appendix E of this document.

Linearity Check (Prior to initiation of engine test program)

Prior to initiation of the test program, analyzer linearity checks were performed. This procedure is referenced as ACE (analyzer calibration error check) in the CSU "Scope of Work". The oxygen, carbon monoxide, total hydrocarbon, methane/non-methane and oxides of nitrogen analyzers were "zeroed" using either zero grade nitrogen, or hydrocarbon free air. The analyzers were allowed stabilize and their output recorded. The analyzers were then "spanned" using the mid-level calibration gases. The analyzers were allowed to stabilize, and their output recorded. From this data a linear fit was developed for each analyzer. The voltages for each analyzer were recorded and used in the following formula:

$Y = MX + B$, where

B = Intercept

M = Slope

X = Analyzer or transducer voltage

Y = Engineering Units

Using the linear fit, the linear response of the analyzer was calculated. Low level and high-level calibration gases were individually introduced to the analyzers. For each calibration gas, the analyzers were allowed to stabilize and their outputs were recorded. Each analyzers' linearity was acceptable as the predicted values of a linear curve determined from the zero and mid-level calibration gas responses agreed with the actual responses of the low level and high level calibration gases within ±2.0% of the analyzer span value. The methane/non-methane analyzers' linearity was acceptable as the predicted values agreed with the actual response of the low level and high level calibration gases within ±5.0% of the actual calibration gas value. This procedure was performed for one range setting for each analyzer. The Linearity Check data sheets are presented in Appendix E of this document.

NO_2 Converter Check (Prior to initiation of engine test program)

Prior to initiation of the test program, NO_2 converter checks were performed. A calibration gas mixture of known concentrations between 240 and 270 PPM nitrogen dioxide (NO_2) and 160 to 190 PPM nitric oxide (NO) with a balance of nitrogen was used. The calibration gas mixture was introduced to the oxides of nitrogen (NO_X) analyzer until a stable response was recorded. The converter is considered acceptable if the instrument response indicated a 90 percent or greater NO_2 to NO conversion. The NO_2 Converter Check data sheets are presented in Appendix E of this document.

Sample Line Leak Check (Prior to initiation of engine test program)

The sample lines were leak checked before the engine test program. The leak check procedure was performed for both pre-catalyst and post-catalyst sample trains. The procedure involved closing the valve on the inlet to the sample filter located just downstream of the exhaust stack probe. With the sample pump operating, a vacuum was pulled on the exhaust sample train. Once the maximum vacuum was reached, the valve on the pressure side of the pump was closed thus sealing off the vacuum section of the sampling system. The pump was turned off and the pressure in the sample system was monitored. The leak test was acceptable as the vacuum gauge reading dropped by an amount less than 1 inch of mercury over a period of 1 minute. The Sample Line Leak Check data sheets are presented in Appendix E of this document.

Sample Line Integrity Check (Daily)

A sample line integrity check was performed prior to and upon completion of each test day. This procedure is referenced as SSB (Sampling System Bias Check) in the CSU "Scope of Work". The analyzer's response was tested by first introducing the mid level calibration gas directly to the NO_X analyzer. The analyzer was allowed to stabilize and the response recorded. The same mid level calibration gas was then introduced to the analyzer through the sampling system. The calibration gas was introduced into the sample line at the stack, upstream of the inlet sample filter. The analyzer was allowed to stabilize and the response recorded. The analyzer response values were compared and the percent difference did not to exceed ±5 % of the analyzer span value (range setting).

The SSB procedure was to be performed for both the NO_x and methane/non-methane analyzers. It was determined to perform the integrity check for the NO_x analyzers only. The SSB procedure was performed for the methane/non-methane analyzers prior to and upon completion of the test program. The Sample Line Integrity Check data sheets are presented in Appendix E of this document.

Carbon Balance Check (Continuous)

One of the methods used to calculate mass emissions was a carbon balance calculation developed by Southwest Research Institute specifically for the American Gas Association. As part of a QC check, the calculations involve performing a theoretical O_2 calculation based upon measured exhaust stack constituents and fuel gas composition. The theoretical exhaust O_2 is then compared to the measured exhaust O_2. The percent difference between the actual and theoretical O_2 measurements was within ±5 % of the measured O_2 reading. The O_2 balance was performed for every one-minute average and the thirty-three minute averaged value for each test point. The averaged value for each test point is included in the test point data in Appendix A.

Fuel Gas Analysis & Fuel Flow Measurements

Natural Gas Fuel Gas:

Engine fuel gas was analyzed on a real time basis with a dedicated Daniels Industries GC. The GC was calibrated on a daily basis against a known standard. A daily gas analysis was acquired for each test day. This analysis gave the actual specific gravity, mole fractions of specific hydrocarbons and BTU content so that fuel flow and mass emissions could be accurately calculated. Fuel flow measurements were made using an AGA specified orifice meter run equipped with dedicated high accuracy pressure and temperature transmitters. All fuel flow calculations were in accordance with AGA

Report #3. Additionally, stoichiometric air to fuel ratio calculations were made using the fuel gas analysis. From this information, the equivalence ratios for each day of testing were determined. All fuel gas calibrations and analysis are presented in Appendix O and Appendix N, respectively. Stoichiometric air to fuel ratio calculations are presented in Appendix Q. Calculations for fuel flow, stoichiometric air-to-fuel ratio calculations, and fuel specific F Factor are presented in Appendix V, Appendix Q, and Appendix P, respectively.

A blind sample provided by PES was analyzed. The results are included in Appendix N of this report.

4.8 TEST SPECIFICS: FTIR CALIBRATION PROCEDURES

Calibration was performed on the FTIR instrument prior to each phase of the test program and at the beginning and end of each test day. The calibration procedures described within this document are consistent with procedures found in the following documents:

"Measurement of Select Hazardous Air Pollutants, Criteria Pollutants, and Moisture Using Fourier Transform Infrared (FTIR) Spectroscopy" – Prepared by Radian International for the Gas Research Institute.

"Protocol for Performing Extractive FTIR Measurements to Characterize Various Gas Industry Sources for Air Toxics" – Prepared by Radian International for the Gas Research Institute.

Both documents are contained with the Gas Research Institute Report Number GRI-95/0271 entitled, "Fourier Transform Infrared (FTIR) Method Validation at a Natural Gas-Fired Internal Combustion Engine" – Prepared by Radian International for the Gas Research Institute.

Instrument Description

Dedicated FTIR analyzers and sampling conditioning systems were used to measure pre-catalyst and post-catalyst exhaust emissions. A description of each unit is presented in Table 9:

TABLE 9

FTIR EQUIPMENT DESCRIPTION

Pre-catalyst Analyzer	
Manufacturer and Type	Nicolet Rega 7000
Spectral Resolution	$0.5cm^{-1}$
Detector Type	MCT-A
Cell Type	4.2 Meter – Fixed Path Length
Cell Temperature	185°C
Cell Pressure	600 Torr
Cell Window Material	Zinc Cellinide
Post-catalyst Analyzer	
Manufacturer and Type	Nicolet Magna 560
Spectral Resolution	$0.5cm^{-1}$
Detector Type	MCT-A
Cell Type	2.0 Meter – Fixed Path Length
Cell Temperature	165°C
Cell Pressure	600 Torr
Cell Window Material	KBr

Each unit and the associated test method have been designed for measurement of raw exhaust gases from internal combustion engines. Dedicated temperature controllers maintained cell temperature and associated sample lines at the appropriate the design temperature. Pressure was controlled by means of an MKS pressure controller for each system. Sample flow to each analyzer was between 8 – 15 liters/minute. The units utilized a high-energy mid-range IR source and are equipped with modulating, potassium bromide beamsplitters with MCT-A liquid nitrogen cooled detectors. The cells have been equipped with specific optical windows to prevent signal degradation from damaged optics due to moisture and corrosive gases present in the exhaust stream.

Pre Engine Test Calibration

Prior to initiation of an engine specific test program, the FTIR sampling systems, both pre and post-catalyst sample trains underwent an EPA Method 301 validation process. The validation process was to verify the sample and analytical system performance in relation to precision and accuracy of data collected. Additional calibration procedures prior to testing of the engine were as follows:

1.) *Source Evaluation* - Acquired initial source data to verify concentration ranges of target compounds and possible interferants. This was accomplished prior to and during the Method 301 validation process

2.) *Sample System Leak Check* –Sample system leak checks were performed. The leak check procedure encompassed the sample train from the sample filter to the pump outlet. A dedicated rotameter was installed on the discharge side of the sample pump. With the sample system operating at typical temperatures and pressures (sample pump will pull a slight vacuum on the suction side), the sample flow rate from the rotameter was recorded. The inlet to the sample filter located just downstream of the sample probe was closed and the flow rate through the rotameter was monitored. The flow rate through the rotameter went to zero. The leak checks were determined to be acceptable, as the leak rate was less than 4% of the standard sampling rate or 500ml/min, whichever is less. Sample system leak check data sheets are provided in Appendix F of this document.

3.) *Analyzer Leak Check* – With the FTIR analyzers operating at normal operating temperatures and pressures, the operating pressures were recorded. The automatic pressure controllers were then disabled, and the inlet valves to the FTIR analyzers were then closed. The measurement cells were then evacuated to 20% or less of their normal operating pressure. After the measurement cells were evacuated, each measurement cell was then isolated and the cell pressure monitored with a dedicated pressure sensor. The leak rate of each measurement cell was less than 10 Torr per minute for a one-minute period. The analyzer leak rate was determined to be acceptable. Analyzer leak check data sheets are provided in Appendix F of this document.

4.) *Cell Pathlength Determination* – The cell pathlength was to be determined using the measurement procedures as outlined in the Field Procedure Section of the document entitled "Protocol For Performing Extractive FTIR Measurements To Characterize Various Gas Industry Sources For Air Toxics", prepared by Radian International for the Gas Research Institute. Because the units are fixed pathlength (non-adjustable) measurement cells which are stationary units dedicated to a specific task, the pathlength determination process was determined not to be necessary. The units are "as specified" from the manufacturer, and have passed all validation and calibration procedures at this fixed pathlength.

Daily Calibration Procedures – Pre Test

The following daily calibration procedures were performed prior to the initiation of each day's testing.

1.) *Instrument Stabilization* – To ensure the FTIR instruments were operating in a stable manner, verification of the operation of the following components at the beginning of each day was performed:
   a.) All instrument heated devices and temperature controller were at operating temperature and performing properly.
   b.) Pressure sensor and pressure controllers were at operating conditions and performing properly.
   c.) Sample systems (pumps, filters, flow meters, and water knockouts) were functioning properly.
2.) Instruments were operated on a conditioned air source for a minimum of 30 minutes prior to conducting background spectrum procedures. When the instruments were in standby mode, between test days, the analyzers and all components were kept at normal operating temperatures. The analyzers operated on conditioned air at all times when not involved with data acquisition.
3.) *Background spectrum procedures* – After purging with a conditioned air source for a minimum of 30 minutes, the instruments were allowed to stabilize by flowing an ultra high purity N_2 gas through the measurement cell for a minimum of ten minutes. During the stabilization process, the FTIR spectra were monitored until the concentrations of CO and H_2O were reduced and normal steady state background levels had been achieved. The following procedures were then performed:
   a.) Check for proper interferogram signal using alignment software
   b.) Collect a single beam spectrum and inspect for irregularities
   c.) Check the single beam spectrum for detector non-linearity and correct if necessary
   d.) Perform an instrument alignment procedure
   e.) Collect a background spectrum – The background spectrum was comprised 256 scans, which was equal to or greater than the number of scans used for sample analysis.
4.) *Analyzer Diagnostics* – Perform an analyzer diagnostic procedure by analyzing a diagnostic standard. The standard was a EPA Protocol 1 CO gas standard at concentration levels indicative of the emissions source, 109 ppm. A CO standard was recommended due to the distinct spectral features, which are sensitive to variations in system operation and performance. The standard was introduced directly into the instrument. The instrument readings were allowed to stabilize and a

five-minute set of data was acquired. The calculated accuracy and precision based on equations from the document entitled "Protocol for Performing Extractive FTIR Measurements To Characterize Various Gas Industry Sources for Air Toxics", prepared by Radian International for the Gas Research Institute, was acceptable. The pass/fail criteria for accuracy and precision was ± 10% of the known standard for the instrument to be acceptable. Each instrument meets this criteria for all daily calibrations. Analyzer diagnostic data sheets are provided in Appendix F of this document.

5.) *Additional Analyzer Diagnostic* - An additional diagnostic check was performed to ensure system operation and performance. A second diagnostic standard comprised of a multi-gas composition was analyzed by the same procedure. The gas consisted of CO_2, CO, CH_4, and NO_x in concentrations similar to exhaust gas composition. The same pass/fail criteria was used to evaluate each analyzer's performance when analyzing the multi-gas standard. Each instrument meets this criteria for all daily calibrations. Analyzer diagnostic data sheets are provided in Appendix F of this document.

6.) *Indicator Check & Sample Integrity Check* - An indicator check procedure was performed on each analyzer by analyzing a certified indicator standard. The standard was either a NIST traceable, EPA Protocol 1 gas standard, or highest grade standard available of a surrogate/analyte gas concentration at levels indicative of the emissions source. A formaldehyde standard (concentration of 10.66 ppm) was used due to the fact that formaldehyde represents a sampling challenge because of its solubility in water. The standard was introduced directly into the instrument. The instrument readings were allowed to stabilize and a five-minute set of data was acquired. Next, the indicator standard was introduced into the sample system at the sample filter located just downstream of the sample probe. The instrument readings were allowed to stabilize and a five-minute set of data was acquired. The calculated accuracy and precision based on equations from the document entitled "Protocol For Performing Extractive FTIR Measurements To Characterize Various Gas Industry Sources For Air Toxics", prepared by Radian International for the Gas Research Institute. The pass/fail criteria for accuracy, precision, and recovery was ± 10% of the known standard (recovery was ± 10% of the instrument reading with the indicator gas introduced directly into the instrument.) for the instrument to be acceptable. Each instrument meets this criteria for all daily calibrations. Indicator check and sample integrity check data sheets are provided in Appendix F of this document.

Daily Calibration Procedures – Background assessment

The baseline absorbance was continually monitored during data acquisition procedures. If it was determined by PES, ERG, and CSU personnel that the baseline had changed by more than 0.1 absorbance units, the instrument interferometer was realigned and a background spectrum collected.

Daily Calibration Procedures – Post Test

Upon completion of the daily test program steps 4 – 6 of the pre test calibration procedures were repeated. Both analyzers meet all acceptance criteria for calibration procedures. All post test calibration data sheets are presented in Appendix F of this document.

4.9 TEST SPECIFIC – FTIR VALIDATION PROCEDURES

To ensure the accuracy of data collected during testing, the test program required procedures to evaluate instrument performance. Prior to collecting test data, a validation procedure was performed on each FTIR sample train, both pre-catalyst and post-catalyst, for the natural gas fueled engine classification. The specific sample trains are as follows:

1.) Pre-catalyst emissions sample trains from the exhaust of natural gas fueled engines. This comprises the two-stroke lean burn engine class and four-stroke lean burn engine.
2.) Post-catalyst emissions sample trains from the exhaust of natural gas fueled engines. This comprises the two-stroke lean burn engine and four-stroke lean burn engine.

Each sample train was validated for the following target compounds:

1.) Formaldehyde
2.) Acetaldehyde
3.) Acrolein

Instrument Description

Refer to FTIR calibration procedures for FTIR instrument description.

Procedures

Eastern Research Group, ERG, performed the validation for the target aldehyde compounds. The validation procedure was conducted in basic accordance with procedures outlined in Method 301-"Field Validation of Pollutant Measurement Methods from Various Waste Media". Validation procedures for aldehydes utilized an analyte spiking technique as specified in Method 301. The procedures for the validation process are as follows:

Analyte Spiking:

The process was carried out by means of dynamic analyte spiking of the sample gas. The sample stream of the exhaust gas was spiked with the specific analyte after the sample probe, and before the sample filter. Spike levels for the specific aldehydes were determined and the spike gas concentrations were generated for the specific aldehydes using the following methods:

Formaldehyde:

Formaldehyde spike gas was generated by volatilization of a formalin solution prepared from a stock formalin solution of 37% formaldehyde by weight. The solution was injected into a heated vaporization block. The vaporized formalin solution was mixed with a acetylaldehyde/acrolein carrier gas and carried into the sample exhaust stream. Carrier gas flow rate was measured by a mass flow meter equipped with readout

Acetlyaldehyde/Acrolein:

Acetlyaldehyde and acrolein spike samples were generated from a certified gas standard (Scott Specialty Gases, ±2% analytical accuracy) which contained both analyte species and a sulfur hexaflouride (SF6) tracer gas. Carrier gas flow rate was measured by a mass flow meter equipped with readout.

Analyte specific spike gas was introduced to the FTIR sample train upstream of the sample system filter. The spike gas was introduced at a known flow rate. The spike gas flow was controlled by a three-way solenoid valve, which directed gas either into the sample stream or diverted the spike gas to the atmosphere. This allowed for uninterrupted flow of the analyte spike gas source during the validation procedures.

The formaldehyde and acetylaldehyde/acrolein validation runs were conducted simultaneously. The validation test runs consisted of 24 test runs, 12 spiked and 12 unspiked runs, which were paired and grouped further into six groups of 2 spiked/unspiked pairs to simulate the "quad train" approach used for Method 301 statistical calculations. Samples were one minute in duration. Measurement procedures for acquiring the spiked/unspiked pairs are as follows:

1.) Verify stable engine operation
2.) Begin measurement of the unspiked native exhaust stack gas.
3.) Upon completion of acquiring the unspiked sample, initiate spike gas flow into sample stream.
4.) Let system equilibrate.
5.) Begin measurement of the spiked exhaust gas sample.
6.) Upon completion of acquiring the spiked sample, divert spike gas flow to atmosphere.
7.) Let system equilibrate.
8.) Repeat items 2 through 7.

This procedure was performed twelve times to acquire the appropriate number of spiked/unspiked pairs. To ensure stable engine operation during the validation procedure, engine operating data was collected during the spiking process.

4.10 TEST SPECIFIC - GENERAL CALIBRATION

To ensure the accuracy of data collected during testing, the test procedure required that all instrumentation be routinely calibrated. Calibrations and/or calibration checks were performed within one week before initiation of testing, and upon completion of the entire test program to ensure that no "drift" has occurred. The devices calibrated included the dynamometer 5000-lb. load cell and amplifier, all thermocouples, pressure transducers, and all pressure transmitters.

Dynamometer Load Cell and Amplifier (Daily)

The 5000 pound load cell and amplifier was calibrated prior to the engine test section. The calibration procedure is outlined in a document contained in Appendix M of this document. Calibration of the load cell and amplifier were then be verified by applying the full range of load without any adjustments to the offset or gain of the instrumentation. Calibration checks were performed on a daily basis prior to starting the engine to identify and correct any drift in the load cell or amplifier. These checks used the same procedure as the calibration verification. If the daily calibration check showed an indicated load that exceeded ±1.0% of the torque applied by the standard weights, the full calibration procedure was performed. The dynamometer was within acceptable limits during the test program. Dynamometer calibration data sheets are provided in Appendix L of this document.

Thermocouples (Within one week prior to initiation of each engine test program)

K-type insertion thermocouples are used throughout the Large Bore Engine Testbed with compensation performed through the engine control and data acquisition hardware. The thermocouples were calibrated using a Ronan X88 portable calibrator calibrated within ±1.0°F of N.I.S.T. standard by an independent laboratory. The thermocouple signal was zeroed and the gain adjusted at full span until the value displayed by the NetCon 5000 matched the setting of the Ronan X88 within ±2.0°F. Once the zero and gain have been set a minimum of two mid-point temperatures were checked to verify the calibration. Thermocouple calibration data sheets are provided in Appendix J of this report.

Pressure Transducers (Within one week prior to initiation of each engine test program)

A 3-way valve has been installed to allow pressure transducer calibration without removing the sensor from the system. The Model 320 Beta calibrator used for transducers calibration provides an accuracy of 0.05% of reading or 0.02% of full span and is calibrated to N.I.S.T. standards by an independent laboratory. The transducer was zeroed and the gain adjusted at full span until the value displayed by the NetCon 5000 was within ±1.0 psig of the pressure supplied by the pressure calibration standard. A minimum of two midpoints was checked to verify calibration. Pressure transducer calibration data sheets are provided in Appendix J of this report.

Pressure Transmitters (Within one week prior to initiation of each engine test program)

Pressures, which were critical to control, and emissions calculations were measured using Rosemount® 3051C transmitters. The calibration was performed at the transmitter and no adjustments are made to the current loop. A known pressure was supplied to the sensing port of the transmitter using the Model 320 Beta calibrator. The transmitter was zeroed and then spanned at the full range value of the system. Once spanned, the value displayed by the NetCon 5000 within ±0.5% of the full range value. A minimum of two mid-span points was checked to verify calibration. Pressure transmitter calibration data sheets are provided in Appendix J of this report.

4.11 TEST SPECIFICS - TEST BED GENERAL DESCRIPTION

Colorado State University's Engines & Energy Conversion Laboratory

The continued operation of stationary reciprocating internal combustion engines is faced with tremendous challenges in meeting ever tightening restrictions on air borne pollutants. The regulatory environment continues to evolve toward lower allowable limits for criteria pollutants, including new limitations on hazardous air pollutants (HAPs), even as current statutes are being implemented. Although ominous the task of meeting compliance, difficulties involved in complying with tightening emissions regulations have advanced the knowledge and understanding of engine emissions and performance. The mechanism, which has elevated the understanding of exhaust emissions, is research and development. To aid in this effort the Engines & Energy Conversion Laboratory was established at Colorado State University. The engines located at the Engines & Energy Conversion Laboratory (EECL) located at Colorado State University, and are representative of the types used by the oil and gas industries as well as power generation markets. The CSU facility currently comprises the only independent large-bore industrial engine test facility in North America. Engines that are located at the facility are as follows:

- Cooper –Bessemer GMV-4-TF , Two-Stroke Lean Burn Natural Gas Fired Engine
- Waukesha 3521GL, Four-Stroke Lean Burn Natural Gas Fired Engine
- White Superior 6G825, Four Stroke, Rich Burn Natural Gas Fired Engine
- Caterpillar 3508, Four Stroke, Lean Burn Diesel Fueled Engine

The natural gas pipeline industry has supported the installation of three four-stroke engines in the same manner as the original engine installation. The program sponsor for the installation of the engines is the Gas Research Institute (GRI). The additional engines have been installed at the facility to assist research efforts in addressing needs, both emissions and performance related, on multiple engine types. The high-speed, four-cycle, industrial engines (approximately 1000-1800 rpm) represent a large portion of the current horsepower in operation within the oil and gas industry and power generation markets.

APPENDIX A

ENGINE TEST DATA

Colorado State University
~~August 4-6, 1999~~
EPA RICE Testing
Waukesha
Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Waukesha				
ENGINE OPERATING PARAMETERS	Run 1	Run 2	Run 3	Run 4
Ignition Type	PCC	PCC	PCC	PCC
Dynamometer Torque (ft-lb)	3236	2263	2264	3234
Brake Horsepower (bhp)	737	516	432	617
BSFC (btu/bhp-hr)	7411	8166	7658	7308
Engine Speed (rpm)	1197	1197	1002	1002
Timing (Degrees BTDC)	10.00	10.00	10.00	10.00
A/F (Wet)	28.7	28.8	28.2	28.9
Pressures				
Air Manifold (in. Hg)	5.02	5.00	5.00	5.00
Fuel Manifold (psig)	4.12	6.60	6.88	6.21
Fuel Supply (psig)	46.73	47.17	47.45	47.16
Intercooler Air Differential (in. H_2O)	9.26	5.85	4.79	6.59
Post Intercooler Air Manifold (in. Hg)	69.21	66.06	54.27	66.48
Intercooler Water Differential (in. H_2O)	157.45	157.45	157.45	157.45
Intercooler Supply (psi)	3.12	2.72	2.83	2.72
Pre-Turbo Exhaust (in. Hg)	36.51	28.80	21.26	30.55
Post- Turbo Exhaust (in. Hg)	4.82	4.99	4.98	5.16
Turbo Oil (in. Hg)	46.91	47.35	45.32	44.90
Catalyst Differential (in. H_2O)	9.1	5.6	3.9	6.0
Temperatures (°F) and Flows (GPM)				
Air Supply Temperature	99.5	99.9	99.7	99.3
Fuel Manifold Temperature	85.6	87.9	84.7	86.1
Exhaust Stack Temperature	704.5	676.4	640.4	656.9
Exhaust Header Temperature	704.5	676.4	640.4	656.9
Jacket Water Inlet Temperature	173.1	175.3	176.4	175.4
Jacket Water Outlet Temperature	179.4	179.0	178.8	179.5
Lube Oil Inlet Temperature	81.1	81.5	82.7	76.9
Lube Oil Outlet Temperature	86.7	86.6	86.9	81.6
Lube Oil Flow	129.2	129.2	129.3	128.3
Engine Oil In Temperature	164.6	163.3	162.8	162.4
Engine Oil Out Temperature	185.7	183.2	180.0	181.1
Intercooler Air In Temperature	296.9	280.9	232.3	282.3
Intercooler Air Out Temperature	142.2	137.1	135.2	138.5
Intercooler Water In Temperature	131.6	127.6	130.3	128.5
Intercooler Water Out Temperature	142.9	137.1	135.7	138.7
Intercooler Water Flow	62.6	55.5	58.5	55.5
Pre-Turbo ExhaustTemperature	961.0	926.7	860.6	905.0
Post-Turbo Exhaust Temperature	797.9	750.4	725.6	725.8
Pre-Catalyst Temperature	734.5	705.5	677.0	685.2
Post-Catalyst Temperature	739.56	709.99	679.03	688.42

Colorado State University

August 4-6, 1999

EPA RICE Testing

Waukesha

Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Waukesha				
ENGINE OPERATING PARAMETERS	Run 1	Run 2	Run 3	Run 4
Ignition Type	PCC	PCC	PCC	PCC
Fuel Measurements				
Static Fuel (psia)	46.5	46.6	46.9	46.6
Fuel Differential (in. H_2O)	14.4	8.4	5.1	9.6
Orifice Temperature (°F)	85.6	87.9	84.7	86.1
Fuel Flow (scfh)	5418	4114	3229	4401
Fuel Consumption (BSFC)	7411	8166	7658	7308
Lower Heating Value-Dry (Btu)	1008	1024	1024	1024
Fuel Tube I.D. (in.)	3.068	3.068	3.068	3.068
Fuel Orifice O.D. (in.)	0.5	0.5	0.5	0.5
Annubar Flow Rates				
Inlet Air Flow (scfm)	1713.6	1291.8	1020.5	1377.1
Exhaust Flow (scfm)	2013.1	1545.7	1192.6	1660.1
Ambient Conditions				
Barometric Pressure (psia)	12.08	12.07	12.07	12.07
Dry Bulb Temperature (°F)	64.0	65.0	69.0	62.1
Relative Humidity (%)	80.0	74.6	63.9	78.0
Absolute Humidity (lb/lb)	0.012	0.012	0.012	0.011
Absolute Humidity (gr/lb)	86.668	83.651	82.295	78.961
Air Manifold Conditions				
Boost Pressure (in. Hg)	5.02	5.00	5.00	5.00
Dry Bulb Temperature (°F)	99.5	99.9	99.7	99.3
Relative Humidity (%)	37.8	30.4	37.3	36.1
Relative Humidity (%) - Corrected*	51.2	41.7	50.9	48.7
Absolute Humidity (lb/lb)	0.016	0.013	0.015	0.015
Absolute Humidity (gr/lb)	108.712	88.188	108.105	103.280

*Air manifold relative humidity corrected to the reference ambient conditions of 90°F, 14.696 psi.

Cylinder Exhaust Temperatures (Degrees °F)				
Cylinder 1	976.9	960.5	884.2	908.3
Cylinder 2	977.8	953.2	880.5	910.3
Cylinder 3	980.4	954.7	877.5	913.0
Cylinder 4	954.3	931.2	861.6	893.0
Cylinder 5	945.3	913.2	850.8	886.8
Cylinder 6	929.7	914.2	843.4	873.4
Engine Average	960.73	937.84	843.41	873.35

Colorado State University
August 4-6, 1999
EPA RICE Testing
Waukesha
Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Waukesha				
MEASURED EMISSIONS	Run 1	Run 2	Run 3	Run 4
Ignition Type	PCC	PCC	PCC	PCC
Air Manifold Pressure ("Hg)	5.02	5.00	5.00	5.00
Brake Horsepower (bhp)	737	516	432	617
Emissions Measured (Dry)				
NO_x (ppm): Pre-Catalyst	112.26	76.27	72.83	107.78
NO_x (ppm): Post-Catalyst	119.34	82.48	81.66	113.18
CO (ppm): Pre-Catalyst	620.26	590.96	573.32	590.78
CO (ppm): Post-Catalyst	41.32	26.75	21.89	30.19
THC (ppm): Pre-Catalyst	1785.06	2129.30	2424.42	2166.33
THC (ppm): Post-Catalyst	1869.94	2172.32	2458.76	2165.00
O_2 %: Pre-Catalyst	9.80	9.82	9.81	9.80
O_2 %: Post-Catalyst	9.80	9.83	9.81	9.80
CO_2 %: Pre-Catalyst	6.29	6.23	6.37	6.24
CO_2 %: Post-Catalyst	6.46	6.42	6.40	6.41
Emissions Measured (Wet)				
Methane (ppm): Pre-Catalyst	1266.40	1462.36	1661.04	1498.39
Methane (ppm): Post-Catalyst	1100.08	1326.13	1391.50	1358.65
Non-Methane (ppm): Pre-Catalyst	148.47	160.09	183.77	130.64
Non-Methane (ppm): Post-Catalyst	117.90	131.14	147.28	113.19
Carbon Balance Calculations				
Exhaust H_2O% (Pre-Catalyst)	12.25	11.73	12.30	12.02
Exhaust H_2O% (Post-Catalyst)	12.42	11.92	12.25	12.19
O_2 %	10.11	10.20	9.98	10.22
O_2 Balance	-1.44	-1.84	-0.89	-1.91
Exhaust Flow (lb/hr)	8262.0	6369.3	4897.3	6822.5
Air Flow (lb/hr)	7984.0	6155.8	4729.8	6594.1
Air/Fuel Ratio	28.7	28.8	28.2	28.9
F-Factor Emissions Calculations				
NO_x (g/bhp-hr): Pre-Catalyst	0.815	0.610	0.546	0.771
NO_x (lb/hr): Pre-Catalyst	1.325	0.694	0.520	1.047
NO_x (g/bhp-hr): Post-Catalyst	0.866	0.660	0.612	0.809
NO_x (lb/hr): Post-Catalyst	1.408	0.751	0.582	1.100
THC (g/bhp-hr): Pre-Catalyst	4.589	6.035	6.436	5.485
THC (lb/hr): Pre-Catalyst	7.460	6.863	6.124	7.456
THC (g/bhp-hr): Post-Catalyst	4.808	6.157	6.527	5.481
THC (lb/hr): Post-Catalyst	7.814	7.001	6.211	7.451
CO (g/bhp-hr): Pre-Catalyst	2.784	2.925	2.657	2.611
CO (lb/hr): Pre-Catalyst	4.526	3.325	2.529	3.550
CO (g/bhp-hr): Post-Catalyst	0.185	0.132	0.101	0.133
CO (lb/hr): Post-Catalyst	0.301	0.151	0.097	0.181
Methane (g/bhp-hr): Pre-Catalyst	3.752	4.745	5.074	4.361
Methane (lb/hr): Pre-Catalyst	6.099	5.395	4.828	5.929
Methane (g/bhp-hr): Post-Catalyst	3.260	4.303	4.250	3.955
Methane (lb/hr): Post-Catalyst	5.298	4.892	4.045	5.376
Non-Methane (g/bhp-hr): Pre-Catalyst	1.209	1.428	1.543	1.045
Non-Methane (lb/hr): Pre-Catalyst	1.966	1.623	1.468	1.421
Non-Methane (g/bhp-hr): Post-Catalyst	0.960	1.170	1.237	0.906
Non-Methane (lb/hr): Post-Catalyst	1.561	1.330	1.177	1.231
Formaldehyde (g/bhp-hr): Pre-Catalyst	0.312	0.369	0.329	0.301
Formaldehyde (lb/hr): Pre-Catalyst	0.508	0.420	0.314	0.409
Formaldehyde (g/bhp-hr): Post-Catalyst	0.100	0.093	0.061	0.088
Formaldehyde (lb/hr): Post-Catalyst	0.162	0.106	0.058	0.120
Acetaldehyde (g/bhp-hr): Pre-Catalyst	-0.028	-0.037	-0.047	-0.031
Acetaldehyde (lb/hr): Pre-Catalyst	-0.046	-0.042	-0.044	-0.042
Acetaldehyde (g/bhp-hr): Post-Catalyst	0.000	0.000	0.000	0.000
Acetaldehyde (lb/hr): Post-Catalyst	0.000	0.000	0.000	0.000
Acrolein (g/bhp-hr): Pre-Catalyst	0.004	-0.003	-0.004	0.000
Acrolein (g/bhp-hr): Pre-Catalyst	0.006	-0.003	-0.004	0.001
Acrolein (g/bhp-hr): Post-Catalyst	0.000	0.000	0.000	0.000
Acrolein (lb/hr): Post-Catalyst	0.0	0.0	0.0	0.0

Colorado State University
August 4-6, 1999
EPA RICE Testing
Waukesha
Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Waukesha				
MEASURED EMISSIONS	Run 1	Run 2	Run 3	Run 4
Ignition Type	PCC	PCC	PCC	PCC
Air Manifold Pressure ("Hg)	5.02	5.00	5.00	5.00
Brake Horsepower (bhp)	737	516	432	617
FTIR Measured Emissions (ppm, Wet)				
Water-H_2O	132315	126394	130933	130209
Carbon Monoxide-CO (ppm): Pre-Catalyst	532.071	512.242	496.451	511.649
Carbon Monoxide-CO (ppm): Post-Catalyst	24.137	11.351	6.267	14.166
Carbon Dioxide-CO_2 (ppm): Pre-Catalyst	56847	55598	56370	55618
Carbon Dioxide-CO_2 (ppm): Post-Catalyst	54430	54281	53813	53975
Nitric Oxide-NO (ppm): Pre-Catalyst	34.762	15.089	16.156	37.505
Nitric Oxide-NO (ppm): Post-Catalyst	90.771	60.962	60.266	85.112
Nitrogen Dioxide-NO_2 (ppm): Pre-Catalyst	52.508	43.941	41.465	47.879
Nitrogen Dioxide-NO_2 (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Nitrous Oxide-N_2O (ppm): Pre-Catalyst	0.491	0.492	0.458	0.483
Nitrous Oxide-N_2O (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Ammonia-NH_3 (ppm): Pre-Catalyst	0.000	0.000	0.000	0.000
Ammonia-NH_3 (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Oxides of Nitrogen-NO_X (ppm): Pre-Catalyst	87.271	59.029	57.621	85.385
Oxides of Nitrogen-NO_X (ppm): Post-Catalyst	90.771	60.962	58.790	85.112
Methane-CH_4 (ppm): Pre-Catalyst	1390.505	1694.023	1883.877	1730.944
Methane-CH_4 (ppm): Post-Catalyst	1394.899	1654.721	1810.803	1668.765
Acetylene-C_2H_2 (ppm): Pre-Catalyst	0.004	0.103	0.363	0.000
Acetylene-C_2H_2 (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Ethylene-C_2H_4 (ppm): Pre-Catalyst	59.778	61.237	59.081	48.021
Ethylene-C_2H_4 (ppm): Post-Catalyst	22.421	15.968	9.756	12.296
Ethane-C_2H_6 (ppm): Pre-Catalyst	154.137	173.349	208.761	155.649
Ethane-C_2H_6 (ppm): Post-Catalyst	208.203	229.031	279.990	203.376
Cyclopropene-C_3H_6 (ppm): Pre-Catalyst	1.527	2.425	1.858	1.289
Cyclopropene-C_3H_6 (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Formaldehyde-H_2CO (ppm): Pre-Catalyst	56.310	60.753	57.630	55.249
Formaldehyde-H_2CO (ppm): Post-Catalyst	17.970	15.326	10.604	16.225
Methanol-CH_3OH (ppm): Pre-Catalyst	1.729	1.843	1.871	1.435
Methanol-CH_3OH (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Propane-C_3H_8 (ppm): Pre-Catalyst	32.908	37.072	43.230	33.995
Propane-C_3H_8 (ppm): Post-Catalyst	27.758	30.019	35.193	27.606
Sulfur Dioxide-SO_2 (ppm): Pre-Catalyst	1.678	2.895	2.303	3.175
Sulfur Dioxide-SO_2 (ppm): Post-Catalyst	1.893	1.191	0.000	1.298
Total Hydrocarbons-THC (ppm): Pre-Catalyst	1897.534	2256.388	2526.730	2222.342
Total Hydrocarbons-THC (ppm): Post-Catalyst	2076.828	2401.490	2675.504	2355.141
Acetaldehyde-CH_3CHO (ppm): Pre-Catalyst	-3.441	-4.132	-5.545	-3.892
Acetaldehyde-CH_3CHO (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Acrolein CH_2=CHCHO (ppm): Pre-Catalyst	0.382	-0.232	-0.345	0.041
Acrolein CH_2=CHCHO (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
1-3 Butadiene (ppm): Pre-Catalyst	0.818	1.246	1.480	1.302
1-3 Butadiene (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Isobutylene (ppm): Pre-Catalyst	0.001	0.000	0.000	0.000
Isobutylene (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Calculated Catalyst Efficiency				
Carbon Monoxide-CO (%)	95.46%	97.78%	98.74%	97.23%
Formaldehyde-H_2CO (%)	68.09%	74.77%	81.60%	70.63%

Colorado State University

~~August 4-6, 1999~~

EPA RICE Testing

Waukesha

Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Waukesha				
ENGINE OPERATING PARAMETERS	Run 5	Run 6	Run 7	Run 8
Ignition Type	PCC	PCC	PCC	PCC
Dynamometer Torque (ft-lb)	3235	3234	2263	3234
Brake Horsepower (bhp)	737	737	516	617
BSFC (btu/bhp-hr)	7728	7468	8078	7400
Engine Speed (rpm)	1197	1197	1197	1001
Timing (Degrees BTDC)	10.00	10.00	10.00	10.00
A/F (Wet)	30.3	27.4	27.3	30.4
Pressures				
Air Manifold (in. Hg)	5.00	5.00	5.00	5.00
Fuel Manifold (psig)	0.68	8.53	7.68	2.68
Fuel Supply (psig)	46.79	46.87	47.14	47.26
Intercooler Air Differential (in. H_2O)	10.73	8.39	5.38	7.54
Post Intercooler Air Manifold (in. Hg)	67.88	69.41	65.46	66.62
Intercooler Water Differential (in. H_2O)	157.45	157.45	157.45	157.45
Intercooler Supply (psi)	2.76	2.76	2.72	2.67
Pre-Turbo Exhaust (in. Hg)	40.48	34.24	27.29	32.04
Post- Turbo Exhaust (in. Hg)	5.55	4.47	4.94	4.95
Turbo Oil (in. Hg)	47.11	46.91	47.33	44.99
Catalyst Differential (in. H_2O)	10.1	8.5	5.1	6.6
Temperatures (°F) and Flows (GPM)				
Air Supply Temperature	99.7	99.6	99.9	99.5
Fuel Manifold Temperature	87.5	88.1	88.1	84.1
Exhaust Stack Temperature	684.7	722.5	694.4	640.8
Exhaust Header Temperature	684.7	722.5	694.4	640.8
Jacket Water Inlet Temperature	173.8	174.8	175.3	175.2
Jacket Water Outlet Temperature	179.5	180.3	179.2	178.8
Lube Oil Inlet Temperature	85.2	84.2	82.1	78.7
Lube Oil Outlet Temperature	90.8	89.8	87.7	83.3
Lube Oil Flow	129.9	129.7	129.3	128.6
Engine Oil In Temperature	164.0	164.8	163.8	162.0
Engine Oil Out Temperature	185.1	186.1	183.7	180.8
Intercooler Air In Temperature	303.0	297.4	278.7	284.6
Intercooler Air Out Temperature	145.5	139.5	138.4	138.7
Intercooler Water In Temperature	130.4	128.2	129.0	128.7
Intercooler Water Out Temperature	144.2	140.3	138.2	139.6
Intercooler Water Flow	56.2	56.3	55.7	54.8
Pre-Turbo ExhaustTemperature	936.7	987.7	950.3	880.6
Post-Turbo Exhaust Temperature	748.3	805.6	776.5	702.3
Pre-Catalyst Temperature	711.2	758.9	728.4	662.8
Post-Catalyst Temperature	717.84	760.19	731.12	668.52

Colorado State University
~~August 4-6, 1999~~
EPA RICE Testing
Waukesha
Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Waukesha				
ENGINE OPERATING PARAMETERS	Run 5	Run 6	Run 7	Run 8
Ignition Type	PCC	PCC	PCC	PCC
Fuel Measurements				
Static Fuel (psia)	46.4	46.4	46.6	46.6
Fuel Differential (in. H_2O)	15.4	14.4	8.2	9.8
Orifice Temperature (°F)	87.5	88.1	88.1	84.1
Fuel Flow (scfh)	5564	5377	4070	4457
Fuel Consumption (BSFC)	7728	7468	8078	7400
Lower Heating Value-Dry (Btu)	1024	1024	1024	1024
Fuel Tube I.D. (in.)	3.068	3.068	3.068	3.068
Fuel Orifice O.D. (in.)	0.5	0.5	0.5	0.5
Annubar Flow Rates				
Inlet Air Flow (scfm)	1853.1	1611.8	1212.4	1474.3
Exhaust Flow (scfm)	2194.2	1940.0	1456.4	1760.3
Ambient Conditions				
Barometric Pressure (psia)	12.07	12.07	12.07	12.07
Dry Bulb Temperature (°F)	67.0	65.5	65.0	63.4
Relative Humidity (%)	71.5	74.0	74.0	77.5
Absolute Humidity (lb/lb)	0.012	0.012	0.012	0.012
Absolute Humidity (gr/lb)	86.000	84.516	83.016	82.332
Air Manifold Conditions				
Boost Pressure (in. Hg)	5.00	5.00	5.00	5.00
Dry Bulb Temperature (°F)	99.7	99.6	99.9	99.5
Relative Humidity (%)	36.5	37.6	31.0	37.0
Relative Humidity (%) - Corrected*	49.8	51.2	42.5	50.1
Absolute Humidity (lb/lb)	0.015	0.016	0.013	0.015
Absolute Humidity (gr/lb)	105.581	108.575	89.816	106.295

*Air manifold relative humidity corrected to the reference ambient conditions of 90°F, 14.696 psi.

Cylinder Exhaust Temperatures (Degrees °F)				
Cylinder 1	969.8	1001.8	987.3	886.5
Cylinder 2	970.7	1003.3	979.4	887.8
Cylinder 3	967.5	1006.8	980.4	888.8
Cylinder 4	931.6	979.0	956.1	868.0
Cylinder 5	911.7	970.2	937.3	860.0
Cylinder 6	901.3	957.3	941.6	846.2
Engine Average	901.30	957.31	941.55	846.18

Colorado State University
~~August 4-6, 1999~~
EPA RICE Testing
Waukesha
Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Waukesha				
MEASURED EMISSIONS	Run 5	Run 6	Run 7	Run 8
Ignition Type	PCC	PCC	PCC	PCC
Air Manifold Pressure ("Hg)	5.00	5.00	5.00	5.00
Brake Horsepower (bhp)	737	737	516	617
Emissions Measured (Dry)				
NO_x (ppm): Pre-Catalyst	71.73	205.31	145.99	60.93
NO_x (ppm): Post-Catalyst	78.16	214.12	154.06	65.73
CO (ppm): Pre-Catalyst	740.59	669.76	639.84	641.35
CO (ppm): Post-Catalyst	53.69	39.54	26.35	35.85
THC (ppm): Pre-Catalyst	2456.71	1604.71	1821.07	2513.17
THC (ppm): Post-Catalyst	2479.44	1593.88	1843.11	2602.35
O_2 %: Pre-Catalyst	10.51	9.10	9.20	10.50
O_2 %: Post-Catalyst	10.44	9.01	9.09	10.50
CO_2 %: Pre-Catalyst	5.86	6.65	6.65	5.86
CO_2 %: Post-Catalyst	5.96	6.83	6.79	5.99
Emissions Measured (Wet)				
Methane (ppm): Pre-Catalyst	1652.46	1109.58	1260.52	1766.78
Methane (ppm): Post-Catalyst	1483.13	983.53	1124.82	1178.97
Non-Methane (ppm): Pre-Catalyst	185.52	116.99	145.37	171.12
Non-Methane (ppm): Post-Catalyst	154.94	91.09	110.19	171.12
Carbon Balance Calculations				
Exhaust H_2O% (Pre-Catalyst)	11.56	12.71	12.35	11.55
Exhaust H_2O% (Post-Catalyst)	11.60	12.86	12.46	11.66
O_2 %	10.79	9.52	9.52	10.80
O_2 Balance	-1.43	-1.88	-1.48	-1.56
Exhaust Flow (lb/hr)	9044.4	7938.8	5978.4	7255.7
Air Flow (lb/hr)	8755.6	7659.7	5767.1	7024.3
Air/Fuel Ratio	30.3	27.4	27.3	30.4
F-Factor Emissions Calculations				
NO_x (g/bhp-hr): Pre-Catalyst	0.579	1.411	1.094	0.471
NO_x (lb/hr): Pre-Catalyst	0.941	2.293	1.245	0.640
NO_x (g/bhp-hr): Post-Catalyst	0.631	1.472	1.155	0.508
NO_x (lb/hr): Post-Catalyst	1.026	2.391	1.313	0.690
THC (g/bhp-hr): Pre-Catalyst	7.026	3.906	4.835	6.877
THC (lb/hr): Pre-Catalyst	11.418	6.347	5.498	9.350
THC (g/bhp-hr): Post-Catalyst	7.091	3.879	4.894	7.121
THC (lb/hr): Post-Catalyst	11.524	6.304	5.565	9.681
CO (g/bhp-hr): Pre-Catalyst	3.698	2.846	2.966	3.064
CO (lb/hr): Pre-Catalyst	6.010	4.625	3.373	4.166
CO (g/bhp-hr): Post-Catalyst	0.268	0.168	0.122	0.171
CO (lb/hr): Post-Catalyst	0.436	0.273	0.139	0.233
Methane (g/bhp-hr): Pre-Catalyst	5.398	3.132	3.862	5.523
Methane (lb/hr): Pre-Catalyst	8.772	5.090	4.392	7.508
Methane (g/bhp-hr): Post-Catalyst	4.845	2.776	3.447	3.685
Methane (lb/hr): Post-Catalyst	7.873	4.512	3.919	5.010
Non-Methane (g/bhp-hr): Pre-Catalyst	1.666	0.908	1.224	1.470
Non-Methane (lb/hr): Pre-Catalyst	2.707	1.475	1.392	1.999
Non-Methane (g/bhp-hr): Post-Catalyst	1.391	0.707	0.928	1.470
Non-Methane (lb/hr): Post-Catalyst	2.261	1.149	1.055	1.999
Formaldehyde (g/bhp-hr): Pre-Catalyst	0.398	0.312	0.378	0.339
Formaldehyde (lb/hr): Pre-Catalyst	0.647	0.507	0.429	0.461
Formaldehyde (g/bhp-hr): Post-Catalyst	0.135	0.076	0.075	0.117
Formaldehyde (lb/hr): Post-Catalyst	0.219	0.123	0.085	0.159
Acetaldehyde (g/bhp-hr): Pre-Catalyst	-0.041	-0.019	-0.022	-0.043
Acetaldehyde (lb/hr): Pre-Catalyst	-0.066	-0.031	-0.025	-0.059
Acetaldehyde (g/bhp-hr): Post-Catalyst	0.000	0.000	0.000	0.000
Acetaldehyde (lb/hr): Post-Catalyst	0.000	0.000	0.000	0.000
Acrolein (g/bhp-hr): Pre-Catalyst	-0.005	0.000	-0.002	-0.001
Acrolein (g/bhp-hr): Pre-Catalyst	-0.008	0.000	-0.003	-0.001
Acrolein (g/bhp-hr): Post-Catalyst	0.000	0.000	0.000	0.000
Acrolein (lb/hr): Post-Catalyst	0.0	0.0	0.0	0.0

Colorado State University
August 4-6, 1999
EPA RICE Testing
Waukesha
Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Waukesha				
MEASURED EMISSIONS	Run 5	Run 6	Run 7	Run 8
Ignition Type	PCC	PCC	PCC	PCC
Air Manifold Pressure ("Hg)	5.00	5.00	5.00	5.00
Brake Horsepower (bhp)	737	737	516	617
FTIR Measured Emissions (ppm, Wet)				
Water-H_2O	124497	137775	133514	124578
Carbon Monoxide-CO (ppm): Pre-Catalyst	643.758	576.025	551.260	556.962
Carbon Monoxide-CO (ppm): Post-Catalyst	35.850	21.516	9.785	20.259
Carbon Dioxide-CO_2 (ppm): Pre-Catalyst	52179	59100	59090	52100
Carbon Dioxide-CO_2 (ppm): Post-Catalyst	51028	56904	57007	51095
Nitric Oxide-NO (ppm): Pre-Catalyst	13.288	98.067	55.238	9.314
Nitric Oxide-NO (ppm): Post-Catalyst	58.462	168.311	117.940	47.021
Nitrogen Dioxide-NO_2 (ppm): Pre-Catalyst	43.621	67.850	60.557	38.290
Nitrogen Dioxide-NO_2 (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Nitrous Oxide-N_2O (ppm): Pre-Catalyst	0.509	0.515	0.502	0.494
Nitrous Oxide-N_2O (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Ammonia-NH_3 (ppm): Pre-Catalyst	0.000	0.000	0.000	0.000
Ammonia-NH_3 (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Oxides of Nitrogen-NO_X (ppm): Pre-Catalyst	56.908	165.917	115.794	47.602
Oxides of Nitrogen-NO_X (ppm): Post-Catalyst	58.462	168.311	117.940	47.021
Methane-CH_4 (ppm): Pre-Catalyst	1929.117	1234.992	1440.179	2072.326
Methane-CH_4 (ppm): Post-Catalyst	1876.674	1219.923	1413.275	1996.249
Acetylene-C_2H_2 (ppm): Pre-Catalyst	0.227	0.060	0.057	0.168
Acetylene-C_2H_2 (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Ethylene-C_2H_4 (ppm): Pre-Catalyst	69.755	54.317	62.895	55.663
Ethylene-C_2H_4 (ppm): Post-Catalyst	28.756	17.404	13.992	16.438
Ethane-C_2H_6 (ppm): Pre-Catalyst	196.055	119.758	143.511	190.740
Ethane-C_2H_6 (ppm): Post-Catalyst	262.745	156.034	187.358	253.424
Cyclopropene-C_3H_6 (ppm): Pre-Catalyst	3.092	1.784	2.643	1.787
Cyclopropene-C_3H_6 (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Formaldehyde-H_2CO (ppm): Pre-Catalyst	65.158	59.073	65.850	57.971
Formaldehyde-H_2CO (ppm): Post-Catalyst	22.068	14.380	13.054	19.994
Methanol-CH_3OH (ppm): Pre-Catalyst	1.913	1.363	1.783	1.700
Methanol-CH_3OH (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Propane-C_3H_8 (ppm): Pre-Catalyst	41.596	27.709	32.285	39.094
Propane-C_3H_8 (ppm): Post-Catalyst	35.072	20.718	24.423	32.943
Sulfur Dioxide-SO_2 (ppm): Pre-Catalyst	3.045	3.322	3.230	2.813
Sulfur Dioxide-SO_2 (ppm): Post-Catalyst	1.406	1.985	3.610	3.019
Total Hydrocarbons-THC (ppm): Pre-Catalyst	2565.305	1654.960	1936.690	2660.617
Total Hydrocarbons-THC (ppm): Post-Catalyst	2752.199	1752.803	2032.664	2839.269
Acetaldehyde-CH_3CHO (ppm): Pre-Catalyst	-4.549	-2.422	-2.578	-5.042
Acetaldehyde-CH_3CHO (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Acrolein CH_2=CHCHO (ppm): Pre-Catalyst	-0.445	0.017	-0.227	-0.068
Acrolein CH_2=CHCHO (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
1-3 Butadiene (ppm): Pre-Catalyst	1.108	1.552	1.422	1.102
1-3 Butadiene (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Isobutylene (ppm): Pre-Catalyst	0.000	0.000	0.015	0.001
Isobutylene (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Calculated Catalyst Efficiency				
Carbon Monoxide-CO (%)	94.43%	96.26%	98.23%	96.36%
Formaldehyde-H_2CO (%)	66.13%	75.66%	80.18%	65.51%

Colorado State University

~~August 4-6, 1999~~

EPA RICE Testing

Waukesha

Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Waukesha				
ENGINE OPERATING PARAMETERS	Run 9	Run 10	Run 11	Run 12
Ignition Type	PCC	PCC	PCC	PCC
Dynamometer Torque (ft-lb)	3234	3237	3238	3236
Brake Horsepower (bhp)	737	738	738	738
BSFC (btu/bhp-hr)	7431	7467	7482	7568
Engine Speed (rpm)	1197	1197	1197	1197
Timing (Degrees BTDC)	10.00	10.00	10.00	10.00
A/F (Wet)	28.4	28.6	28.8	28.8
Pressures				
Air Manifold (in. Hg)	5.02	5.00	5.00	5.00
Fuel Manifold (psig)	5.24	4.84	4.87	5.30
Fuel Supply (psig)	47.09	46.43	46.32	46.61
Intercooler Air Differential (in. H_2O)	8.99	9.40	9.39	9.45
Post Intercooler Air Manifold (in. Hg)	69.30	68.82	68.70	68.84
Intercooler Water Differential (in. H_2O)	157.45	157.45	157.45	157.45
Intercooler Supply (psi)	3.23	2.64	2.66	2.65
Pre-Turbo Exhaust (in. Hg)	36.23	36.50	36.90	36.99
Post- Turbo Exhaust (in. Hg)	4.76	4.89	4.93	4.98
Turbo Oil (in. Hg)	47.02	46.76	47.08	46.67
Catalyst Differential (in. H_2O)	9.0	9.0	9.0	9.2
Temperatures (°F) and Flows (GPM)				
Air Supply Temperature	99.5	99.5	99.4	99.5
Fuel Manifold Temperature	83.5	92.9	91.7	90.1
Exhaust Stack Temperature	704.0	705.0	701.2	704.5
Exhaust Header Temperature	704.0	705.0	701.2	704.5
Jacket Water Inlet Temperature	172.8	173.9	163.7	184.1
Jacket Water Outlet Temperature	179.0	180.5	170.1	190.2
Lube Oil Inlet Temperature	82.8	96.2	92.4	91.7
Lube Oil Outlet Temperature	88.2	101.7	98.2	97.5
Lube Oil Flow	129.4	131.7	131.2	131.0
Engine Oil In Temperature	164.1	166.1	164.4	166.6
Engine Oil Out Temperature	185.4	187.1	184.8	188.1
Intercooler Air In Temperature	298.2	298.9	299.3	299.6
Intercooler Air Out Temperature	131.6	152.4	142.2	142.9
Intercooler Water In Temperature	119.4	141.1	129.0	130.1
Intercooler Water Out Temperature	131.2	153.6	142.0	143.1
Intercooler Water Flow	64.8	54.1	54.5	54.8
Pre-Turbo ExhaustTemperature	962.7	964.2	958.2	963.4
Post-Turbo Exhaust Temperature	798.6	780.4	774.9	779.0
Pre-Catalyst Temperature	735.0	736.6	731.3	736.0
Post-Catalyst Temperature	739.63	740.58	735.71	739.63

Colorado State University
~~August 4-6, 1999~~
EPA RICE Testing
Waukesha
Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Waukesha				
ENGINE OPERATING PARAMETERS	Run 9	Run 10	Run 11	Run 12
Ignition Type	PCC	PCC	PCC	PCC
Fuel Measurements				
Static Fuel (psia)	46.5	46.3	46.3	46.3
Fuel Differential (in. H_2O)	14.4	14.6	14.7	14.9
Orifice Temperature (°F)	83.5	92.9	91.7	90.1
Fuel Flow (scfh)	5430	5381	5393	5452
Fuel Consumption (BSFC)	7431	7467	7482	7568
Lower Heating Value-Dry (Btu)	1008	1024	1024	1024
Fuel Tube I.D. (in.)	3.068	3.068	3.068	3.068
Fuel Orifice O.D. (in.)	0.5	0.5	0.5	0.5
Annubar Flow Rates				
Inlet Air Flow (scfm)	1702.7	1699.3	1717.9	1720.3
Exhaust Flow (scfm)	1998.2	2009.7	2032.6	2049.5
Ambient Conditions				
Barometric Pressure (psia)	12.08	12.07	12.07	12.07
Dry Bulb Temperature (°F)	64.0	78.1	74.9	72.9
Relative Humidity (%)	72.8	43.9	55.3	52.3
Absolute Humidity (lb/lb)	0.011	0.011	0.012	0.011
Absolute Humidity (gr/lb)	78.731	76.637	87.117	76.915
Air Manifold Conditions				
Boost Pressure (in. Hg)	5.02	5.00	5.00	5.00
Dry Bulb Temperature (°F)	99.5	99.5	99.4	99.5
Relative Humidity (%)	37.1	34.9	37.8	34.1
Relative Humidity (%) - Corrected*	50.3	47.2	51.0	46.2
Absolute Humidity (lb/lb)	0.015	0.014	0.015	0.014
Absolute Humidity (gr/lb)	106.773	100.000	108.266	97.839

*Air manifold relative humidity corrected to the reference ambient conditions of 90°F, 14.696 psi.

Cylinder Exhaust Temperatures (Degrees °F)				
Cylinder 1	978.9	980.1	972.8	976.9
Cylinder 2	978.4	980.6	975.0	978.8
Cylinder 3	980.6	983.0	977.1	981.5
Cylinder 4	955.4	957.0	951.8	954.9
Cylinder 5	946.4	947.7	942.1	945.9
Cylinder 6	932.3	932.7	928.1	933.0
Engine Average	932.33	932.66	928.06	933.05

Colorado State University

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EPA RICE Testing

Waukesha

Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Waukesha				
MEASURED EMISSIONS	Run 9	Run 10	Run 11	Run 12
Ignition Type	PCC	PCC	PCC	PCC
Air Manifold Pressure ("Hg)	5.02	5.00	5.00	5.00
Brake Horsepower (bhp)	737	738	738	738
Emissions Measured (Dry)				
NO_x (ppm): Pre-Catalyst	107.35	131.74	109.71	111.22
NO_x (ppm): Post-Catalyst	117.91	137.06	118.10	117.87
CO (ppm): Pre-Catalyst	619.70	625.61	620.51	612.71
CO (ppm): Post-Catalyst	40.61	41.97	41.72	41.10
THC (ppm): Pre-Catalyst	1816.38	1713.37	1840.30	1756.44
THC (ppm): Post-Catalyst	1870.48	1797.47	1893.63	1888.97
O_2 %: Pre-Catalyst	9.69	9.80	9.81	9.90
O_2 %: Post-Catalyst	9.70	9.73	9.79	9.85
CO_2 %: Pre-Catalyst	6.35	6.35	6.29	6.29
CO_2 %: Post-Catalyst	6.51	6.50	6.47	6.41
Emissions Measured (Wet)				
Methane (ppm): Pre-Catalyst	1288.95	1097.60	1179.57	1221.95
Methane (ppm): Post-Catalyst	1135.12	1078.57	1136.88	1149.71
Non-Methane (ppm): Pre-Catalyst	147.15	125.42	140.37	126.93
Non-Methane (ppm): Post-Catalyst	115.47	111.49	129.50	107.32
Carbon Balance Calculations				
Exhaust H_2O% (Pre-Catalyst)	12.31	12.12	12.19	12.00
Exhaust H_2O% (Post-Catalyst)	12.46	12.25	12.36	12.08
O_2 %	10.00	10.03	10.13	10.13
O_2 Balance	-1.42	-1.09	-1.51	-1.09
Exhaust Flow (lb/hr)	8194.8	8261.2	8345.4	8431.3
Air Flow (lb/hr)	7916.3	7982.0	8065.5	8148.3
Air/Fuel Ratio	28.4	28.6	28.8	28.8
F-Factor Emissions Calculations				
NO_x (g/bhp-hr): Pre-Catalyst	0.774	0.962	0.803	0.831
NO_x (lb/hr): Pre-Catalyst	1.257	1.565	1.307	1.351
NO_x (g/bhp-hr): Post-Catalyst	0.850	1.001	0.865	0.881
NO_x (lb/hr): Post-Catalyst	1.380	1.628	1.407	1.432
THC (g/bhp-hr): Pre-Catalyst	4.636	4.433	4.773	4.647
THC (lb/hr): Pre-Catalyst	7.531	7.209	7.765	7.555
THC (g/bhp-hr): Post-Catalyst	4.774	4.650	4.912	4.997
THC (lb/hr): Post-Catalyst	7.755	7.563	7.990	8.126
CO (g/bhp-hr): Pre-Catalyst	2.762	2.826	2.810	2.830
CO (lb/hr): Pre-Catalyst	4.486	4.596	4.571	4.602
CO (g/bhp-hr): Post-Catalyst	0.181	0.190	0.189	0.190
CO (lb/hr): Post-Catalyst	0.294	0.308	0.307	0.309
Methane (g/bhp-hr): Pre-Catalyst	3.799	3.265	3.524	3.712
Methane (lb/hr): Pre-Catalyst	6.171	5.311	5.734	6.036
Methane (g/bhp-hr): Post-Catalyst	3.346	3.209	3.397	3.493
Methane (lb/hr): Post-Catalyst	5.435	5.219	5.526	5.679
Non-Methane (g/bhp-hr): Pre-Catalyst	1.192	1.026	1.153	1.060
Non-Methane (lb/hr): Pre-Catalyst	1.937	1.668	1.875	1.723
Non-Methane (g/bhp-hr): Post-Catalyst	0.935	0.912	1.064	0.896
Non-Methane (lb/hr): Post-Catalyst	1.520	1.483	1.730	1.457
Formaldehyde (g/bhp-hr): Pre-Catalyst	0.311	0.317	0.313	0.326
Formaldehyde (lb/hr): Pre-Catalyst	0.505	0.515	0.510	0.530
Formaldehyde (g/bhp-hr): Post-Catalyst	0.097	0.101	0.101	0.100
Formaldehyde (lb/hr): Post-Catalyst	0.157	0.165	0.164	0.163
Acetaldehyde (g/bhp-hr): Pre-Catalyst	-0.028	-0.026	-0.028	-0.025
Acetaldehyde (lb/hr): Pre-Catalyst	-0.046	-0.042	-0.046	-0.041
Acetaldehyde (g/bhp-hr): Post-Catalyst	0.000	0.000	0.000	0.000
Acetaldehyde (lb/hr): Post-Catalyst	0.000	0.000	0.000	0.000
Acrolein (g/bhp-hr): Pre-Catalyst	0.005	0.000	0.001	0.000
Acrolein (g/bhp-hr): Pre-Catalyst	0.008	0.000	0.001	0.000
Acrolein (g/bhp-hr): Post-Catalyst	0.000	0.000	0.000	0.000
Acrolein (lb/hr): Post-Catalyst	0.0	0.0	0.0	0.0

Colorado State University
~~August 4-6, 1999~~
EPA RICE Testing
Waukesha
Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Waukesha				
MEASURED EMISSIONS	Run 9	Run 10	Run 11	Run 12
Ignition Type	PCC	PCC	PCC	PCC
Air Manifold Pressure ("Hg)	5.02	5.00	5.00	5.00
Brake Horsepower (bhp)	737	738	738	738
FTIR Measured Emissions (ppm, Wet)				
Water-H_2O	134019	130366	131944	129202
Carbon Monoxide-CO (ppm): Pre-Catalyst	530.509	537.803	528.723	527.869
Carbon Monoxide-CO (ppm): Post-Catalyst	23.367	23.859	24.585	24.505
Carbon Dioxide-CO_2 (ppm): Pre-Catalyst	57297	56827	56658	56219
Carbon Dioxide-CO_2 (ppm): Post-Catalyst	54245	54480	54056	54190
Nitric Oxide-NO (ppm): Pre-Catalyst	33.413	45.902	33.405	35.260
Nitric Oxide-NO (ppm): Post-Catalyst	89.705	104.997	89.422	90.195
Nitrogen Dioxide-NO_2 (ppm): Pre-Catalyst	52.027	57.475	52.693	53.089
Nitrogen Dioxide-NO_2 (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Nitrous Oxide-N_2O (ppm): Pre-Catalyst	0.495	0.509	0.503	0.503
Nitrous Oxide-N_2O (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Ammonia-NH_3 (ppm): Pre-Catalyst	0.000	0.000	0.000	0.000
Ammonia-NH_3 (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Oxides of Nitrogen-NO_X (ppm): Pre-Catalyst	85.442	103.377	86.098	88.348
Oxides of Nitrogen-NO_X (ppm): Post-Catalyst	89.705	104.997	89.422	90.195
Methane-CH_4 (ppm): Pre-Catalyst	1394.005	1358.367	1388.548	1468.834
Methane-CH_4 (ppm): Post-Catalyst	1395.953	1336.043	1386.366	1443.901
Acetylene-C_2H_2 (ppm): Pre-Catalyst	0.118	0.013	0.020	0.045
Acetylene-C_2H_2 (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Ethylene-C_2H_4 (ppm): Pre-Catalyst	59.641	57.785	60.385	53.638
Ethylene-C_2H_4 (ppm): Post-Catalyst	22.283	21.432	23.316	19.932
Ethane-C_2H_6 (ppm): Pre-Catalyst	152.604	147.073	158.956	139.273
Ethane-C_2H_6 (ppm): Post-Catalyst	206.363	194.821	214.203	183.162
Cyclopropene-C_3H_6 (ppm): Pre-Catalyst	1.475	1.918	2.336	1.843
Cyclopropene-C_3H_6 (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Formaldehyde-H_2CO (ppm): Pre-Catalyst	56.331	56.859	56.037	57.272
Formaldehyde-H_2CO (ppm): Post-Catalyst	17.506	18.225	17.980	17.645
Methanol-CH_3OH (ppm): Pre-Catalyst	1.625	1.361	1.493	1.437
Methanol-CH_3OH (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Propane-C_3H_8 (ppm): Pre-Catalyst	33.021	32.340	35.187	30.892
Propane-C_3H_8 (ppm): Post-Catalyst	27.580	25.948	28.777	24.933
Sulfur Dioxide-SO_2 (ppm): Pre-Catalyst	1.520	3.300	3.759	3.002
Sulfur Dioxide-SO_2 (ppm): Post-Catalyst	2.053	2.958	2.779	1.917
Total Hydrocarbons-THC (ppm): Pre-Catalyst	1898.284	1849.784	1917.097	1933.020
Total Hydrocarbons-THC (ppm): Post-Catalyst	2073.779	1978.605	2083.221	2071.755
Acetaldehyde-CH_3CHO (ppm): Pre-Catalyst	-3.461	-3.145	-3.467	-3.044
Acetaldehyde-CH_3CHO (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Acrolein CH_2=CHCHO (ppm): Pre-Catalyst	0.477	-0.014	0.073	-0.011
Acrolein CH_2=CHCHO (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
1-3 Butadiene (ppm): Pre-Catalyst	0.762	1.486	1.588	1.367
1-3 Butadiene (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Isobutylene (ppm): Pre-Catalyst	0.050	0.000	0.000	0.000
Isobutylene (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Calculated Catalyst Efficiency				
Carbon Monoxide-CO (%)	95.60%	95.56%	95.35%	95.36%
Formaldehyde-H_2CO (%)	68.92%	67.95%	67.91%	69.19%

Colorado State University
~~August 4-6, 1999~~
EPA RICE Testing
Waukesha
Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Waukesha				
ENGINE OPERATING PARAMETERS	Run 13	Run 14	Run 15	Run 16
Ignition Type	PCC	PCC	PCC	PCC
Dynamometer Torque (ft-lb)	3236	3235	3236	3235
Brake Horsepower (bhp)	737	737	737	737
BSFC (btu/bhp-hr)	7951	7268	7627	7516
Engine Speed (rpm)	1197	1197	1197	1197
Timing (Degrees BTDC)	6.00	14.00	10 (Cyl 6 - 6)	10 (Cyl 6 - 14)
A/F (Wet)	28.9	28.9	29.1	29.0
Pressures				
Air Manifold (in. Hg)	5.00	5.02	5.00	5.00
Fuel Manifold (psig)	4.31	4.09	4.13	4.17
Fuel Supply (psig)	46.70	46.84	46.78	46.82
Intercooler Air Differential (in. H_2O)	10.09	9.06	9.61	9.42
Post Intercooler Air Manifold (in. Hg)	69.35	68.84	68.85	68.73
Intercooler Water Differential (in. H_2O)	157.45	157.45	157.45	157.45
Intercooler Supply (psi)	2.84	3.11	2.84	2.84
Pre-Turbo Exhaust (in. Hg)	39.47	35.62	37.64	36.85
Post- Turbo Exhaust (in. Hg)	5.52	4.59	5.08	4.91
Turbo Oil (in. Hg)	47.16	46.87	47.06	46.94
Catalyst Differential (in. H_2O)	10.2	8.7	9.4	9.1
Temperatures (°F) and Flows (GPM)				
Air Supply Temperature	99.6	99.7	99.6	99.7
Fuel Manifold Temperature	86.4	86.3	86.0	87.1
Exhaust Stack Temperature	733.6	685.1	706.8	698.1
Exhaust Header Temperature	733.6	685.1	706.8	698.1
Jacket Water Inlet Temperature	176.5	173.4	172.8	174.1
Jacket Water Outlet Temperature	183.0	179.1	178.7	180.2
Lube Oil Inlet Temperature	88.1	80.7	87.5	87.5
Lube Oil Outlet Temperature	93.6	86.3	92.9	92.9
Lube Oil Flow	130.4	129.1	130.3	130.3
Engine Oil In Temperature	164.5	164.7	164.3	164.8
Engine Oil Out Temperature	185.5	186.4	185.4	186.0
Intercooler Air In Temperature	304.1	295.2	300.4	298.9
Intercooler Air Out Temperature	142.2	141.7	140.8	142.3
Intercooler Water In Temperature	128.4	131.6	128.1	130.2
Intercooler Water Out Temperature	141.7	142.7	140.8	142.8
Intercooler Water Flow	58.0	62.5	57.9	57.9
Pre-Turbo ExhaustTemperature	1000.4	936.3	967.2	954.3
Post-Turbo Exhaust Temperature	807.8	809.5	780.3	771.2
Pre-Catalyst Temperature	767.1	722.2	737.8	730.3
Post-Catalyst Temperature	771.28	718.36	741.89	732.86

Colorado State University
August 4-6, 1999
EPA RICE Testing
Waukesha
Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Waukesha				
ENGINE OPERATING PARAMETERS	Run 13	Run 14	Run 15	Run 16
Ignition Type	PCC	PCC	PCC	PCC
Fuel Measurements				
Static Fuel (psia)	46.4	46.4	46.5	46.5
Fuel Differential (in. H_2O)	16.3	13.9	15.0	14.6
Orifice Temperature (°F)	86.4	86.3	86.0	87.1
Fuel Flow (scfh)	5726	5312	5493	5413
Fuel Consumption (BSFC)	7951	7268	7627	7516
Lower Heating Value-Dry (Btu)	1024	1008	1024	1024
Fuel Tube I.D. (in.)	3.068	3.068	3.068	3.068
Fuel Orifice O.D. (in.)	0.5	0.5	0.5	0.5
Annubar Flow Rates				
Inlet Air Flow (scfm)	1808.1	1686.5	1744.4	1715.5
Exhaust Flow (scfm)	2158.2	1983.5	2086.4	2054.5
Ambient Conditions				
Barometric Pressure (psia)	12.07	12.08	12.07	12.07
Dry Bulb Temperature (°F)	69.0	62.0	69.0	69.0
Relative Humidity (%)	66.1	80.0	68.7	68.0
Absolute Humidity (lb/lb)	0.012	0.012	0.013	0.013
Absolute Humidity (gr/lb)	85.160	80.679	88.593	87.676
Air Manifold Conditions				
Boost Pressure (in. Hg)	5.00	5.02	5.00	5.00
Dry Bulb Temperature (°F)	99.6	99.7	99.6	99.7
Relative Humidity (%)	36.1	36.2	37.2	37.3
Relative Humidity (%) - Corrected*	49.1	49.3	50.5	50.8
Absolute Humidity (lb/lb)	0.015	0.015	0.015	0.015
Absolute Humidity (gr/lb)	104.064	104.432	107.224	107.785

*Air manifold relative humidity corrected to the reference ambient conditions of 90°F, 14.696 psi.

Cylinder Exhaust Temperatures (Degrees °F)				
Cylinder 1	1012.9	953.6	976.0	975.8
Cylinder 2	1015.7	953.5	977.3	976.7
Cylinder 3	1013.8	956.2	977.1	976.8
Cylinder 4	988.2	928.7	951.4	951.0
Cylinder 5	978.6	921.7	942.3	941.7
Cylinder 6	963.3	910.4	947.7	918.8
Engine Average	963.33	910.37	947.69	918.84

Colorado State University
~~August 4-6, 1999~~
EPA RICE Testing
Waukesha
Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Waukesha				
MEASURED EMISSIONS	Run 13	Run 14	Run 15	Run 16
Ignition Type	PCC	PCC	PCC	PCC
Air Manifold Pressure ("Hg)	**5.00**	**5.02**	**5.00**	**5.00**
Brake Horsepower (bhp)	**737**	**737**	**737**	**737**
Emissions Measured (Dry)				
NO_x (ppm): Pre-Catalyst	64.65	174.30	94.19	108.39
NO_x (ppm): Post-Catalyst	70.85	183.80	102.07	117.02
CO (ppm): Pre-Catalyst	619.92	655.62	625.17	627.01
CO (ppm): Post-Catalyst	44.53	42.27	42.56	42.14
THC (ppm): Pre-Catalyst	1904.33	1773.43	1851.82	1859.21
THC (ppm): Post-Catalyst	2002.80	1817.69	1964.55	1911.39
O_2 %: Pre-Catalyst	10.44	9.81	9.90	9.82
O_2 %: Post-Catalyst	9.81	9.89	9.82	9.80
CO_2 %: Pre-Catalyst	6.27	6.24	6.22	6.23
CO_2 %: Post-Catalyst	6.38	6.41	6.35	6.36
Emissions Measured (Wet)				
Methane (ppm): Pre-Catalyst	1377.56	1249.40	1331.48	1306.95
Methane (ppm): Post-Catalyst	1248.62	1088.91	1193.13	1166.45
Non-Methane (ppm): Pre-Catalyst	167.00	133.26	160.15	150.09
Non-Methane (ppm): Post-Catalyst	109.40	108.78	115.08	118.19
Carbon Balance Calculations				
Exhaust H_2O% (Pre-Catalyst)	12.08	12.11	12.08	12.10
Exhaust H_2O% (Post-Catalyst)	12.16	12.26	12.17	12.21
O_2 %	10.14	10.19	10.23	10.23
O_2 Balance	1.02	-1.69	-1.55	-1.84
Exhaust Flow (lb/hr)	8877.8	8145.9	8572.4	8439.8
Air Flow (lb/hr)	8580.7	7873.4	8287.3	8158.9
Air/Fuel Ratio	28.9	28.9	29.1	29.0
F-Factor Emissions Calculations				
NO_x (g/bhp-hr): Pre-Catalyst	0.534	1.243	0.709	0.799
NO_x (lb/hr): Pre-Catalyst	0.867	2.019	1.153	1.298
NO_x (g/bhp-hr): Post-Catalyst	0.585	1.310	0.769	0.862
NO_x (lb/hr): Post-Catalyst	0.951	2.129	1.249	1.402
THC (g/bhp-hr): Pre-Catalyst	5.567	4.478	4.938	4.852
THC (lb/hr): Pre-Catalyst	9.049	7.275	8.027	7.887
THC (g/bhp-hr): Post-Catalyst	5.855	4.590	5.239	4.988
THC (lb/hr): Post-Catalyst	9.517	7.457	8.516	8.108
CO (g/bhp-hr): Pre-Catalyst	3.164	2.890	2.911	2.857
CO (lb/hr): Pre-Catalyst	5.143	4.696	4.732	4.644
CO (g/bhp-hr): Post-Catalyst	0.227	0.186	0.198	0.192
CO (lb/hr): Post-Catalyst	0.369	0.303	0.322	0.312
Methane (g/bhp-hr): Pre-Catalyst	4.628	3.632	4.084	3.923
Methane (lb/hr): Pre-Catalyst	7.523	5.901	6.639	6.378
Methane (g/bhp-hr): Post-Catalyst	4.195	3.165	3.660	3.502
Methane (lb/hr): Post-Catalyst	6.819	5.143	5.949	5.692
Non-Methane (g/bhp-hr): Pre-Catalyst	1.542	1.065	1.350	1.239
Non-Methane (lb/hr): Pre-Catalyst	2.507	1.730	2.195	2.013
Non-Methane (g/bhp-hr): Post-Catalyst	1.010	0.869	0.970	0.975
Non-Methane (lb/hr): Post-Catalyst	1.642	1.412	1.577	1.585
Formaldehyde (g/bhp-hr): Pre-Catalyst	0.360	0.305	0.330	0.323
Formaldehyde (lb/hr): Pre-Catalyst	0.585	0.496	0.537	0.525
Formaldehyde (g/bhp-hr): Post-Catalyst	0.098	0.101	0.100	0.098
Formaldehyde (lb/hr): Post-Catalyst	0.159	0.165	0.163	0.160
Acetaldehyde (g/bhp-hr): Pre-Catalyst	-0.032	-0.023	-0.031	-0.029
Acetaldehyde (lb/hr): Pre-Catalyst	-0.051	-0.038	-0.050	-0.046
Acetaldehyde (g/bhp-hr): Post-Catalyst	0.000	0.000	0.000	0.000
Acetaldehyde (lb/hr): Post-Catalyst	0.000	0.000	0.000	0.000
Acrolein (g/bhp-hr): Pre-Catalyst	-0.006	0.004	-0.002	-0.001
Acrolein (g/bhp-hr): Pre-Catalyst	-0.010	0.007	-0.003	-0.002
Acrolein (g/bhp-hr): Post-Catalyst	0.000	0.000	0.000	0.000
Acrolein (lb/hr): Post-Catalyst	0.0	0.0	0.0	0.0

Colorado State University
August 4-6, 1999
EPA RICE Testing
Waukesha
Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Waukesha				
MEASURED EMISSIONS	Run 13	Run 14	Run 15	Run 16
Ignition Type	PCC	PCC	PCC	PCC
Air Manifold Pressure ("Hg)	5.00	5.02	5.00	5.00
Brake Horsepower (bhp)	737	737	737	737
FTIR Measured Emissions (ppm, Wet)				
Water-H_2O	129906	131421	130651	130722
Carbon Monoxide-CO (ppm): Pre-Catalyst	534.173	559.274	541.852	542.232
Carbon Monoxide-CO (ppm): Post-Catalyst	26.730	25.335	25.017	24.738
Carbon Dioxide-CO_2 (ppm): Pre-Catalyst	56005	56713	55288	55403
Carbon Dioxide-CO_2 (ppm): Post-Catalyst	53676	55011	53522	53613
Nitric Oxide-NO (ppm): Pre-Catalyst	10.020	77.413	26.790	34.488
Nitric Oxide-NO (ppm): Post-Catalyst	52.452	145.274	79.062	90.150
Nitrogen Dioxide-NO_2 (ppm): Pre-Catalyst	39.757	63.298	49.092	52.342
Nitrogen Dioxide-NO_2 (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Nitrous Oxide-N_2O (ppm): Pre-Catalyst	0.434	0.509	0.491	0.488
Nitrous Oxide-N_2O (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Ammonia-NH_3 (ppm): Pre-Catalyst	0.000	0.000	0.000	0.000
Ammonia-NH_3 (ppm): Post-Catalyst	0.000	0.000	0.079	0.000
Oxides of Nitrogen-NO_X (ppm): Pre-Catalyst	49.776	140.711	75.883	86.830
Oxides of Nitrogen-NO_X (ppm): Post-Catalyst	52.452	145.274	79.062	90.150
Methane-CH_4 (ppm): Pre-Catalyst	1544.510	1364.436	1509.454	1472.120
Methane-CH_4 (ppm): Post-Catalyst	1507.699	1383.045	1473.176	1438.888
Acetylene-C_2H_2 (ppm): Pre-Catalyst	0.334	0.072	0.160	0.019
Acetylene-C_2H_2 (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Ethylene-C_2H_4 (ppm): Pre-Catalyst	61.241	55.428	58.184	57.332
Ethylene-C_2H_4 (ppm): Post-Catalyst	23.415	20.298	22.225	21.371
Ethane-C_2H_6 (ppm): Pre-Catalyst	156.029	143.372	154.733	150.909
Ethane-C_2H_6 (ppm): Post-Catalyst	205.047	192.068	204.154	198.930
Cyclopropene-C_3H_6 (ppm): Pre-Catalyst	2.595	0.902	2.172	2.130
Cyclopropene-C_3H_6 (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Formaldehyde-H_2CO (ppm): Pre-Catalyst	57.257	56.075	57.525	57.511
Formaldehyde-H_2CO (ppm): Post-Catalyst	15.537	18.637	17.413	17.471
Methanol-CH_3OH (ppm): Pre-Catalyst	1.889	1.624	1.552	1.490
Methanol-CH_3OH (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Propane-C_3H_8 (ppm): Pre-Catalyst	33.611	31.930	33.585	33.564
Propane-C_3H_8 (ppm): Post-Catalyst	27.122	26.962	27.070	27.397
Sulfur Dioxide-SO_2 (ppm): Pre-Catalyst	2.838	1.813	2.959	2.923
Sulfur Dioxide-SO_2 (ppm): Post-Catalyst	0.000	2.550	1.432	2.136
Total Hydrocarbons-THC (ppm): Pre-Catalyst	2065.695	1838.207	2020.185	1973.490
Total Hydrocarbons-THC (ppm): Post-Catalyst	2197.216	2027.018	2154.498	2105.708
Acetaldehyde-CH_3CHO (ppm): Pre-Catalyst	-3.421	-2.911	-3.641	-3.468
Acetaldehyde-CH_3CHO (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Acrolein CH_2=CHCHO (ppm): Pre-Catalyst	-0.502	0.438	-0.155	-0.113
Acrolein CH_2=CHCHO (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
1-3 Butadiene (ppm): Pre-Catalyst	1.294	0.766	1.262	1.312
1-3 Butadiene (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Isobutylene (ppm): Pre-Catalyst	0.000	0.000	0.000	0.000
Isobutylene (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Calculated Catalyst Efficiency				
Carbon Monoxide-CO (%)	95.00%	95.47%	95.38%	95.44%
Formaldehyde-H_2CO (%)	72.86%	66.76%	69.73%	69.62%

APPENDIX B

BASELINE

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Baseline 8-5 - 736BHP 1200RPM 10BTDC

Data Point Number: Baseline **Date:** 08/05/99 **Time:** 15:11:38

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	73.00	73.00	73.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	61.51	60.00	62.00	0.86	1.40
AIR MANIFOLD PRESSURE ("Hg)	5.01	4.76	5.19	0.09	1.80
AIR MANIFOLD RELATIVE HUMIDITY (%)	37.85	36.00	39.00	1.06	2.81
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01561	0.01422	0.01669		
AIR SUPPLY TEMPERATURE (F)	99.63	98.00	101.00	0.60	0.60
INTAKE AIR FLOW (scfm)	1747.25	1734.02	1758.27	5.28	0.30
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	699.38	698.99	699.79	0.22	0.03
CYLINDER 1 EXHAUST TEMPERATURE (F)	975.36	973.60	976.97	0.71	0.07
CYLINDER 2 EXHAUST TEMPERATURE (F)	974.40	972.61	975.98	0.74	0.08
CYLINDER 3 EXHAUST TEMPERATURE (F)	974.36	972.61	975.98	0.69	0.07
CYLINDER 4 EXHAUST TEMPERATURE (F)	949.03	947.41	950.98	0.78	0.08
CYLINDER 5 EXHAUST TEMPERATURE (F)	939.66	938.08	941.06	0.51	0.05
CYLINDER 6 EXHAUST TEMPERATURE (F)	928.50	927.17	929.95	0.63	0.07
CYLINDER EXHAUST AVERAGE TEMP (F)	956.92	955.94	957.93	0.52	0.05
EXHAUST HEADER TEMPERATURE (F)	699.38	698.99	699.79	0.22	0.03
PRE TURBO EXHAUST PRESSURE ("Hg)	37.63	37.41	37.92	0.13	0.36
PRE TURBO EXHAUST TEMPERATURE (F)	957.21	955.94	958.52	0.64	0.07
POST TURBO EXHAUST PRESSURE ("Hg)	5.06	5.01	5.12	0.02	0.43
POST TURBO EXHAUST TEMPERATURE (F)	772.01	771.02	773.00	0.52	0.07
TURBO OIL PRESSURE ("Hg)	47.10	46.16	47.77	0.31	0.66
ENGINE SPEED (rpm)	1196.86	1191.73	1200.00	1.48	0.12
ENGINE HORSEPOWER (bhp)	737.44	735.01	739.70	1.09	0.15
ENGINE OIL PRESSURE (psig)	52.19	51.64	52.93	0.32	0.61
ENGINE OIL TEMPERATURE IN (F)	165.17	164.86	165.45	0.16	0.10
ENGINE OIL TEMPERATURE OUT (F)	186.07	185.89	186.49	0.14	0.07
SPECIFIC GRAVITY	0.69	0.69	0.69	0.00	0.00
FUEL TEMPERATURE (F)	91.36	91.05	91.64	0.15	0.16
FUEL PRESSURE ("H2O above amp)	4.07	3.44	4.66	0.21	5.15
FUEL SUPPLY PRESSURE (psig)	46.83	46.75	46.90	0.04	0.08
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	15.19	14.65	15.86	0.31	2.06
ORIFICE STATIC PRESSURE (psig)	46.41	46.35	46.48	0.03	0.07
ORIFICE TEMPERATURE (F)	88.18	88.04	88.30	0.05	0.05
FUEL FLOW (SCFH)	5474.35				
CALCULATED FUEL CONSUMPTION (BSFC)	7717.47				
FUEL HEATING VALUE (Btu)	1039.60	1039.60	1039.60	0.00	0.00
AIR FUEL RATIO	28.30	28.30	28.30	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	9.72	9.43	9.87	0.09	0.90
INTERCOOLER AIR TEMP IN (F)	299.90	299.19	300.38	0.28	0.09
INTERCOOLER AIR TEMP OUT (F)	143.43	142.64	143.83	0.35	0.24
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	68.79	68.49	68.99	0.09	0.14
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	57.90	57.20	58.49	0.28	0.49
INTERCOOLER WATER TEMP IN (F)	131.13	129.74	131.72	0.57	0.43
INTERCOOLER WATER TEMP OUT (F)	143.56	142.44	144.02	0.43	0.30
INTERCOOLER SUPPLY PRESSURE (psi)	2.81	2.77	2.87	0.02	0.62
PRE CATALYST TEMPERATURE (F)	730.58	729.75	731.34	0.40	0.05
POST CATALYST TEMPERATURE (F)	734.79	734.11	735.70	0.35	0.05
CATALYST DIFFERENTIAL PRESSURE ("H2O)	9.50	9.43	9.62	0.04	0.47
B.S. CO (g/bhp-hr): Pre-Catalyst	4.16	4.05	4.26	0.04	1.06
B.S. CO (g/bhp-hr): Post-Catalyst	0.29	0.28	0.30	0.00	1.48
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Baseline 8-5 - 736BHP 1200RPM 10BTDC

Data Point Number: Baseline **Date:** 08/05/99 **Time:** 15:11:38

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	1.01	0.98	1.09	0.03	2.71
B.S. NOx (g/bhp-hr): Post-Catalyst	1.11	1.09	1.18	0.02	1.45
B.S. THC (g/bhp-hr): Pre-Catalyst	9.34	8.95	9.57	0.12	1.25
B.S. THC (g/bhp-hr): Post-Catalyst	9.37	9.16	9.60	0.10	1.04
B.S. Methane (g/bhp-hr): Pre-Catalyst	4.27	4.20	4.37	0.04	0.91
B.S. Methane (g/bhp-hr): Post-Catalyst	3.48	3.37	3.66	0.08	2.34
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.19	0.18	0.21	0.01	7.36
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.15	0.13	0.16	0.01	5.58
O2 (ppm): Pre-Catalyst	9.90	9.90	9.90	0.00	0.00
O2 (ppm): Post-Catalyst	9.90	9.90	9.90	0.00	0.00
CO (ppm): Pre-Catalyst	621.17	614.40	624.70	3.34	0.54
CO (ppm): Post-Catalyst	43.25	42.80	43.70	0.20	0.47
CO2 (ppm): Pre-Catalyst	6.29	6.29	6.29	0.00	0.00
CO2 (ppm): Post-Catalyst	6.30	6.28	6.32	0.01	0.16
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Post-Catalyst	54.21	53.40	57.40	0.60	1.10
NOx (ppm): Pre-Catalyst	92.24	90.90	97.90	2.27	2.47
NOx (ppm): Post-Catalyst	100.56	99.20	106.50	1.08	1.07
THC (ppm): Pre-Catalyst	2024.33	1969.00	2047.00	17.80	0.88
THC (ppm): Post-Catalyst	2017.11	1987.90	2034.30	9.44	0.47
Methane (ppm): Pre-Catalyst	1400.68	1399.90	1403.10	1.38	0.10
Methane (ppm): Post-Catalyst	1135.08	1120.50	1171.70	23.18	2.04
Non-Methane (ppm): Pre-Catalyst	123.40	117.00	137.80	9.52	7.71
Non-Methane (ppm): Post-Catalyst	96.72	87.90	99.60	4.97	5.14
DYNO WATER IN TEMPERATURE (F)	82.87	82.71	82.91	0.08	0.09
DYNO WATER OUT TEMPERATURE (F)	129.28	129.14	130.14	0.21	0.16
JACKET WATER IN TEMPERATURE (F)	174.86	174.58	174.98	0.13	0.07
JACKET WATER OUT TEMPERATURE (F)	180.32	179.00	182.00	0.54	0.30
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	89.86	89.86	89.86	0.00	0.00
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	95.65	95.41	95.81	0.14	0.15
LUBE OIL FLOW (GPM)	130.72	129.86	131.63	0.28	0.22
CO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
CO F-Factor: Post-Catalyst	0.31	0.30	0.32	0.00	1.03
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Post-Catalyst	1.19	1.16	1.25	0.02	1.35
THC F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
THC F-Factor: Post-Catalyst	9.83	9.60	10.07	0.10	1.00
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3235.75	3233.08	3238.45	1.82	0.06

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Baseline - 735BHP 1200RPM 10BTDC

Data Point Number: Baseline 8/6 **Date:** 08/06/99 **Time:** 14:16:35

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	77.00	77.00	77.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	54.62	54.00	56.00	0.93	1.70
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.87	5.16	0.06	1.18
AIR MANIFOLD RELATIVE HUMIDITY (%)	38.37	38.00	39.00	0.48	1.26
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01585	0.01497	0.01670		
AIR MANIFOLD TEMPERATURE (F)	99.66	98.00	101.00	0.75	0.75
INTAKE AIR FLOW (scfm)	1712.03	1700.19	1724.44	5.23	0.31
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	704.59	704.15	704.95	0.19	0.03
CYLINDER 1 EXHAUST TEMPERATURE (F)	976.17	974.59	977.57	0.65	0.07
CYLINDER 2 EXHAUST TEMPERATURE (F)	977.77	975.19	978.76	0.91	0.09
CYLINDER 3 EXHAUST TEMPERATURE (F)	980.03	978.36	981.54	0.73	0.07
CYLINDER 4 EXHAUST TEMPERATURE (F)	954.39	952.77	956.14	0.79	0.08
CYLINDER 5 EXHAUST TEMPERATURE (F)	945.56	944.24	947.21	0.76	0.08
CYLINDER 6 EXHAUST TEMPERATURE (F)	932.59	931.54	934.12	0.65	0.07
CYLINDER EXHAUST AVERAGE TEMP (F)	961.08	959.71	962.46	0.59	0.06
EXHAUST HEADER TEMPERATURE (F)	704.59	704.15	704.95	0.19	0.03
PRE TURBO EXHAUST PRESSURE ("Hg)	36.76	36.54	36.95	0.11	0.31
PRE TURBO EXHAUST TEMPERATURE (F)	962.40	961.50	963.88	0.60	0.06
POST TURBO EXHAUST PRESSURE ("Hg)	4.91	4.87	5.01	0.03	0.56
POST TURBO EXHAUST TEMPERATURE (F)	778.87	777.96	779.55	0.41	0.05
TURBO OIL PRESSURE ("Hg)	46.84	46.00	47.45	0.28	0.59
ENGINE SPEED (rpm)	1196.86	1193.61	1201.13	1.47	0.12
ENGINE HORSEPOWER (bhp)	737.95	735.76	740.17	0.87	0.12
ENGINE OIL PRESSURE (psig)	52.03	51.40	52.77	0.33	0.63
ENGINE OIL TEMPERATURE IN (F)	165.90	165.65	166.05	0.13	0.08
ENGINE OIL TEMPERATURE OUT (F)	186.81	186.49	187.08	0.14	0.08
SPECIFIC GRAVITY	0.66	0.66	0.66	0.00	0.00
FUEL TEMPERATURE (F)	96.38	96.21	96.41	0.07	0.07
FUEL PRESSURE ("H2O above amp)	4.90	4.08	5.37	0.25	5.09
FUEL SUPPLY PRESSURE (psig)	46.23	46.11	46.32	0.05	0.10
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	14.59	14.06	15.28	0.29	1.98
ORIFICE STATIC PRESSURE (psig)	46.23	46.13	46.31	0.04	0.08
ORIFICE TEMPERATURE (F)	92.95	92.79	93.15	0.09	0.09
FUEL FLOW (SCFH)	5462.78				
CALCULATED FUEL CONSUMPTION (BSFC)	7302.69				
FUEL HEATING VALUE (Btu)	986.50	986.50	986.50	0.00	0.00
AIR FUEL RATIO	28.60	28.60	28.60	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	9.34	9.17	9.51	0.09	0.92
INTERCOOLER AIR TEMP IN (F)	299.16	298.59	299.58	0.30	0.10
INTERCOOLER AIR TEMP OUT (F)	142.43	139.46	144.62	1.67	1.17
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	68.77	68.66	68.91	0.08	0.11
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	54.43	53.65	54.94	0.23	0.42
INTERCOOLER WATER TEMP IN (F)	129.31	125.77	132.32	2.29	1.77
INTERCOOLER WATER TEMP OUT (F)	142.41	138.87	145.02	2.07	1.45
INTERCOOLER SUPPLY PRESSURE (psi)	2.66	2.62	2.71	0.02	0.66
PRE CATALYST TEMPERATURE (F)	735.04	734.31	736.10	0.47	0.06
POST CATALYST TEMPERATURE (F)	739.40	738.88	739.87	0.30	0.04
CATALYST DIFFERENTIAL PRESSURE ("H2O)	8.97	8.89	9.11	0.05	0.55
B.S. CO (g/bhp-hr): Pre-Catalyst	2.39	2.35	2.45	0.03	1.06

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Baseline - 735BHP 1200RPM 10BTDC

Data Point Number: Baseline 8/6 **Date:** 08/06/99 **Time:** 14:16:35

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
B.S. CO (g/bhp-hr): Post-Catalyst	0.15	0.15	0.15	0.00	0.00
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.71	0.69	0.73	0.01	1.26
B.S. NOx (g/bhp-hr): Post-Catalyst	0.74	0.72	0.77	0.01	1.59
B.S. THC (g/bhp-hr): Pre-Catalyst	4.54	4.44	4.64	0.05	1.12
B.S. THC (g/bhp-hr): Post-Catalyst	4.54	4.43	4.64	0.05	1.06
B.S. Methane (g/bhp-hr): Pre-Catalyst	1.97	1.93	2.01	0.02	1.05
B.S. Methane (g/bhp-hr): Post-Catalyst	2.03	1.99	2.07	0.02	1.05
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.07	0.07	0.08	0.00	6.00
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.07	0.07	0.07	0.00	0.00
O2 (ppm): Pre-Catalyst	9.80	9.80	9.80	0.00	0.00
O2 (ppm): Post-Catalyst	9.78	9.70	9.80	0.04	0.37
CO (ppm): Pre-Catalyst	621.84	618.90	624.30	1.51	0.24
CO (ppm): Post-Catalyst	41.09	40.80	41.60	0.19	0.47
CO2 (ppm): Pre-Catalyst	6.32	6.26	6.32	0.02	0.25
CO2 (ppm): Post-Catalyst	6.51	6.50	6.52	0.01	0.11
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	60.21	59.10	61.10	0.41	0.68
NOx (ppm - Corrected): Post-Catalyst	64.29	62.80	65.50	0.70	1.09
NOx (ppm): Pre-Catalyst	113.06	111.10	114.20	0.82	0.72
NOx (ppm): Post-Catalyst	120.94	118.10	123.20	1.41	1.16
THC (ppm): Pre-Catalyst	1812.50	1797.90	1823.70	5.61	0.31
THC (ppm): Post-Catalyst	1850.66	1837.30	1864.20	6.06	0.33
Methane (ppm): Pre-Catalyst	1033.00	1033.00	1033.00	0.00	0.00
Methane (ppm): Post-Catalyst	1089.46	1086.40	1089.50	0.36	0.03
Non-Methane (ppm): Pre-Catalyst	131.61	130.00	136.40	2.79	2.12
Non-Methane (ppm): Post-Catalyst	126.96	123.10	130.50	3.55	2.80
DYNO WATER IN TEMPERATURE (F)	82.68	82.52	82.91	0.10	0.12
DYNO WATER OUT TEMPERATURE (F)	129.12	128.95	129.14	0.07	0.05
JACKET WATER IN TEMPERATURE (F)	173.09	172.20	173.99	0.46	0.26
JACKET WATER OUT TEMPERATURE (F)	179.80	178.00	182.00	0.72	0.40
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	94.53	94.22	94.82	0.30	0.32
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	100.07	99.78	100.57	0.23	0.23
LUBE OIL FLOW (GPM)	131.45	130.99	131.95	0.23	0.17
CO F-Factor: Pre-Catalyst	4.19	4.11	4.31	0.04	1.04
CO F-Factor: Post-Catalyst	0.28	0.27	0.28	0.00	1.11
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	1.25	1.22	1.29	0.02	1.20
NOx F-Factor: Post-Catalyst	1.34	1.29	1.38	0.02	1.45
THC F-Factor: Pre-Catalyst	7.81	7.63	8.03	0.09	1.14
THC F-Factor: Post-Catalyst	7.96	7.78	8.16	0.09	1.10
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3238.33	3235.77	3241.14	0.72	0.02

APPENDIX C

QC CHECK

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 1 QC - 736BHP 1200RPM 10BTDC

Data Point Number: Run 1 QC **Date:** 08/04/99 **Time:** 17:47:52

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	64.00	64.00	64.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.08	12.08	12.08	0.00	0.00
AMBIENT HUMIDITY (%)	79.89	78.00	80.00	0.45	0.56
AIR MANIFOLD PRESSURE ("Hg)	5.02	4.81	5.18	0.07	1.36
AIR MANIFOLD RELATIVE HUMIDITY (%)	37.24	37.00	38.00	0.43	1.15
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01531	0.01459	0.01624		
AIR MANIFOLD TEMPERATURE (F)	99.57	98.00	101.00	0.72	0.73
INTAKE AIR FLOW (scfm)	1717.45	1706.39	1729.51	4.19	0.24
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	702.81	702.37	703.36	0.22	0.03
CYLINDER 1 EXHAUST TEMPERATURE (F)	975.44	973.80	976.97	0.66	0.07
CYLINDER 2 EXHAUST TEMPERATURE (F)	975.93	974.20	977.77	0.65	0.07
CYLINDER 3 EXHAUST TEMPERATURE (F)	979.08	977.57	980.74	0.73	0.07
CYLINDER 4 EXHAUST TEMPERATURE (F)	953.81	952.37	954.75	0.47	0.05
CYLINDER 5 EXHAUST TEMPERATURE (F)	943.58	942.05	944.63	0.52	0.06
CYLINDER 6 EXHAUST TEMPERATURE (F)	928.98	927.57	930.15	0.59	0.06
CYLINDER EXHAUST AVERAGE TEMP (F)	959.46	958.52	960.44	0.44	0.05
EXHAUST HEADER TEMPERATURE (F)	702.81	702.37	703.36	0.22	0.03
PRE TURBO EXHAUST PRESSURE ("Hg)	36.64	36.36	36.89	0.13	0.37
PRE TURBO EXHAUST TEMPERATURE (F)	959.42	958.72	960.51	0.46	0.05
POST TURBO EXHAUST PRESSURE ("Hg)	4.84	4.77	4.92	0.03	0.53
POST TURBO EXHAUST TEMPERATURE (F)	796.54	795.42	797.80	0.54	0.07
TURBO OIL PRESSURE ("Hg)	46.95	46.08	47.61	0.29	0.62
ENGINE SPEED (rpm)	1196.56	1192.86	1201.13	1.59	0.13
ENGINE HORSEPOWER (bhp)	737.22	734.31	740.63	1.34	0.18
ENGINE OIL PRESSURE (psig)	52.15	51.48	52.85	0.32	0.61
ENGINE OIL TEMPERATURE IN (F)	164.50	164.26	164.66	0.16	0.10
ENGINE OIL TEMPERATURE OUT (F)	185.64	185.49	185.89	0.10	0.05
SPECIFIC GRAVITY	0.68	0.68	0.68	0.00	0.00
FUEL TEMPERATURE (F)	90.20	90.06	90.45	0.10	0.11
FUEL PRESSURE ("H2O above amp)	4.06	3.64	4.74	0.21	5.19
FUEL SUPPLY PRESSURE (psig)	46.79	46.64	46.90	0.05	0.11
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	14.45	13.70	15.35	0.32	2.22
ORIFICE STATIC PRESSURE (psig)	46.47	46.35	46.56	0.04	0.09
ORIFICE TEMPERATURE (F)	85.15	85.04	85.26	0.05	0.05
FUEL FLOW (SCFH)	5388.45				
CALCULATED FUEL CONSUMPTION (BSFC)	7483.85				
FUEL HEATING VALUE (Btu)	1023.90	1023.90	1023.90	0.00	0.00
AIR FUEL RATIO	29.00	29.00	29.00	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	9.29	9.12	9.50	0.08	0.84
INTERCOOLER AIR TEMP IN (F)	297.38	297.00	297.80	0.25	0.08
INTERCOOLER AIR TEMP OUT (F)	140.54	139.26	141.45	0.57	0.40
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	69.19	68.99	69.33	0.07	0.11
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	62.69	61.55	63.32	0.38	0.61
INTERCOOLER WATER TEMP IN (F)	129.41	128.35	130.73	0.68	0.53
INTERCOOLER WATER TEMP OUT (F)	141.17	140.06	142.24	0.59	0.42
INTERCOOLER SUPPLY PRESSURE (psi)	3.11	3.08	3.15	0.02	0.50
PRE CATALYST TEMPERATURE (F)	732.96	732.53	733.72	0.30	0.04
POST CATALYST TEMPERATURE (F)	738.09	737.29	738.68	0.32	0.04
CATALYST DIFFERENTIAL PRESSURE ("H2O)	9.13	9.04	9.22	0.05	0.52
B.S. CO (g/bhp-hr): Pre-Catalyst	2.42	2.36	2.48	0.03	1.25
B.S. CO (g/bhp-hr): Post-Catalyst	0.15	0.15	0.16	0.00	3.12
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 1 QC - 736BHP 1200RPM 10BTDC

Data Point Number: Run 1 QC **Date:** 08/04/99 **Time:** 17:47:52

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.68	0.66	0.71	0.01	1.64
B.S. NOx (g/bhp-hr): Post-Catalyst	0.71	0.68	0.73	0.01	1.64
B.S. THC (g/bhp-hr): Pre-Catalyst	4.78	4.69	4.91	0.06	1.20
B.S. THC (g/bhp-hr): Post-Catalyst	4.88	4.75	5.00	0.06	1.25
B.S. Methane (g/bhp-hr): Pre-Catalyst	2.29	2.24	2.35	0.03	1.15
B.S. Methane (g/bhp-hr): Post-Catalyst	2.02	1.97	2.07	0.02	1.17
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.11	0.10	0.12	0.01	6.69
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.09	0.09	0.09	0.00	0.00
O2 (ppm): Pre-Catalyst	9.80	9.70	9.80	0.01	0.10
O2 (ppm): Post-Catalyst	9.80	9.80	9.80	0.00	0.00
CO (ppm): Pre-Catalyst	624.76	618.30	628.60	3.09	0.50
CO (ppm): Post-Catalyst	42.07	41.60	42.50	0.19	0.45
CO2 (ppm): Pre-Catalyst	6.24	6.24	6.24	0.00	0.00
CO2 (ppm): Post-Catalyst	6.45	6.44	6.46	0.01	0.09
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	57.51	56.20	58.10	0.57	0.99
NOx (ppm - Corrected): Post-Catalyst	61.56	59.80	62.50	0.64	1.04
NOx (ppm): Pre-Catalyst	108.21	105.90	109.40	1.09	1.00
NOx (ppm): Post-Catalyst	115.23	111.80	116.90	1.22	1.06
THC (ppm): Pre-Catalyst	1823.25	1810.70	1835.10	5.92	0.32
THC (ppm): Post-Catalyst	1903.79	1890.40	1917.20	6.81	0.36
Methane (ppm): Pre-Catalyst	1266.40	1266.40	1266.40	0.00	0.00
Methane (ppm): Post-Catalyst	1141.90	1141.90	1141.90	0.00	0.00
Non-Methane (ppm): Pre-Catalyst	139.11	135.50	153.60	7.18	5.16
Non-Methane (ppm): Post-Catalyst	122.03	117.60	122.40	1.10	0.90
DYNO WATER IN TEMPERATURE (F)	80.53	80.33	80.73	0.10	0.12
DYNO WATER OUT TEMPERATURE (F)	127.18	126.96	127.56	0.17	0.13
JACKET WATER IN TEMPERATURE (F)	172.98	172.80	173.19	0.08	0.05
JACKET WATER OUT TEMPERATURE (F)	178.95	177.00	180.00	0.66	0.37
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	81.13	81.13	81.13	0.00	0.00
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	86.88	86.68	87.08	0.10	0.11
LUBE OIL FLOW (GPM)	129.22	128.73	129.70	0.23	0.18
CO F-Factor: Pre-Catalyst	4.30	4.19	4.42	0.05	1.27
CO F-Factor: Post-Catalyst	0.29	0.28	0.30	0.00	1.24
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	1.22	1.18	1.26	0.02	1.53
NOx F-Factor: Post-Catalyst	1.31	1.25	1.35	0.02	1.54
THC F-Factor: Pre-Catalyst	8.37	8.19	8.59	0.10	1.22
THC F-Factor: Post-Catalyst	8.78	8.56	9.00	0.11	1.23
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3235.54	3233.08	3238.45	1.99	0.06

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 2 QC - 515BHP 1200RPM 10BTDC

Data Point Number: Run 2 QC **Date:** 08/06/99 **Time:** 03:15:15

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	65.00	65.00	65.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	74.00	74.00	74.00	0.00	0.00
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.88	5.14	0.06	1.15
AIR MANIFOLD RELATIVE HUMIDITY (%)	30.00	30.00	30.00	0.00	0.00
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01265	0.01212	0.01317		
AIR MANIFOLD TEMPERATURE (F)	100.52	99.00	102.00	0.63	0.63
INTAKE AIR FLOW (scfm)	1289.69	1280.64	1298.12	3.96	0.31
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	677.27	676.97	677.56	0.17	0.03
CYLINDER 1 EXHAUST TEMPERATURE (F)	960.69	959.51	962.69	0.63	0.07
CYLINDER 2 EXHAUST TEMPERATURE (F)	954.07	953.16	955.15	0.46	0.05
CYLINDER 3 EXHAUST TEMPERATURE (F)	954.62	953.76	955.54	0.38	0.04
CYLINDER 4 EXHAUST TEMPERATURE (F)	931.81	930.74	933.12	0.58	0.06
CYLINDER 5 EXHAUST TEMPERATURE (F)	913.66	912.49	914.87	0.48	0.05
CYLINDER 6 EXHAUST TEMPERATURE (F)	914.50	913.48	915.27	0.41	0.05
CYLINDER EXHAUST AVERAGE TEMP (F)	938.22	937.69	939.04	0.27	0.03
EXHAUST HEADER TEMPERATURE (F)	677.27	676.97	677.56	0.17	0.03
PRE TURBO EXHAUST PRESSURE ("Hg)	28.77	28.56	29.20	0.12	0.43
PRE TURBO EXHAUST TEMPERATURE (F)	926.84	925.98	927.57	0.31	0.03
POST TURBO EXHAUST PRESSURE ("Hg)	4.98	4.91	5.09	0.04	0.72
POST TURBO EXHAUST TEMPERATURE (F)	750.13	749.79	750.78	0.24	0.03
TURBO OIL PRESSURE ("Hg)	47.40	46.72	48.09	0.26	0.56
ENGINE SPEED (rpm)	1196.91	1193.61	1201.13	1.72	0.14
ENGINE HORSEPOWER (bhp)	515.86	514.46	517.83	0.81	0.16
ENGINE OIL PRESSURE (psig)	52.61	51.80	53.41	0.36	0.69
ENGINE OIL TEMPERATURE IN (F)	163.43	163.27	163.67	0.10	0.06
ENGINE OIL TEMPERATURE OUT (F)	183.26	183.11	183.51	0.10	0.06
SPECIFIC GRAVITY	0.69	0.69	0.69	0.00	0.00
FUEL TEMPERATURE (F)	91.94	91.84	92.04	0.10	0.11
FUEL PRESSURE ("H2O above amp)	6.56	6.14	6.89	0.17	2.58
FUEL SUPPLY PRESSURE (psig)	47.13	47.09	47.20	0.03	0.06
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	8.41	8.09	8.81	0.15	1.80
ORIFICE STATIC PRESSURE (psig)	46.63	46.59	46.67	0.01	0.03
ORIFICE TEMPERATURE (F)	88.13	88.05	88.20	0.03	0.03
FUEL FLOW (SCFH)	4080.93				
CALCULATED FUEL CONSUMPTION (BSFC)	8224.22				
FUEL HEATING VALUE (Btu)	1039.60	1039.60	1039.60	0.00	0.00
AIR FUEL RATIO	28.89	28.89	28.89	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	5.84	5.71	6.04	0.07	1.23
INTERCOOLER AIR TEMP IN (F)	281.50	281.13	281.92	0.17	0.06
INTERCOOLER AIR TEMP OUT (F)	137.19	136.88	137.48	0.16	0.12
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	66.04	65.91	66.16	0.06	0.09
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	55.74	55.10	56.39	0.29	0.53
INTERCOOLER WATER TEMP IN (F)	127.71	127.56	127.95	0.14	0.11
INTERCOOLER WATER TEMP OUT (F)	137.13	136.88	137.48	0.15	0.11
INTERCOOLER SUPPLY PRESSURE (psi)	2.73	2.69	2.76	0.02	0.59
PRE CATALYST TEMPERATURE (F)	706.42	706.14	706.93	0.19	0.03
POST CATALYST TEMPERATURE (F)	710.77	710.50	711.10	0.14	0.02
CATALYST DIFFERENTIAL PRESSURE ("H2O)	5.57	5.48	5.67	0.05	0.82
B.S. CO (g/bhp-hr): Pre-Catalyst	2.47	2.41	2.53	0.02	0.96

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 2 QC - 515BHP 1200RPM 10BTDC

Data Point Number: Run 2 QC **Date:** 08/06/99 **Time:** 03:15:15

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
B.S. CO (g/bhp-hr): Post-Catalyst	0.11	0.10	0.11	0.00	4.50
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.53	0.52	0.54	0.01	1.05
B.S. NOx (g/bhp-hr): Post-Catalyst	0.56	0.55	0.57	0.01	1.11
B.S. THC (g/bhp-hr): Pre-Catalyst	6.05	5.92	6.21	0.06	0.94
B.S. THC (g/bhp-hr): Post-Catalyst	6.08	5.96	6.22	0.05	0.88
B.S. Methane (g/bhp-hr): Pre-Catalyst	2.83	2.76	2.90	0.03	0.97
B.S. Methane (g/bhp-hr): Post-Catalyst	2.44	2.40	2.55	0.03	1.19
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.15	0.14	0.16	0.01	4.47
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.12	0.12	0.12	0.00	0.00
O2 (ppm): Pre-Catalyst	9.80	9.80	9.80	0.00	0.00
O2 (ppm): Post-Catalyst	9.80	9.80	9.80	0.00	0.00
CO (ppm): Pre-Catalyst	591.66	590.10	594.30	0.88	0.15
CO (ppm): Post-Catalyst	26.89	26.50	27.20	0.15	0.55
CO2 (ppm): Pre-Catalyst	6.25	6.23	6.29	0.03	0.43
CO2 (ppm): Post-Catalyst	6.43	6.42	6.44	0.00	0.06
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	41.32	41.10	41.70	0.14	0.34
NOx (ppm - Corrected): Post-Catalyst	44.65	43.90	45.40	0.28	0.64
NOx (ppm): Pre-Catalyst	77.38	76.90	78.00	0.29	0.38
NOx (ppm): Post-Catalyst	83.45	82.10	84.80	0.50	0.60
THC (ppm): Pre-Catalyst	2102.67	2095.70	2110.30	4.32	0.21
THC (ppm): Post-Catalyst	2159.16	2146.50	2173.30	5.65	0.26
Methane (ppm): Pre-Catalyst	1487.30	1487.30	1487.30	0.00	0.00
Methane (ppm): Post-Catalyst	1314.76	1312.00	1361.10	11.06	0.84
Non-Methane (ppm): Pre-Catalyst	157.37	153.10	162.50	4.66	2.96
Non-Methane (ppm): Post-Catalyst	130.71	128.40	133.20	2.39	1.83
DYNO WATER IN TEMPERATURE (F)	74.57	74.38	74.78	0.07	0.10
DYNO WATER OUT TEMPERATURE (F)	108.92	108.71	109.10	0.13	0.12
JACKET WATER IN TEMPERATURE (F)	174.83	174.58	174.98	0.10	0.06
JACKET WATER OUT TEMPERATURE (F)	178.82	178.00	180.00	0.62	0.35
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	82.12	82.12	82.12	0.00	0.00
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	87.31	87.08	87.48	0.10	0.12
LUBE OIL FLOW (GPM)	129.30	128.73	129.86	0.25	0.19
CO F-Factor: Pre-Catalyst	3.14	3.08	3.20	0.03	0.86
CO F-Factor: Post-Catalyst	0.14	0.14	0.15	0.00	0.93
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	0.67	0.66	0.69	0.01	0.91
NOx F-Factor: Post-Catalyst	0.73	0.71	0.74	0.01	0.98
THC F-Factor: Pre-Catalyst	7.55	7.42	7.73	0.07	0.88
THC F-Factor: Post-Catalyst	7.76	7.62	7.93	0.07	0.89
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	2263.55	2261.01	2266.38	1.19	0.05

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 3 QC - 730BHP 1000RPM 10BTDC

Data Point Number: Run 3 QC **Date:** 08/05/99 **Time:** 13:02:03

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	69.00	69.00	69.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	65.14	64.00	66.00	0.99	1.53
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.85	5.13	0.06	1.20
AIR MANIFOLD RELATIVE HUMIDITY (%)	33.56	33.00	34.00	0.50	1.49
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01375	0.01297	0.01453		
AIR MANIFOLD TEMPERATURE (F)	99.51	98.00	101.00	0.58	0.58
INTAKE AIR FLOW (scfm)	1018.09	1008.84	1028.57	3.78	0.37
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	640.03	639.87	640.26	0.10	0.02
CYLINDER 1 EXHAUST TEMPERATURE (F)	884.40	883.32	885.70	0.53	0.06
CYLINDER 2 EXHAUST TEMPERATURE (F)	880.85	879.95	881.73	0.60	0.07
CYLINDER 3 EXHAUST TEMPERATURE (F)	877.49	876.18	878.96	0.59	0.07
CYLINDER 4 EXHAUST TEMPERATURE (F)	861.77	860.70	862.88	0.62	0.07
CYLINDER 5 EXHAUST TEMPERATURE (F)	850.94	849.59	852.37	0.59	0.07
CYLINDER 6 EXHAUST TEMPERATURE (F)	842.86	842.05	843.84	0.35	0.04
CYLINDER EXHAUST AVERAGE TEMP (F)	866.40	865.60	867.22	0.38	0.04
EXHAUST HEADER TEMPERATURE (F)	640.03	639.87	640.26	0.10	0.02
PRE TURBO EXHAUST PRESSURE ("Hg)	21.18	21.03	21.40	0.09	0.45
PRE TURBO EXHAUST TEMPERATURE (F)	860.44	859.31	861.30	0.50	0.06
POST TURBO EXHAUST PRESSURE ("Hg)	4.96	4.89	5.07	0.03	0.63
POST TURBO EXHAUST TEMPERATURE (F)	725.44	724.79	726.18	0.40	0.06
TURBO OIL PRESSURE ("Hg)	45.50	44.71	46.16	0.25	0.55
ENGINE SPEED (rpm)	1001.56	998.50	1006.39	1.37	0.14
ENGINE HORSEPOWER (bhp)	431.66	430.67	433.61	0.60	0.14
ENGINE OIL PRESSURE (psig)	50.63	49.87	51.15	0.26	0.51
ENGINE OIL TEMPERATURE IN (F)	162.73	162.48	163.07	0.14	0.09
ENGINE OIL TEMPERATURE OUT (F)	179.94	179.74	180.14	0.15	0.08
SPECIFIC GRAVITY	0.69	0.69	0.69	0.00	0.00
FUEL TEMPERATURE (F)	89.52	89.46	89.66	0.09	0.10
FUEL PRESSURE ("H2O above amp)	6.91	6.49	7.30	0.17	2.53
FUEL SUPPLY PRESSURE (psig)	47.49	47.42	47.54	0.02	0.04
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	5.11	4.84	5.38	0.10	2.00
ORIFICE STATIC PRESSURE (psig)	46.85	46.81	46.87	0.01	0.03
ORIFICE TEMPERATURE (F)	84.43	84.29	84.55	0.05	0.05
FUEL FLOW (SCFH)	3199.22				
CALCULATED FUEL CONSUMPTION (BSFC)	7704.96				
FUEL HEATING VALUE (Btu)	1039.60	1039.60	1039.60	0.00	0.00
AIR FUEL RATIO	32.29	32.29	32.29	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	4.79	4.67	4.95	0.06	1.15
INTERCOOLER AIR TEMP IN (F)	231.83	231.53	232.12	0.15	0.07
INTERCOOLER AIR TEMP OUT (F)	136.97	136.68	137.28	0.18	0.13
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	54.19	53.91	54.41	0.10	0.18
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	61.75	61.06	62.67	0.35	0.56
INTERCOOLER WATER TEMP IN (F)	132.69	132.12	133.11	0.28	0.21
INTERCOOLER WATER TEMP OUT (F)	137.56	137.08	138.07	0.28	0.21
INTERCOOLER SUPPLY PRESSURE (psi)	3.02	2.97	3.08	0.02	0.73
PRE CATALYST TEMPERATURE (F)	677.40	676.77	677.76	0.25	0.04
POST CATALYST TEMPERATURE (F)	679.06	678.56	679.55	0.22	0.03
CATALYST DIFFERENTIAL PRESSURE ("H2O)	3.87	3.80	3.95	0.03	0.74
B.S. CO (g/bhp-hr): Pre-Catalyst	2.21	2.16	2.26	0.02	0.98
B.S. CO (g/bhp-hr): Post-Catalyst	0.08	0.08	0.08	0.00	0.00
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 3 QC - 730BHP 1000RPM 10BTDC

Data Point Number: Run 3 QC **Date:** 08/05/99 **Time:** 13:02:03

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.49	0.47	0.50	0.01	1.46
B.S. NOx (g/bhp-hr): Post-Catalyst	0.54	0.53	0.56	0.01	1.30
B.S. THC (g/bhp-hr): Pre-Catalyst	6.40	6.27	6.53	0.06	0.87
B.S. THC (g/bhp-hr): Post-Catalyst	6.44	6.30	6.58	0.06	0.97
B.S. Methane (g/bhp-hr): Pre-Catalyst	2.90	2.84	2.96	0.03	0.92
B.S. Methane (g/bhp-hr): Post-Catalyst	2.42	2.37	2.47	0.02	0.89
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.16	0.16	0.17	0.00	2.61
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.13	0.12	0.13	0.00	1.24
O2 (ppm): Pre-Catalyst	100.00	100.00	100.00	0.00	0.00
O2 (ppm): Post-Catalyst	9.80	9.80	9.80	0.00	0.00
CO (ppm): Pre-Catalyst	571.20	568.20	573.40	1.33	0.23
CO (ppm): Post-Catalyst	21.96	21.80	22.30	0.11	0.50
CO2 (ppm): Pre-Catalyst	6.35	6.35	6.41	0.01	0.19
CO2 (ppm): Post-Catalyst	6.40	6.38	6.42	0.01	0.12
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Post-Catalyst	46.12	45.20	47.00	0.42	0.91
NOx (ppm): Pre-Catalyst	77.13	75.50	78.50	0.71	0.92
NOx (ppm): Post-Catalyst	86.30	84.60	88.00	0.80	0.93
THC (ppm): Pre-Catalyst	2402.23	2394.00	2413.50	5.08	0.21
THC (ppm): Post-Catalyst	2417.82	2407.50	2436.80	6.88	0.28
Methane (ppm): Pre-Catalyst	1648.55	1648.30	1651.50	0.87	0.05
Methane (ppm): Post-Catalyst	1373.41	1373.30	1376.70	0.61	0.04
Non-Methane (ppm): Pre-Catalyst	183.68	181.60	190.70	3.73	2.03
Non-Methane (ppm): Post-Catalyst	147.63	146.10	148.50	1.14	0.77
DYNO WATER IN TEMPERATURE (F)	72.97	72.79	73.19	0.11	0.16
DYNO WATER OUT TEMPERATURE (F)	101.72	101.56	101.76	0.08	0.08
JACKET WATER IN TEMPERATURE (F)	177.01	176.76	177.36	0.13	0.08
JACKET WATER OUT TEMPERATURE (F)	179.52	178.00	181.00	0.62	0.35
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	82.64	82.12	82.71	0.19	0.23
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	86.79	86.48	87.08	0.11	0.13
LUBE OIL FLOW (GPM)	129.38	128.73	129.86	0.25	0.19
CO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
CO F-Factor: Post-Catalyst	0.09	0.09	0.09	0.00	1.07
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Post-Catalyst	0.59	0.57	0.61	0.01	1.27
THC F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
THC F-Factor: Post-Catalyst	6.84	6.69	6.99	0.06	0.94
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	2263.43	2261.01	2266.38	0.97	0.04

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 5 QC - 736BHP 1200RPM 10BTDC

Data Point Number: Run 5 QC **Date:** 08/05/99 **Time:** 21:01:58

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	67.00	67.00	67.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	72.00	72.00	72.00	0.00	0.00
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.84	5.14	0.06	1.17
AIR MANIFOLD RELATIVE HUMIDITY (%)	36.67	33.00	39.00	2.18	5.96
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01515	0.01297	0.01671		
AIR MANIFOLD TEMPERATURE (F)	99.70	98.00	101.00	0.70	0.70
INTAKE AIR FLOW (scfm)	1846.13	1824.25	1860.90	6.52	0.35
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	686.27	685.90	686.89	0.18	0.03
CYLINDER 1 EXHAUST TEMPERATURE (F)	969.49	966.66	972.01	1.34	0.14
CYLINDER 2 EXHAUST TEMPERATURE (F)	969.81	966.85	972.21	1.23	0.13
CYLINDER 3 EXHAUST TEMPERATURE (F)	966.57	963.28	968.84	1.17	0.12
CYLINDER 4 EXHAUST TEMPERATURE (F)	932.58	930.15	934.31	0.86	0.09
CYLINDER 5 EXHAUST TEMPERATURE (F)	915.22	913.08	918.24	1.22	0.13
CYLINDER 6 EXHAUST TEMPERATURE (F)	904.53	902.77	906.34	0.91	0.10
CYLINDER EXHAUST AVERAGE TEMP (F)	943.05	941.69	944.17	0.56	0.06
EXHAUST HEADER TEMPERATURE (F)	686.27	685.90	686.89	0.18	0.03
PRE TURBO EXHAUST PRESSURE ("Hg)	40.27	39.76	40.58	0.17	0.43
PRE TURBO EXHAUST TEMPERATURE (F)	938.34	936.89	939.47	0.50	0.05
POST TURBO EXHAUST PRESSURE ("Hg)	5.51	5.42	5.57	0.03	0.60
POST TURBO EXHAUST TEMPERATURE (F)	750.23	749.39	751.38	0.43	0.06
TURBO OIL PRESSURE ("Hg)	47.11	46.40	47.77	0.29	0.62
ENGINE SPEED (rpm)	1196.70	1190.60	1202.63	2.35	0.20
ENGINE HORSEPOWER (bhp)	737.09	733.85	741.10	1.42	0.19
ENGINE OIL PRESSURE (psig)	52.22	51.64	52.93	0.32	0.61
ENGINE OIL TEMPERATURE IN (F)	164.07	163.67	164.46	0.16	0.10
ENGINE OIL TEMPERATURE OUT (F)	185.13	184.70	185.49	0.17	0.09
SPECIFIC GRAVITY	0.69	0.69	0.69	0.00	0.00
FUEL TEMPERATURE (F)	91.47	91.25	91.64	0.12	0.13
FUEL PRESSURE ("H2O above amp)	0.70	-0.08	1.26	0.23	32.28
FUEL SUPPLY PRESSURE (psig)	46.81	46.75	46.88	0.04	0.08
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	15.28	14.49	16.01	0.35	2.27
ORIFICE STATIC PRESSURE (psig)	46.44	46.36	46.55	0.04	0.08
ORIFICE TEMPERATURE (F)	86.51	86.43	86.58	0.03	0.03
FUEL FLOW (SCFH)	5499.76				
CALCULATED FUEL CONSUMPTION (BSFC)	7756.92				
FUEL HEATING VALUE (Btu)	1039.60	1039.60	1039.60	0.00	0.00
AIR FUEL RATIO	30.20	30.20	30.20	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	10.63	10.44	10.82	0.10	0.94
INTERCOOLER AIR TEMP IN (F)	302.87	301.96	303.75	0.44	0.15
INTERCOOLER AIR TEMP OUT (F)	145.79	145.61	146.21	0.16	0.11
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	67.95	67.74	68.16	0.08	0.12
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	57.67	56.23	58.65	0.59	1.03
INTERCOOLER WATER TEMP IN (F)	131.67	131.13	132.12	0.22	0.17
INTERCOOLER WATER TEMP OUT (F)	144.94	144.42	145.61	0.25	0.17
INTERCOOLER SUPPLY PRESSURE (psi)	2.83	2.75	2.90	0.03	1.10
PRE CATALYST TEMPERATURE (F)	712.47	711.89	714.27	0.48	0.07
POST CATALYST TEMPERATURE (F)	719.47	719.03	720.22	0.28	0.04
CATALYST DIFFERENTIAL PRESSURE ("H2O)	10.09	9.95	10.23	0.05	0.51
B.S. CO (g/bhp-hr): Pre-Catalyst	3.01	2.89	3.11	0.05	1.51
B.S. CO (g/bhp-hr): Post-Catalyst	0.21	0.20	0.22	0.00	1.92
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 5 QC - 736BHP 1200RPM 10BTDC

Data Point Number: Run 5 QC   **Date:** 08/05/99   **Time:** 21:01:58

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.48	0.46	0.50	0.01	1.76
B.S. NOx (g/bhp-hr): Post-Catalyst	0.52	0.50	0.54	0.01	1.98
B.S. THC (g/bhp-hr): Pre-Catalyst	6.81	6.48	7.05	0.13	1.87
B.S. THC (g/bhp-hr): Post-Catalyst	6.85	6.49	7.11	0.14	2.09
B.S. Methane (g/bhp-hr): Pre-Catalyst	3.10	3.04	3.19	0.04	1.14
B.S. Methane (g/bhp-hr): Post-Catalyst	2.67	2.60	2.79	0.05	1.88
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.17	0.17	0.18	0.00	2.71
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.14	0.14	0.15	0.00	1.50
O2 (ppm): Pre-Catalyst	10.49	10.40	10.50	0.03	0.28
O2 (ppm): Post-Catalyst	10.40	10.40	10.40	0.00	0.00
CO (ppm): Pre-Catalyst	725.83	706.70	733.90	7.01	0.97
CO (ppm): Post-Catalyst	52.17	50.40	53.20	0.67	1.29
CO2 (ppm): Pre-Catalyst	5.88	5.86	5.92	0.03	0.50
CO2 (ppm): Post-Catalyst	5.99	5.97	6.01	0.01	0.15
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	40.26	39.30	41.20	0.52	1.28
NOx (ppm - Corrected): Post-Catalyst	43.81	42.40	45.80	0.85	1.94
NOx (ppm): Pre-Catalyst	70.89	69.50	72.50	0.89	1.26
NOx (ppm): Post-Catalyst	77.47	75.10	80.90	1.42	1.83
THC (ppm): Pre-Catalyst	2381.05	2300.30	2428.10	36.52	1.53
THC (ppm): Post-Catalyst	2410.39	2329.40	2470.90	41.47	1.72
Methane (ppm): Pre-Catalyst	1640.81	1640.50	1643.60	0.93	0.06
Methane (ppm): Post-Catalyst	1423.58	1404.10	1453.30	22.59	1.59
Non-Methane (ppm): Pre-Catalyst	184.58	182.00	192.60	4.42	2.40
Non-Methane (ppm): Post-Catalyst	151.97	151.60	154.20	0.85	0.56
DYNO WATER IN TEMPERATURE (F)	81.25	80.93	81.52	0.12	0.14
DYNO WATER OUT TEMPERATURE (F)	127.12	126.76	127.75	0.18	0.14
JACKET WATER IN TEMPERATURE (F)	172.89	172.60	173.19	0.12	0.07
JACKET WATER OUT TEMPERATURE (F)	178.66	178.00	180.00	0.58	0.32
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	85.69	85.69	85.69	0.00	0.00
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	91.47	91.25	91.64	0.13	0.14
LUBE OIL FLOW (GPM)	129.93	129.54	130.34	0.21	0.16
CO F-Factor: Pre-Catalyst	5.53	5.28	5.69	0.08	1.49
CO F-Factor: Post-Catalyst	0.39	0.38	0.41	0.01	1.66
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	0.89	0.86	0.93	0.01	1.54
NOx F-Factor: Post-Catalyst	0.96	0.93	1.01	0.02	1.96
THC F-Factor: Pre-Catalyst	12.28	11.64	12.73	0.24	1.96
THC F-Factor: Post-Catalyst	12.38	11.75	12.86	0.26	2.08
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3234.54	3230.40	3238.45	1.75	0.05

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 7 QC - 515BHP 1200RPM 10BTDC

Data Point Number: Run 7 QC **Date:** 08/06/99 **Time:** 01:57:03

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	65.00	65.00	65.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	74.00	74.00	74.00	0.00	0.00
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.86	5.11	0.05	0.97
AIR MANIFOLD RELATIVE HUMIDITY (%)	31.09	31.00	32.00	0.28	0.91
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01276	0.01216	0.01366		
AIR MANIFOLD TEMPERATURE (F)	99.61	98.00	101.00	0.77	0.78
INTAKE AIR FLOW (scfm)	1212.51	1203.95	1223.12	4.22	0.35
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	695.08	694.63	695.62	0.27	0.04
CYLINDER 1 EXHAUST TEMPERATURE (F)	987.22	985.90	989.08	0.58	0.06
CYLINDER 2 EXHAUST TEMPERATURE (F)	978.98	977.77	980.74	0.53	0.05
CYLINDER 3 EXHAUST TEMPERATURE (F)	980.61	979.35	981.54	0.53	0.05
CYLINDER 4 EXHAUST TEMPERATURE (F)	955.47	954.35	956.93	0.49	0.05
CYLINDER 5 EXHAUST TEMPERATURE (F)	937.39	936.10	938.68	0.57	0.06
CYLINDER 6 EXHAUST TEMPERATURE (F)	940.58	939.27	942.25	0.70	0.07
CYLINDER EXHAUST AVERAGE TEMP (F)	963.37	962.65	964.11	0.35	0.04
EXHAUST HEADER TEMPERATURE (F)	695.08	694.63	695.62	0.27	0.04
PRE TURBO EXHAUST PRESSURE ("Hg)	27.23	26.95	27.87	0.17	0.64
PRE TURBO EXHAUST TEMPERATURE (F)	950.24	949.00	950.98	0.36	0.04
POST TURBO EXHAUST PRESSURE ("Hg)	4.93	4.85	5.10	0.05	0.97
POST TURBO EXHAUST TEMPERATURE (F)	776.57	776.18	777.17	0.30	0.04
TURBO OIL PRESSURE ("Hg)	47.27	46.56	47.93	0.28	0.59
ENGINE SPEED (rpm)	1196.91	1194.36	1204.51	1.99	0.17
ENGINE HORSEPOWER (bhp)	515.67	514.18	517.87	0.90	0.18
ENGINE OIL PRESSURE (psig)	52.47	51.88	53.33	0.34	0.65
ENGINE OIL TEMPERATURE IN (F)	163.82	163.47	164.06	0.13	0.08
ENGINE OIL TEMPERATURE OUT (F)	183.82	183.51	184.10	0.15	0.08
SPECIFIC GRAVITY	0.69	0.69	0.69	0.00	0.00
FUEL TEMPERATURE (F)	91.62	91.44	91.84	0.10	0.11
FUEL PRESSURE ("H2O above amp)	7.66	7.23	8.08	0.16	2.08
FUEL SUPPLY PRESSURE (psig)	47.19	47.12	47.26	0.03	0.07
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	8.21	7.88	8.53	0.14	1.73
ORIFICE STATIC PRESSURE (psig)	46.64	46.62	46.68	0.01	0.03
ORIFICE TEMPERATURE (F)	87.91	87.83	88.00	0.03	0.03
FUEL FLOW (SCFH)	4032.46				
CALCULATED FUEL CONSUMPTION (BSFC)	8129.51				
FUEL HEATING VALUE (Btu)	1039.60	1039.60	1039.60	0.00	0.00
AIR FUEL RATIO	27.20	27.20	27.20	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	5.37	5.21	5.68	0.11	2.07
INTERCOOLER AIR TEMP IN (F)	278.23	277.76	278.75	0.18	0.06
INTERCOOLER AIR TEMP OUT (F)	137.57	136.88	138.07	0.38	0.27
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	65.44	65.16	65.83	0.16	0.24
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	55.71	55.10	56.23	0.23	0.41
INTERCOOLER WATER TEMP IN (F)	128.44	127.95	128.95	0.37	0.29
INTERCOOLER WATER TEMP OUT (F)	137.23	136.68	137.87	0.41	0.30
INTERCOOLER SUPPLY PRESSURE (psi)	2.72	2.68	2.76	0.02	0.60
PRE CATALYST TEMPERATURE (F)	728.54	727.96	729.75	0.26	0.04
POST CATALYST TEMPERATURE (F)	731.73	731.34	732.33	0.29	0.04
CATALYST DIFFERENTIAL PRESSURE ("H2O)	5.13	5.07	5.28	0.04	0.84
B.S. CO (g/bhp-hr): Pre-Catalyst	2.51	2.46	2.56	0.02	0.98

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 7 QC - 515BHP 1200RPM 10BTDC

Data Point Number: Run 7 QC **Date:** 08/06/99 **Time:** 01:57:03

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
B.S. CO (g/bhp-hr): Post-Catalyst	0.10	0.09	0.10	0.00	1.80
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.94	0.91	0.97	0.01	1.37
B.S. NOx (g/bhp-hr): Post-Catalyst	0.98	0.95	1.01	0.01	1.38
B.S. THC (g/bhp-hr): Pre-Catalyst	4.92	4.82	5.03	0.04	0.91
B.S. THC (g/bhp-hr): Post-Catalyst	4.90	4.78	5.03	0.05	1.01
B.S. Methane (g/bhp-hr): Pre-Catalyst	2.22	2.17	2.27	0.02	0.97
B.S. Methane (g/bhp-hr): Post-Catalyst	1.97	1.93	2.02	0.02	0.99
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.14	0.13	0.14	0.00	2.90
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.09	0.09	0.09	0.00	0.00
O2 (ppm): Pre-Catalyst	9.20	9.10	9.20	0.02	0.20
O2 (ppm): Post-Catalyst	9.08	9.00	9.10	0.04	0.42
CO (ppm): Pre-Catalyst	641.53	638.70	643.80	1.39	0.22
CO (ppm): Post-Catalyst	26.38	26.00	26.60	0.11	0.42
CO2 (ppm): Pre-Catalyst	6.65	6.65	6.65	0.00	0.00
CO2 (ppm): Post-Catalyst	6.80	6.78	6.81	0.01	0.09
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	74.05	72.80	74.70	0.57	0.76
NOx (ppm - Corrected): Post-Catalyst	77.47	75.80	78.90	0.79	1.02
NOx (ppm): Pre-Catalyst	146.87	144.70	148.20	1.08	0.74
NOx (ppm): Post-Catalyst	154.86	151.50	157.80	1.68	1.08
THC (ppm): Pre-Catalyst	1828.38	1820.50	1836.30	3.64	0.20
THC (ppm): Post-Catalyst	1841.06	1829.40	1853.80	6.21	0.34
Methane (ppm): Pre-Catalyst	1247.31	1245.10	1248.10	1.33	0.11
Methane (ppm): Post-Catalyst	1124.70	1124.70	1124.70	0.00	0.00
Non-Methane (ppm): Pre-Catalyst	155.88	147.40	158.00	4.24	2.72
Non-Methane (ppm): Post-Catalyst	103.15	102.90	103.20	0.11	0.10
DYNO WATER IN TEMPERATURE (F)	74.66	74.58	74.78	0.10	0.13
DYNO WATER OUT TEMPERATURE (F)	108.84	108.51	109.30	0.15	0.14
JACKET WATER IN TEMPERATURE (F)	175.24	174.98	175.37	0.11	0.06
JACKET WATER OUT TEMPERATURE (F)	179.21	177.00	181.00	0.71	0.39
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	82.12	82.12	82.12	0.00	0.00
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	87.60	87.48	87.87	0.11	0.13
LUBE OIL FLOW (GPM)	129.42	128.73	130.02	0.20	0.15
CO F-Factor: Pre-Catalyst	3.18	3.12	3.25	0.03	1.05
CO F-Factor: Post-Catalyst	0.13	0.13	0.13	0.00	1.13
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	1.20	1.16	1.23	0.02	1.28
NOx F-Factor: Post-Catalyst	1.25	1.21	1.30	0.02	1.34
THC F-Factor: Pre-Catalyst	6.14	6.01	6.28	0.06	0.94
THC F-Factor: Post-Catalyst	6.14	5.99	6.30	0.06	1.05
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	2263.34	2261.01	2266.38	1.19	0.05

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 8 QC - 616BHP 1000RPM 10BTDC

Data Point Number: Run 8 QC **Date:** 08/06/99 **Time:** 07:14:36

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	63.00	63.00	63.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	80.00	80.00	80.00	0.00	0.00
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.87	5.15	0.07	1.37
AIR MANIFOLD RELATIVE HUMIDITY (%)	36.00	36.00	36.00	0.00	0.00
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01479	0.01417	0.01539		
AIR MANIFOLD TEMPERATURE (F)	99.54	98.00	101.00	0.68	0.68
INTAKE AIR FLOW (scfm)	1471.45	1461.65	1483.08	5.17	0.35
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	641.99	641.45	642.44	0.28	0.04
CYLINDER 1 EXHAUST TEMPERATURE (F)	886.82	885.31	888.48	0.62	0.07
CYLINDER 2 EXHAUST TEMPERATURE (F)	888.22	886.69	889.67	0.52	0.06
CYLINDER 3 EXHAUST TEMPERATURE (F)	889.32	888.28	890.27	0.46	0.05
CYLINDER 4 EXHAUST TEMPERATURE (F)	867.14	865.66	868.44	0.48	0.06
CYLINDER 5 EXHAUST TEMPERATURE (F)	860.33	859.51	861.69	0.52	0.06
CYLINDER 6 EXHAUST TEMPERATURE (F)	847.59	846.81	848.20	0.33	0.04
CYLINDER EXHAUST AVERAGE TEMP (F)	873.23	872.64	873.90	0.32	0.04
EXHAUST HEADER TEMPERATURE (F)	641.99	641.45	642.44	0.28	0.04
PRE TURBO EXHAUST PRESSURE ("Hg)	31.96	31.67	32.20	0.10	0.30
PRE TURBO EXHAUST TEMPERATURE (F)	881.03	880.35	881.73	0.35	0.04
POST TURBO EXHAUST PRESSURE ("Hg)	4.92	4.88	4.98	0.02	0.49
POST TURBO EXHAUST TEMPERATURE (F)	702.44	701.57	703.36	0.37	0.05
TURBO OIL PRESSURE ("Hg)	45.01	44.47	45.52	0.20	0.45
ENGINE SPEED (rpm)	1001.52	996.99	1006.02	1.56	0.16
ENGINE HORSEPOWER (bhp)	616.71	614.67	619.06	0.92	0.15
ENGINE OIL PRESSURE (psig)	50.21	49.62	50.75	0.26	0.52
ENGINE OIL TEMPERATURE IN (F)	162.04	161.68	162.28	0.17	0.10
ENGINE OIL TEMPERATURE OUT (F)	180.78	180.53	180.93	0.13	0.07
SPECIFIC GRAVITY	0.69	0.69	0.69	0.00	0.00
FUEL TEMPERATURE (F)	89.83	89.66	90.06	0.09	0.10
FUEL PRESSURE ("H2O above amp)	2.69	2.31	3.26	0.19	6.99
FUEL SUPPLY PRESSURE (psig)	47.23	47.20	47.29	0.03	0.06
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	9.76	9.54	10.11	0.09	0.95
ORIFICE STATIC PRESSURE (psig)	46.62	46.57	46.65	0.02	0.04
ORIFICE TEMPERATURE (F)	84.00	83.87	84.11	0.06	0.06
FUEL FLOW (SCFH)	4413.10				
CALCULATED FUEL CONSUMPTION (BSFC)	7439.28				
FUEL HEATING VALUE (Btu)	1039.60	1039.60	1039.60	0.00	0.00
AIR FUEL RATIO	30.50	30.50	30.50	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	7.49	7.21	7.69	0.10	1.37
INTERCOOLER AIR TEMP IN (F)	285.06	284.70	285.50	0.23	0.08
INTERCOOLER AIR TEMP OUT (F)	137.98	137.68	138.47	0.18	0.13
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	66.60	66.49	66.74	0.06	0.09
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	54.83	54.14	55.42	0.27	0.49
INTERCOOLER WATER TEMP IN (F)	128.09	127.75	128.55	0.18	0.14
INTERCOOLER WATER TEMP OUT (F)	138.90	138.67	139.26	0.16	0.12
INTERCOOLER SUPPLY PRESSURE (psi)	2.68	2.65	2.73	0.02	0.57
PRE CATALYST TEMPERATURE (F)	663.47	663.08	663.87	0.25	0.04
POST CATALYST TEMPERATURE (F)	669.30	668.83	669.83	0.27	0.04
CATALYST DIFFERENTIAL PRESSURE ("H2O)	6.63	6.53	6.70	0.04	0.60
B.S. CO (g/bhp-hr): Pre-Catalyst	3.06	3.02	3.12	0.02	0.61

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 8 QC - 616BHP 1000RPM 10BTDC

Data Point Number: Run 8 QC **Date:** 08/06/99 **Time:** 07:14:36

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
B.S. CO (g/bhp-hr): Post-Catalyst	0.16	0.16	0.16	0.00	0.00
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.49	0.48	0.50	0.00	0.74
B.S. NOx (g/bhp-hr): Post-Catalyst	0.52	0.51	0.53	0.01	1.31
B.S. THC (g/bhp-hr): Pre-Catalyst	8.16	8.01	8.34	0.06	0.74
B.S. THC (g/bhp-hr): Post-Catalyst	8.32	8.21	8.47	0.05	0.63
B.S. Methane (g/bhp-hr): Pre-Catalyst	3.74	3.68	3.80	0.02	0.63
B.S. Methane (g/bhp-hr): Post-Catalyst	3.41	3.31	3.46	0.03	0.84
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.18	0.18	0.19	0.00	2.55
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.17	0.16	0.17	0.00	3.00
O2 (ppm): Pre-Catalyst	10.50	10.50	10.50	0.00	0.00
O2 (ppm): Post-Catalyst	10.50	10.50	10.50	0.00	0.00
CO (ppm): Pre-Catalyst	640.04	638.70	641.90	0.70	0.11
CO (ppm): Post-Catalyst	35.15	34.80	35.50	0.14	0.40
CO2 (ppm): Pre-Catalyst	5.86	5.86	5.92	0.01	0.12
CO2 (ppm): Post-Catalyst	6.01	6.00	6.02	0.01	0.10
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	35.71	35.50	35.80	0.14	0.38
NOx (ppm - Corrected): Post-Catalyst	38.38	37.80	39.20	0.33	0.85
NOx (ppm): Pre-Catalyst	62.85	62.50	63.00	0.22	0.35
NOx (ppm): Post-Catalyst	67.41	66.30	68.80	0.59	0.87
THC (ppm): Pre-Catalyst	2477.49	2462.20	2492.70	7.48	0.30
THC (ppm): Post-Catalyst	2566.37	2549.00	2590.40	9.37	0.37
Methane (ppm): Pre-Catalyst	1715.61	1713.30	1716.50	1.44	0.08
Methane (ppm): Post-Catalyst	1591.25	1548.50	1597.60	12.04	0.76
Non-Methane (ppm): Pre-Catalyst	167.54	165.50	171.80	2.91	1.74
Non-Methane (ppm): Post-Catalyst	154.98	153.90	156.40	1.18	0.76
DYNO WATER IN TEMPERATURE (F)	76.47	76.37	76.56	0.10	0.13
DYNO WATER OUT TEMPERATURE (F)	116.26	116.05	116.64	0.14	0.12
JACKET WATER IN TEMPERATURE (F)	174.95	174.78	175.18	0.08	0.05
JACKET WATER OUT TEMPERATURE (F)	178.77	177.00	180.00	0.65	0.37
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	77.95	77.95	77.95	0.00	0.00
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	82.45	82.32	82.52	0.10	0.12
LUBE OIL FLOW (GPM)	128.49	128.09	128.89	0.19	0.15
CO F-Factor: Pre-Catalyst	3.91	3.86	3.99	0.02	0.58
CO F-Factor: Post-Catalyst	0.22	0.21	0.22	0.00	0.66
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	0.63	0.62	0.65	0.00	0.70
NOx F-Factor: Post-Catalyst	0.68	0.66	0.69	0.01	1.08
THC F-Factor: Pre-Catalyst	10.27	10.08	10.49	0.07	0.70
THC F-Factor: Post-Catalyst	10.66	10.52	10.86	0.07	0.61
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3233.88	3230.40	3238.45	1.63	0.05

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 9 QC - 736BHP 1200RPM 10BTDC

Data Point Number: Run 9 QC **Date:** 08/04/99 **Time:** 15:21:47

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	66.00	66.00	66.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.08	12.08	12.08	0.00	0.00
AMBIENT HUMIDITY (%)	68.00	68.00	68.00	0.00	0.00
AIR MANIFOLD PRESSURE ("Hg)	5.02	4.79	5.19	0.06	1.24
AIR MANIFOLD RELATIVE HUMIDITY (%)	36.37	36.00	37.00	0.48	1.33
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01494	0.01420	0.01580		
AIR MANIFOLD TEMPERATURE (F)	99.57	98.00	101.00	0.67	0.67
INTAKE AIR FLOW (scfm)	1702.27	1691.17	1718.23	5.45	0.32
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	702.70	702.56	702.96	0.13	0.02
CYLINDER 1 EXHAUST TEMPERATURE (F)	977.27	975.59	978.76	0.74	0.08
CYLINDER 2 EXHAUST TEMPERATURE (F)	977.46	976.38	978.36	0.44	0.05
CYLINDER 3 EXHAUST TEMPERATURE (F)	979.97	978.96	980.74	0.40	0.04
CYLINDER 4 EXHAUST TEMPERATURE (F)	955.13	953.76	956.54	0.54	0.06
CYLINDER 5 EXHAUST TEMPERATURE (F)	945.78	944.24	946.81	0.51	0.05
CYLINDER 6 EXHAUST TEMPERATURE (F)	932.08	930.94	932.93	0.37	0.04
CYLINDER EXHAUST AVERAGE TEMP (F)	961.29	960.24	961.86	0.31	0.03
EXHAUST HEADER TEMPERATURE (F)	702.71	702.56	702.96	0.13	0.02
PRE TURBO EXHAUST PRESSURE ("Hg)	36.29	36.00	36.58	0.11	0.30
PRE TURBO EXHAUST TEMPERATURE (F)	962.28	961.50	963.08	0.33	0.03
POST TURBO EXHAUST PRESSURE ("Hg)	4.76	4.72	4.84	0.03	0.55
POST TURBO EXHAUST TEMPERATURE (F)	798.12	797.21	799.00	0.41	0.05
TURBO OIL PRESSURE ("Hg)	46.96	46.24	47.61	0.27	0.57
ENGINE SPEED (rpm)	1196.58	1193.61	1202.26	1.64	0.14
ENGINE HORSEPOWER (bhp)	736.91	734.77	739.24	1.01	0.14
ENGINE OIL PRESSURE (psig)	52.13	51.40	52.85	0.33	0.63
ENGINE OIL TEMPERATURE IN (F)	164.42	164.06	164.66	0.13	0.08
ENGINE OIL TEMPERATURE OUT (F)	185.61	185.30	185.89	0.14	0.07
SPECIFIC GRAVITY	0.68	0.68	0.68	0.00	0.00
FUEL TEMPERATURE (F)	258.17	101.76	639.67	167.30	64.80
FUEL PRESSURE ("H2O above amp)	5.23	4.53	6.04	0.29	5.57
FUEL SUPPLY PRESSURE (psig)	47.01	46.92	47.14	0.05	0.11
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	14.46	13.84	15.29	0.31	2.12
ORIFICE STATIC PRESSURE (psig)	46.49	46.36	46.59	0.04	0.09
ORIFICE TEMPERATURE (F)	83.83	83.61	84.00	0.10	0.10
FUEL FLOW (SCFH)	5397.59				
CALCULATED FUEL CONSUMPTION (BSFC)	7496.02				
FUEL HEATING VALUE (Btu)	1023.40	1023.40	1023.40	0.00	0.00
AIR FUEL RATIO	28.60	28.60	28.60	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	9.03	8.81	9.28	0.10	1.05
INTERCOOLER AIR TEMP IN (F)	297.00	296.21	297.40	0.24	0.08
INTERCOOLER AIR TEMP OUT (F)	131.60	130.93	132.12	0.28	0.21
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	69.31	69.16	69.49	0.07	0.10
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	64.67	63.80	65.25	0.29	0.45
INTERCOOLER WATER TEMP IN (F)	119.55	119.02	120.02	0.32	0.26
INTERCOOLER WATER TEMP OUT (F)	131.24	130.53	131.92	0.30	0.23
INTERCOOLER SUPPLY PRESSURE (psi)	3.24	3.20	3.27	0.02	0.46
PRE CATALYST TEMPERATURE (F)	741.76	734.51	759.31	6.84	0.92
POST CATALYST TEMPERATURE (F)	739.18	738.88	739.47	0.17	0.02
CATALYST DIFFERENTIAL PRESSURE ("H2O)	9.02	8.92	9.15	0.04	0.50
B.S. CO (g/bhp-hr): Pre-Catalyst	2.36	2.31	2.44	0.03	1.24
B.S. CO (g/bhp-hr): Post-Catalyst	0.15	0.14	0.15	0.00	3.03
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 9 QC - 736BHP 1200RPM 10BTDC

Data Point Number: Run 9 QC **Date:** 08/04/99 **Time:** 15:21:47

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.66	0.65	0.68	0.01	1.34
B.S. NOx (g/bhp-hr): Post-Catalyst	0.72	0.70	0.74	0.01	1.43
B.S. THC (g/bhp-hr): Pre-Catalyst	4.86	4.75	5.00	0.06	1.23
B.S. THC (g/bhp-hr): Post-Catalyst	4.79	4.68	4.93	0.06	1.24
B.S. Methane (g/bhp-hr): Pre-Catalyst	2.25	2.20	2.32	0.03	1.19
B.S. Methane (g/bhp-hr): Post-Catalyst	9.96	9.73	10.24	0.12	1.19
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.11	0.11	0.11	0.00	0.00
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.43	0.42	0.45	0.01	1.36
O2 (ppm): Pre-Catalyst	9.71	9.70	9.80	0.02	0.23
O2 (ppm): Post-Catalyst	9.70	9.70	9.70	0.00	0.00
CO (ppm): Pre-Catalyst	620.81	618.10	624.50	2.32	0.37
CO (ppm): Post-Catalyst	40.15	39.60	40.90	0.28	0.69
CO2 (ppm): Pre-Catalyst	6.36	6.30	6.36	0.01	0.19
CO2 (ppm): Post-Catalyst	6.50	6.49	6.51	0.01	0.09
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	56.29	55.70	56.80	0.25	0.44
NOx (ppm - Corrected): Post-Catalyst	62.01	61.00	63.20	0.46	0.75
NOx (ppm): Pre-Catalyst	106.40	105.40	107.30	0.45	0.42
NOx (ppm): Post-Catalyst	117.11	115.20	119.40	0.90	0.77
THC (ppm): Pre-Catalyst	1883.94	1874.10	1892.30	5.92	0.31
THC (ppm): Post-Catalyst	1880.05	1868.40	1892.80	5.93	0.32
Methane (ppm): Pre-Catalyst	1266.40	1266.40	1266.40	0.00	0.00
Methane (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane (ppm): Pre-Catalyst	142.71	141.20	144.40	1.43	1.00
Non-Methane (ppm): Post-Catalyst	556.50	556.50	556.50	0.00	0.00
DYNO WATER IN TEMPERATURE (F)	80.49	80.14	80.73	0.12	0.15
DYNO WATER OUT TEMPERATURE (F)	126.40	125.97	126.76	0.17	0.14
JACKET WATER IN TEMPERATURE (F)	172.49	172.20	172.80	0.12	0.07
JACKET WATER OUT TEMPERATURE (F)	178.64	177.00	180.00	0.65	0.36
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	83.51	83.51	83.51	0.00	0.00
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	89.06	88.87	89.26	0.10	0.11
LUBE OIL FLOW (GPM)	129.64	129.05	130.18	0.23	0.18
CO F-Factor: Pre-Catalyst	4.26	4.16	4.40	0.05	1.25
CO F-Factor: Post-Catalyst	0.28	0.27	0.29	0.00	1.35
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	1.20	1.17	1.24	0.02	1.26
NOx F-Factor: Post-Catalyst	1.32	1.28	1.37	0.02	1.40
THC F-Factor: Pre-Catalyst	8.61	8.41	8.88	0.11	1.24
THC F-Factor: Post-Catalyst	8.61	8.40	8.86	0.11	1.24
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3234.95	3233.08	3238.45	2.15	0.07

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 10 QC - 735BHP 1200RPM 10BTDC

Data Point Number: Run 10 QC **Date:** 08/06/99 **Time:** 11:19:11

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	77.00	77.00	77.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	46.05	44.00	48.00	1.03	2.24
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.88	5.19	0.07	1.31
AIR MANIFOLD RELATIVE HUMIDITY (%)	35.36	34.00	36.00	0.70	1.97
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01453	0.01336	0.01537		
AIR MANIFOLD TEMPERATURE (F)	99.56	98.00	101.00	0.73	0.73
INTAKE AIR FLOW (scfm)	1702.85	1688.91	1717.67	6.81	0.40
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	704.30	703.56	705.14	0.45	0.06
CYLINDER 1 EXHAUST TEMPERATURE (F)	978.34	975.98	980.15	0.93	0.09
CYLINDER 2 EXHAUST TEMPERATURE (F)	980.11	976.97	981.93	0.87	0.09
CYLINDER 3 EXHAUST TEMPERATURE (F)	982.39	980.15	984.12	0.89	0.09
CYLINDER 4 EXHAUST TEMPERATURE (F)	956.16	954.16	958.12	0.96	0.10
CYLINDER 5 EXHAUST TEMPERATURE (F)	947.51	945.23	949.79	0.98	0.10
CYLINDER 6 EXHAUST TEMPERATURE (F)	932.44	930.94	933.72	0.60	0.06
CYLINDER EXHAUST AVERAGE TEMP (F)	962.81	960.51	964.31	0.78	0.08
EXHAUST HEADER TEMPERATURE (F)	704.30	703.56	705.14	0.45	0.06
PRE TURBO EXHAUST PRESSURE ("Hg)	36.59	36.33	36.90	0.11	0.31
PRE TURBO EXHAUST TEMPERATURE (F)	963.39	961.30	964.87	0.82	0.09
POST TURBO EXHAUST PRESSURE ("Hg)	4.91	4.86	4.99	0.02	0.48
POST TURBO EXHAUST TEMPERATURE (F)	779.70	777.96	781.34	0.77	0.10
TURBO OIL PRESSURE ("Hg)	46.84	46.08	47.37	0.29	0.61
ENGINE SPEED (rpm)	1196.90	1193.61	1200.75	1.41	0.12
ENGINE HORSEPOWER (bhp)	737.75	735.70	740.40	1.04	0.14
ENGINE OIL PRESSURE (psig)	52.04	51.32	52.77	0.35	0.68
ENGINE OIL TEMPERATURE IN (F)	165.68	165.26	165.85	0.17	0.10
ENGINE OIL TEMPERATURE OUT (F)	186.80	186.49	187.08	0.15	0.08
SPECIFIC GRAVITY	0.66	0.66	0.66	0.00	0.00
FUEL TEMPERATURE (F)	94.85	94.62	95.02	0.14	0.15
FUEL PRESSURE ("H2O above amp)	4.83	3.96	5.34	0.24	5.05
FUEL SUPPLY PRESSURE (psig)	46.49	46.39	46.56	0.04	0.08
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	14.67	14.13	15.30	0.26	1.79
ORIFICE STATIC PRESSURE (psig)	46.29	46.19	46.37	0.03	0.07
ORIFICE TEMPERATURE (F)	92.38	92.30	92.44	0.03	0.03
FUEL FLOW (SCFH)	5483.54				
CALCULATED FUEL CONSUMPTION (BSFC)	7332.42				
FUEL HEATING VALUE (Btu)	986.50	986.50	986.50	0.00	0.00
AIR FUEL RATIO	28.70	28.70	28.70	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	9.41	9.22	9.57	0.09	0.93
INTERCOOLER AIR TEMP IN (F)	298.87	298.39	299.38	0.22	0.07
INTERCOOLER AIR TEMP OUT (F)	151.40	149.58	152.76	1.02	0.68
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	68.80	68.66	68.99	0.07	0.11
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	54.32	53.65	55.26	0.34	0.63
INTERCOOLER WATER TEMP IN (F)	140.22	137.87	141.64	1.13	0.80
INTERCOOLER WATER TEMP OUT (F)	152.61	150.57	154.14	1.10	0.72
INTERCOOLER SUPPLY PRESSURE (psi)	2.64	2.60	2.67	0.01	0.56
PRE CATALYST TEMPERATURE (F)	735.84	734.51	737.29	0.75	0.10
POST CATALYST TEMPERATURE (F)	739.77	738.68	741.06	0.62	0.08
CATALYST DIFFERENTIAL PRESSURE ("H2O)	9.03	8.94	9.13	0.04	0.49
B.S. CO (g/bhp-hr): Pre-Catalyst	2.39	2.35	2.45	0.02	0.99

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 10 QC - 735BHP 1200RPM 10BTDC

Data Point Number: Run 10 QC **Date:** 08/06/99 **Time:** 11:19:11

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
B.S. CO (g/bhp-hr): Post-Catalyst	0.15	0.15	0.16	0.00	2.57
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.80	0.77	0.82	0.01	1.62
B.S. NOx (g/bhp-hr): Post-Catalyst	0.83	0.80	0.85	0.01	1.52
B.S. THC (g/bhp-hr): Pre-Catalyst	4.35	4.27	4.48	0.05	1.16
B.S. THC (g/bhp-hr): Post-Catalyst	4.48	4.39	4.57	0.04	1.00
B.S. Methane (g/bhp-hr): Pre-Catalyst	2.19	2.15	2.24	0.02	0.94
B.S. Methane (g/bhp-hr): Post-Catalyst	2.06	1.99	2.15	0.05	2.43
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.07	0.07	0.07	0.00	0.00
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.06	0.06	0.07	0.00	3.71
O2 (ppm): Pre-Catalyst	9.80	9.80	9.80	0.00	0.00
O2 (ppm): Post-Catalyst	9.76	9.70	9.80	0.05	0.49
CO (ppm): Pre-Catalyst	621.62	618.30	624.70	1.85	0.30
CO (ppm): Post-Catalyst	41.65	41.30	41.90	0.12	0.29
CO2 (ppm): Pre-Catalyst	6.34	6.29	6.35	0.02	0.37
CO2 (ppm): Post-Catalyst	6.49	6.46	6.50	0.01	0.18
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	67.36	65.80	68.70	0.83	1.23
NOx (ppm - Corrected): Post-Catalyst	70.97	68.50	72.70	0.77	1.08
NOx (ppm): Pre-Catalyst	126.38	123.10	129.20	1.80	1.43
NOx (ppm): Post-Catalyst	133.46	128.60	136.90	1.63	1.22
THC (ppm): Pre-Catalyst	1736.40	1723.10	1758.40	7.81	0.45
THC (ppm): Post-Catalyst	1812.15	1800.10	1826.90	5.87	0.32
Methane (ppm): Pre-Catalyst	1148.60	1148.60	1148.60	0.00	0.00
Methane (ppm): Post-Catalyst	1098.14	1078.60	1124.70	22.86	2.08
Non-Methane (ppm): Pre-Catalyst	122.50	122.50	122.50	0.00	0.00
Non-Methane (ppm): Post-Catalyst	114.79	114.40	121.70	1.62	1.41
DYNO WATER IN TEMPERATURE (F)	82.41	82.12	82.52	0.12	0.14
DYNO WATER OUT TEMPERATURE (F)	128.87	128.55	129.14	0.17	0.13
JACKET WATER IN TEMPERATURE (F)	172.37	171.80	172.99	0.34	0.20
JACKET WATER OUT TEMPERATURE (F)	178.79	178.00	180.00	0.64	0.36
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	95.41	95.41	95.41	0.00	0.00
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	100.81	100.57	101.17	0.14	0.13
LUBE OIL FLOW (GPM)	131.59	131.15	132.12	0.21	0.16
CO F-Factor: Pre-Catalyst	4.20	4.13	4.28	0.04	0.94
CO F-Factor: Post-Catalyst	0.28	0.28	0.29	0.00	1.03
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	1.40	1.35	1.44	0.02	1.48
NOx F-Factor: Post-Catalyst	1.48	1.43	1.52	0.02	1.42
THC F-Factor: Pre-Catalyst	7.51	7.36	7.69	0.09	1.16
THC F-Factor: Post-Catalyst	7.82	7.68	7.99	0.08	1.03
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3236.99	3233.08	3241.14	1.83	0.06

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 11 QC - 735BHP 1200RPM 10BTDC

Data Point Number: Run 11 QC **Date:** 08/06/99 **Time:** 01:57:03

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	73.00	73.00	73.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	61.42	60.00	64.00	1.28	2.08
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.89	5.16	0.05	1.06
AIR MANIFOLD RELATIVE HUMIDITY (%)	39.54	38.00	41.00	0.71	1.80
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01627	0.10496	0.01758		
AIR MANIFOLD TEMPERATURE (F)	99.51	98.00	101.00	0.74	0.74
INTAKE AIR FLOW (scfm)	1718.97	1709.21	1728.95	4.69	0.27
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	700.67	700.38	701.57	0.33	0.05
CYLINDER 1 EXHAUST TEMPERATURE (F)	973.05	971.02	975.78	1.16	0.12
CYLINDER 2 EXHAUST TEMPERATURE (F)	974.49	973.60	975.98	0.57	0.06
CYLINDER 3 EXHAUST TEMPERATURE (F)	977.03	975.98	977.97	0.50	0.05
CYLINDER 4 EXHAUST TEMPERATURE (F)	951.74	950.78	952.97	0.54	0.06
CYLINDER 5 EXHAUST TEMPERATURE (F)	941.58	940.27	943.04	0.64	0.07
CYLINDER 6 EXHAUST TEMPERATURE (F)	927.93	926.38	929.35	0.65	0.07
CYLINDER EXHAUST AVERAGE TEMP (F)	957.64	956.87	958.95	0.46	0.05
EXHAUST HEADER TEMPERATURE (F)	700.67	700.38	701.57	0.33	0.05
PRE TURBO EXHAUST PRESSURE ("Hg)	36.76	36.41	37.10	0.13	0.37
PRE TURBO EXHAUST TEMPERATURE (F)	958.72	957.93	960.11	0.51	0.05
POST TURBO EXHAUST PRESSURE ("Hg)	4.80	4.72	5.10	0.08	1.68
POST TURBO EXHAUST TEMPERATURE (F)	774.82	773.99	776.18	0.59	0.08
TURBO OIL PRESSURE ("Hg)	47.13	46.16	47.69	0.27	0.58
ENGINE SPEED (rpm)	1196.85	1193.61	1200.00	1.36	0.11
ENGINE HORSEPOWER (bhp)	737.86	736.23	739.94	0.86	0.12
ENGINE OIL PRESSURE (psig)	52.34	51.56	53.09	0.36	0.70
ENGINE OIL TEMPERATURE IN (F)	164.00	163.87	164.26	0.13	0.08
ENGINE OIL TEMPERATURE OUT (F)	184.54	184.30	184.90	0.11	0.07
SPECIFIC GRAVITY	0.68	0.68	0.68	0.68	0.68
FUEL TEMPERATURE (F)	95.70	95.41	95.81	0.11	0.12
FUEL PRESSURE ("H2O above amp)	4.84	4.09	5.35	0.23	4.82
FUEL SUPPLY PRESSURE (psig)	46.34	46.22	46.45	0.06	0.13
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	14.66	14.05	15.44	0.33	2.24
ORIFICE STATIC PRESSURE (psig)	46.24	46.13	46.35	0.05	0.10
ORIFICE TEMPERATURE (F)	91.84	91.61	92.11	0.13	0.13
FUEL FLOW (SCFH)	5376.45				
CALCULATED FUEL CONSUMPTION (BSFC)	7188.22				
FUEL HEATING VALUE (Btu)	986.50	986.50	986.50	0.00	0.00
AIR FUEL RATIO	28.60	28.60	28.60	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	9.39	9.13	9.57	0.10	1.08
INTERCOOLER AIR TEMP IN (F)	298.88	298.39	299.58	0.26	0.09
INTERCOOLER AIR TEMP OUT (F)	142.19	141.64	143.03	0.33	0.23
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	68.80	68.99	68.99	0.08	0.12
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	54.63	54.14	55.10	0.24	0.44
INTERCOOLER WATER TEMP IN (F)	128.78	128.35	129.14	0.19	0.14
INTERCOOLER WATER TEMP OUT (F)	142.02	141.45	143.03	0.37	0.26
INTERCOOLER SUPPLY PRESSURE (psi)	2.66	2.62	2.71	0.02	0.58
PRE CATALYST TEMPERATURE (F)	731.36	730.94	732.13	0.29	0.04
POST CATALYST TEMPERATURE (F)	735.66	735.11	736.30	0.26	0.03
CATALYST DIFFERENTIAL PRESSURE ("H2O)	9.04	8.96	9.17	0.05	0.58
B.S. CO (g/bhp-hr): Pre-Catalyst	2.41	2.35	2.48	0.03	1.20

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 11 QC - 735BHP 1200RPM 10BTDC

Data Point Number: Run 11 QC **Date:** 08/06/99 **Time:** 01:57:03

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
B.S. CO (g/bhp-hr): Post-Catalyst	0.15	0.15	0.16	0.00	2.67
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.67	0.66	0.69	0.01	1.26
B.S. NOx (g/bhp-hr): Post-Catalyst	0.71	0.69	0.72	0.01	1.27
B.S. THC (g/bhp-hr): Pre-Catalyst	4.68	4.57	4.82	0.06	1.22
B.S. THC (g/bhp-hr): Post-Catalyst	4.72	4.60	4.86	0.05	1.11
B.S. Methane (g/bhp-hr): Pre-Catalyst	2.31	2.25	2.37	0.03	1.15
B.S. Methane (g/bhp-hr): Post-Catalyst	2.14	2.08	2.19	0.02	1.05
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.09	0.08	0.09	0.00	4.93
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.08	0.07	0.08	0.00	2.65
O2 (ppm): Pre-Catalyst	9.80	9.80	9.80	0.00	0.00
O2 (ppm): Post-Catalyst	9.80	9.80	9.80	0.00	0.00
CO (ppm): Pre-Catalyst	624.11	622.10	626.30	1.41	0.23
CO (ppm): Post-Catalyst	41.68	41.30	42.60	0.21	0.50
CO2 (ppm): Pre-Catalyst	6.31	6.26	6.32	0.02	0.39
CO2 (ppm): Post-Catalyst	6.47	6.46	6.49	0.01	0.10
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	57.10	56.40	57.80	0.30	0.53
NOx (ppm - Corrected): Post-Catalyst	60.82	59.60	61.90	0.51	0.83
NOx (ppm): Pre-Catalyst	106.97	106.00	108.00	0.42	0.39
NOx (ppm): Post-Catalyst	114.26	112.00	116.20	0.90	0.79
THC (ppm): Pre-Catalyst	1861.45	1850.70	1871.60	4.24	0.24
THC (ppm): Post-Catalyst	1906.80	1895.90	1917.90	6.29	0.33
Methane (ppm): Pre-Catalyst	1206.30	1206.60	1206.30	0.00	0.00
Methane (ppm): Post-Catalyst	1136.00	1136.00	1136.00	0.00	0.00
Non-Methane (ppm): Pre-Catalyst	150.82	136.40	155.50	8.24	5.47
Non-Methane (ppm): Post-Catalyst	141.49	120.60	142.80	4.62	3.27
DYNO WATER IN TEMPERATURE (F)	81.95	81.72	82.32	0.12	0.14
DYNO WATER OUT TEMPERATURE (F)	128.69	128.35	129.14	0.16	0.12
JACKET WATER IN TEMPERATURE (F)	163.67	162.48	164.46	0.53	0.32
JACKET WATER OUT TEMPERATURE (F)	170.58	168.00	172.00	0.87	0.51
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	91.25	91.25	91.25	0.00	0.00
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	96.66	96.41	96.80	0.10	0.11
LUBE OIL FLOW (GPM)	130.93	130.34	131.47	0.27	0.21
CO F-Factor: Pre-Catalyst	4.23	4.11	4.33	0.05	1.15
CO F-Factor: Post-Catalyst	0.28	0.27	0.29	0.00	1.16
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	1.19	1.16	1.22	0.01	1.19
NOx F-Factor: Post-Catalyst	1.27	1.23	1.29	0.02	1.26
THC F-Factor: Pre-Catalyst	8.07	7.86	8.25	0.09	1.16
THC F-Factor: Post-Catalyst	8.24	8.05	8.48	0.09	1.10
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3238.04	3235.77	3241.14	1.11	0.03

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 12 QC - 735BHP 1200RPM 10BTDC

Data Point Number: Run 12 QC **Date:** 08/06/99 **Time:** 09:02:06

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	69.00	69.00	69.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	62.00	62.00	62.00	0.00	0.00
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.87	5.13	0.06	1.15
AIR MANIFOLD RELATIVE HUMIDITY (%)	35.24	35.00	36.00	0.43	1.21
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01442	0.01376	0.01540		
AIR MANIFOLD TEMPERATURE (F)	99.42	98.00	101.00	0.66	0.66
INTAKE AIR FLOW (scfm)	1718.39	1707.52	1731.20	5.24	0.30
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	703.58	702.56	704.35	0.52	0.07
CYLINDER 1 EXHAUST TEMPERATURE (F)	978.04	976.78	978.96	0.55	0.06
CYLINDER 2 EXHAUST TEMPERATURE (F)	979.22	978.36	980.15	0.47	0.05
CYLINDER 3 EXHAUST TEMPERATURE (F)	980.99	979.35	982.53	0.79	0.08
CYLINDER 4 EXHAUST TEMPERATURE (F)	956.36	955.54	957.73	0.47	0.05
CYLINDER 5 EXHAUST TEMPERATURE (F)	946.47	944.63	947.81	0.76	0.08
CYLINDER 6 EXHAUST TEMPERATURE (F)	932.80	930.74	934.51	1.00	0.11
CYLINDER EXHAUST AVERAGE TEMP (F)	962.30	961.30	963.18	0.53	0.06
EXHAUST HEADER TEMPERATURE (F)	703.58	702.56	704.35	0.52	0.07
PRE TURBO EXHAUST PRESSURE ("Hg)	36.95	36.72	37.20	0.11	0.29
PRE TURBO EXHAUST TEMPERATURE (F)	963.40	961.89	964.67	0.68	0.07
POST TURBO EXHAUST PRESSURE ("Hg)	4.97	4.91	5.04	0.03	0.58
POST TURBO EXHAUST TEMPERATURE (F)	779.18	777.96	780.15	0.60	0.08
TURBO OIL PRESSURE ("Hg)	46.77	46.00	47.45	0.31	0.67
ENGINE SPEED (rpm)	1196.98	1194.36	1200.38	1.33	0.11
ENGINE HORSEPOWER (bhp)	737.45	735.93	738.94	0.74	0.10
ENGINE OIL PRESSURE (psig)	51.95	51.32	52.60	0.34	0.66
ENGINE OIL TEMPERATURE IN (F)	165.89	165.65	166.25	0.11	0.07
ENGINE OIL TEMPERATURE OUT (F)	187.46	187.28	187.68	0.14	0.08
SPECIFIC GRAVITY	2.55	2.55	2.55	0.00	0.00
FUEL TEMPERATURE (F)	91.76	91.44	91.84	0.12	0.13
FUEL PRESSURE ("H2O above amp)	5.31	4.86	5.76	0.21	3.94
FUEL SUPPLY PRESSURE (psig)	46.78	46.67	46.90	0.05	0.10
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	14.83	14.24	15.79	0.31	2.08
ORIFICE STATIC PRESSURE (psig)	46.38	46.27	46.46	0.04	0.08
ORIFICE TEMPERATURE (F)	88.43	88.35	88.53	0.03	0.03
FUEL FLOW (SCFH)	12573.12				
CALCULATED FUEL CONSUMPTION (BSFC)	0.00				
FUEL HEATING VALUE (Btu)	0.00	0.00	0.00	0.00	0.00
AIR FUEL RATIO	28.20	28.20	28.20	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	9.40	9.17	9.62	0.10	1.05
INTERCOOLER AIR TEMP IN (F)	299.19	298.59	299.58	0.23	0.08
INTERCOOLER AIR TEMP OUT (F)	141.01	140.65	141.45	0.22	0.16
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	68.89	68.74	69.08	0.07	0.10
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	54.85	54.14	55.59	0.32	0.59
INTERCOOLER WATER TEMP IN (F)	127.81	127.16	128.15	0.34	0.27
INTERCOOLER WATER TEMP OUT (F)	140.90	140.45	141.25	0.26	0.18
INTERCOOLER SUPPLY PRESSURE (psi)	2.66	2.62	2.69	0.01	0.54
PRE CATALYST TEMPERATURE (F)	735.35	734.51	736.10	0.59	0.08
POST CATALYST TEMPERATURE (F)	739.10	738.08	739.87	0.58	0.08
CATALYST DIFFERENTIAL PRESSURE ("H2O)	9.18	9.07	9.28	0.05	0.55
B.S. CO (g/bhp-hr): Pre-Catalyst	6.75	6.58	6.95	0.08	1.15

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 13 QC - 736BHP 1200RPM 6BTDC

Data Point Number: Run 13 QC **Date:** 08/05/99 **Time:** 16:37:20

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.74	0.71	0.77	0.02	2.41
B.S. NOx (g/bhp-hr): Post-Catalyst	0.81	0.76	0.84	0.02	2.56
B.S. THC (g/bhp-hr): Pre-Catalyst	9.12	8.87	9.56	0.17	1.82
B.S. THC (g/bhp-hr): Post-Catalyst	9.52	9.28	9.96	0.17	1.74
B.S. Methane (g/bhp-hr): Pre-Catalyst	4.49	4.41	4.58	0.04	0.91
B.S. Methane (g/bhp-hr): Post-Catalyst	3.85	3.78	3.93	0.04	0.91
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.27	0.27	0.28	0.00	1.30
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.18	0.18	0.19	0.00	1.66
O2 (ppm): Pre-Catalyst	9.87	9.80	9.90	0.05	0.47
O2 (ppm): Post-Catalyst	9.80	9.80	9.80	0.00	0.00
CO (ppm): Pre-Catalyst	618.31	611.20	631.60	7.75	1.25
CO (ppm): Post-Catalyst	44.05	43.30	45.40	0.57	1.28
CO2 (ppm): Pre-Catalyst	6.23	6.23	6.29	0.01	0.20
CO2 (ppm): Post-Catalyst	6.37	6.36	6.40	0.01	0.12
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	34.46	33.20	35.20	0.84	2.42
NOx (ppm - Corrected): Post-Catalyst	37.97	35.80	39.30	0.95	2.50
NOx (ppm): Pre-Catalyst	64.26	62.10	65.60	1.44	2.24
NOx (ppm): Post-Catalyst	70.97	67.10	73.40	1.72	2.42
THC (ppm): Pre-Catalyst	1880.03	1849.70	1939.80	29.33	1.56
THC (ppm): Post-Catalyst	1991.58	1961.10	2056.20	28.08	1.41
Methane (ppm): Pre-Catalyst	1400.68	1399.90	1403.10	1.38	0.10
Methane (ppm): Post-Catalyst	1218.85	1216.80	1219.90	1.47	0.12
Non-Methane (ppm): Pre-Catalyst	167.84	167.30	170.70	1.25	0.74
Non-Methane (ppm): Post-Catalyst	114.84	114.40	118.80	1.32	1.15
DYNO WATER IN TEMPERATURE (F)	82.01	81.72	82.32	0.12	0.15
DYNO WATER OUT TEMPERATURE (F)	128.04	127.75	128.55	0.16	0.13
JACKET WATER IN TEMPERATURE (F)	177.09	176.76	177.36	0.15	0.08
JACKET WATER OUT TEMPERATURE (F)	183.67	182.00	185.00	0.63	0.34
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	88.67	88.67	88.67	0.00	0.00
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	93.93	93.63	94.02	0.10	0.11
LUBE OIL FLOW (GPM)	130.44	129.22	131.15	0.29	0.22
CO F-Factor: Pre-Catalyst	4.60	4.48	4.77	0.07	1.43
CO F-Factor: Post-Catalyst	0.33	0.32	0.34	0.01	1.62
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	0.79	0.75	0.82	0.02	2.52
NOx F-Factor: Post-Catalyst	0.87	0.82	0.90	0.02	2.51
THC F-Factor: Pre-Catalyst	9.47	9.22	9.90	0.16	1.70
THC F-Factor: Post-Catalyst	10.02	9.76	10.48	0.18	1.77
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3235.41	3233.08	3238.45	2.07	0.06

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 14 QC - 736BHP 1200RPM 14BTDC

Data Point Number: Run 14 QC **Date:** 08/04/99 **Time:** 20:20:36

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	62.00	62.00	62.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.08	12.08	12.08	0.00	0.00
AMBIENT HUMIDITY (%)	80.00	80.00	80.00	0.00	0.00
AIR MANIFOLD PRESSURE ("Hg)	5.02	4.85	5.19	0.07	1.42
AIR MANIFOLD RELATIVE HUMIDITY (%)	37.07	36.00	38.00	0.58	1.56
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01519	0.01373	0.01674		
AIR MANIFOLD TEMPERATURE (F)	99.49	97.00	102.00	0.78	0.79
INTAKE AIR FLOW (scfm)	1675.73	1665.79	1684.40	3.88	0.23
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	687.87	687.29	688.87	0.40	0.06
CYLINDER 1 EXHAUST TEMPERATURE (F)	953.74	951.97	955.15	0.56	0.06
CYLINDER 2 EXHAUST TEMPERATURE (F)	954.57	953.76	955.15	0.38	0.04
CYLINDER 3 EXHAUST TEMPERATURE (F)	957.32	955.94	958.72	0.49	0.05
CYLINDER 4 EXHAUST TEMPERATURE (F)	930.87	929.75	932.13	0.44	0.05
CYLINDER 5 EXHAUST TEMPERATURE (F)	922.99	922.01	923.60	0.27	0.03
CYLINDER 6 EXHAUST TEMPERATURE (F)	910.55	909.51	912.09	0.49	0.05
CYLINDER EXHAUST AVERAGE TEMP (F)	938.34	937.82	938.88	0.25	0.03
EXHAUST HEADER TEMPERATURE (F)	687.87	687.29	688.87	0.40	0.06
PRE TURBO EXHAUST PRESSURE ("Hg)	35.29	35.03	35.61	0.11	0.32
PRE TURBO EXHAUST TEMPERATURE (F)	936.66	935.90	937.09	0.28	0.03
POST TURBO EXHAUST PRESSURE ("Hg)	4.54	4.48	4.61	0.03	0.60
POST TURBO EXHAUST TEMPERATURE (F)	883.18	771.81	1202.97	131.90	14.94
TURBO OIL PRESSURE ("Hg)	46.88	45.92	47.61	0.28	0.60
ENGINE SPEED (rpm)	1196.59	1193.61	1200.75	1.46	0.12
ENGINE HORSEPOWER (bhp)	736.95	735.24	739.47	0.99	0.13
ENGINE OIL PRESSURE (psig)	52.07	51.32	52.85	0.34	0.64
ENGINE OIL TEMPERATURE IN (F)	164.50	164.26	164.66	0.12	0.07
ENGINE OIL TEMPERATURE OUT (F)	186.09	185.69	186.29	0.15	0.08
SPECIFIC GRAVITY	0.68	0.68	0.68	0.00	0.00
FUEL TEMPERATURE (F)	89.86	89.66	90.06	0.08	0.09
FUEL PRESSURE ("H2O above amp)	4.10	3.54	4.67	0.24	5.80
FUEL SUPPLY PRESSURE (psig)	46.86	46.77	47.03	0.06	0.13
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	13.63	12.95	14.60	0.32	2.36
ORIFICE STATIC PRESSURE (psig)	46.46	46.36	46.58	0.05	0.11
ORIFICE TEMPERATURE (F)	85.47	85.31	85.64	0.08	0.08
FUEL FLOW (SCFH)	5231.32				
CALCULATED FUEL CONSUMPTION (BSFC)	7268.23				
FUEL HEATING VALUE (Btu)	1023.90	1023.90	1023.90	0.00	0.00
AIR FUEL RATIO	29.00	29.00	29.00	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	8.92	8.76	9.15	0.09	0.99
INTERCOOLER AIR TEMP IN (F)	294.61	294.03	295.22	0.29	0.10
INTERCOOLER AIR TEMP OUT (F)	141.40	141.05	141.64	0.17	0.12
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	68.85	68.74	68.99	0.08	0.11
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	62.59	61.87	63.32	0.36	0.58
INTERCOOLER WATER TEMP IN (F)	131.47	130.93	131.92	0.26	0.20
INTERCOOLER WATER TEMP OUT (F)	142.50	142.04	142.83	0.20	0.14
INTERCOOLER SUPPLY PRESSURE (psi)	3.12	3.08	3.17	0.02	0.62
PRE CATALYST TEMPERATURE (F)	714.61	714.07	715.26	0.27	0.04
POST CATALYST TEMPERATURE (F)	720.50	720.22	721.22	0.22	0.03
CATALYST DIFFERENTIAL PRESSURE ("H2O)	8.65	8.53	8.79	0.06	0.65
B.S. CO (g/bhp-hr): Pre-Catalyst	2.50	2.41	2.57	0.03	1.36
B.S. CO (g/bhp-hr): Post-Catalyst	0.15	0.15	0.16	0.00	1.19
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 14 QC - 736BHP 1200RPM 14BTDC

Data Point Number: Run 14 QC **Date:** 08/04/99 **Time:** 20:20:36

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	1.17	1.13	1.21	0.02	1.45
B.S. NOx (g/bhp-hr): Post-Catalyst	1.21	1.17	1.27	0.02	1.44
B.S. THC (g/bhp-hr): Pre-Catalyst	4.38	4.25	4.53	0.05	1.25
B.S. THC (g/bhp-hr): Post-Catalyst	4.41	4.29	4.54	0.05	1.13
B.S. Methane (g/bhp-hr): Pre-Catalyst	2.08	2.02	2.15	0.03	1.23
B.S. Methane (g/bhp-hr): Post-Catalyst	1.80	1.75	1.85	0.02	1.12
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.11	0.10	0.11	0.00	4.49
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.08	0.08	0.09	0.00	5.82
O2 (ppm): Pre-Catalyst	9.80	9.70	9.80	0.02	0.22
O2 (ppm): Post-Catalyst	9.80	9.80	9.80	0.00	0.00
CO (ppm): Pre-Catalyst	668.76	664.50	673.80	3.17	0.47
CO (ppm): Post-Catalyst	42.56	42.10	43.00	0.24	0.57
CO2 (ppm): Pre-Catalyst	6.27	6.24	6.30	0.03	0.48
CO2 (ppm): Post-Catalyst	6.46	6.45	6.47	0.01	0.08
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	101.70	100.50	103.20	0.72	0.71
NOx (ppm - Corrected): Post-Catalyst	107.27	105.20	110.00	1.05	0.98
NOx (ppm): Pre-Catalyst	191.35	189.70	194.20	1.27	0.66
NOx (ppm): Post-Catalyst	201.14	197.20	206.20	1.96	0.98
THC (ppm): Pre-Catalyst	1725.50	1718.20	1734.00	4.05	0.23
THC (ppm): Post-Catalyst	1772.11	1761.10	1783.00	4.30	0.24
Methane (ppm): Pre-Catalyst	1189.00	1189.00	1189.00	0.00	0.00
Methane (ppm): Post-Catalyst	1049.90	1049.90	1049.90	0.00	0.00
Non-Methane (ppm): Pre-Catalyst	141.94	132.30	147.60	7.18	5.06
Non-Methane (ppm): Post-Catalyst	113.08	108.80	119.80	5.37	4.75
DYNO WATER IN TEMPERATURE (F)	80.49	80.33	80.73	0.09	0.11
DYNO WATER OUT TEMPERATURE (F)	127.01	126.76	127.56	0.17	0.13
JACKET WATER IN TEMPERATURE (F)	174.12	173.99	174.38	0.10	0.06
JACKET WATER OUT TEMPERATURE (F)	179.68	178.00	181.00	0.63	0.35
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	80.53	80.53	80.53	0.00	0.00
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	86.16	85.89	86.29	0.11	0.13
LUBE OIL FLOW (GPM)	129.08	128.57	129.54	0.21	0.16
CO F-Factor: Pre-Catalyst	4.47	4.33	4.58	0.05	1.22
CO F-Factor: Post-Catalyst	0.29	0.28	0.29	0.00	1.30
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	2.10	2.03	2.16	0.03	1.31
NOx F-Factor: Post-Catalyst	2.21	2.15	2.32	0.03	1.44
THC F-Factor: Pre-Catalyst	7.68	7.51	7.92	0.09	1.19
THC F-Factor: Post-Catalyst	7.92	7.71	8.16	0.09	1.15
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3235.26	3230.40	3238.45	2.07	0.06

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 15 QC - 736BHP 1200RPM 10BTDC (cylinder 6-6BTDC)

Data Point Number: Run 15 QC **Date:** 08/05/99 **Time:** 18:05:37

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	69.00	69.00	69.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	66.00	66.00	66.00	0.00	0.00
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.79	5.26	0.11	2.14
AIR MANIFOLD RELATIVE HUMIDITY (%)	37.47	34.00	39.00	1.58	4.22
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01537	0.01340	0.01664		
AIR MANIFOLD TEMPERATURE (F)	99.45	98.00	101.00	0.68	0.68
INTAKE AIR FLOW (scfm)	1743.96	1734.59	1761.09	5.84	0.33
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	707.30	706.73	708.32	0.38	0.05
CYLINDER 1 EXHAUST TEMPERATURE (F)	976.55	974.39	980.35	1.24	0.13
CYLINDER 2 EXHAUST TEMPERATURE (F)	977.30	975.78	980.55	0.83	0.08
CYLINDER 3 EXHAUST TEMPERATURE (F)	976.89	975.78	978.56	0.47	0.05
CYLINDER 4 EXHAUST TEMPERATURE (F)	953.44	949.79	964.28	4.28	0.45
CYLINDER 5 EXHAUST TEMPERATURE (F)	942.75	940.86	945.23	0.96	0.10
CYLINDER 6 EXHAUST TEMPERATURE (F)	948.76	947.21	950.39	0.60	0.06
CYLINDER EXHAUST AVERAGE TEMP (F)	962.61	961.20	965.83	1.08	0.11
EXHAUST HEADER TEMPERATURE (F)	707.30	706.73	708.32	0.38	0.05
PRE TURBO EXHAUST PRESSURE ("Hg)	37.62	37.33	38.12	0.17	0.45
PRE TURBO EXHAUST TEMPERATURE (F)	967.97	966.26	971.82	1.35	0.14
POST TURBO EXHAUST PRESSURE ("Hg)	5.07	5.01	5.20	0.03	0.62
POST TURBO EXHAUST TEMPERATURE (F)	781.17	780.15	783.92	0.84	0.11
TURBO OIL PRESSURE ("Hg)	47.03	46.40	47.61	0.27	0.57
ENGINE SPEED (rpm)	1196.85	1192.11	1201.13	1.82	0.15
ENGINE HORSEPOWER (bhp)	737.30	734.54	739.79	1.25	0.17
ENGINE OIL PRESSURE (psig)	52.24	51.56	52.93	0.33	0.64
ENGINE OIL TEMPERATURE IN (F)	164.71	164.46	164.86	0.13	0.08
ENGINE OIL TEMPERATURE OUT (F)	185.77	185.49	186.09	0.13	0.07
SPECIFIC GRAVITY	0.69	0.69	0.69	0.00	0.00
FUEL TEMPERATURE (F)	91.32	91.25	91.64	0.11	0.12
FUEL PRESSURE ("H2O above amp)	4.10	3.39	4.70	0.27	6.68
FUEL SUPPLY PRESSURE (psig)	46.77	46.67	46.82	0.04	0.08
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	14.98	14.38	15.75	0.32	2.14
ORIFICE STATIC PRESSURE (psig)	46.46	46.35	46.53	0.04	0.08
ORIFICE TEMPERATURE (F)	86.45	86.33	86.59	0.06	0.06
FUEL FLOW (SCFH)	5446.45				
CALCULATED FUEL CONSUMPTION (BSFC)	7679.51				
FUEL HEATING VALUE (Btu)	1039.60	1039.60	1039.60	0.00	0.00
AIR FUEL RATIO	28.89	28.89	28.89	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	9.60	9.45	9.76	0.08	0.80
INTERCOOLER AIR TEMP IN (F)	300.18	299.19	300.77	0.36	0.12
INTERCOOLER AIR TEMP OUT (F)	140.65	140.25	141.25	0.34	0.24
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	68.88	68.66	69.24	0.12	0.18
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	57.96	57.20	58.65	0.33	0.57
INTERCOOLER WATER TEMP IN (F)	127.96	127.56	128.75	0.37	0.29
INTERCOOLER WATER TEMP OUT (F)	140.56	140.25	141.25	0.36	0.26
INTERCOOLER SUPPLY PRESSURE (psi)	2.84	2.80	2.88	0.02	0.58
PRE CATALYST TEMPERATURE (F)	738.20	737.49	740.26	0.78	0.11
POST CATALYST TEMPERATURE (F)	742.39	741.45	744.23	0.73	0.10
CATALYST DIFFERENTIAL PRESSURE ("H2O)	9.46	9.34	9.62	0.05	0.58
B.S. CO (g/bhp-hr): Pre-Catalyst	4.23	4.14	4.33	0.04	1.01
B.S. CO (g/bhp-hr): Post-Catalyst	0.28	0.28	0.29	0.00	0.93
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 15 QC - 736BHP 1200RPM 10BTDC (cylinder 6-6BTDC)

Data Point Number: Run 15 QC **Date:** 08/05/99 **Time:** 18:05:37

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	1.06	1.01	1.12	0.03	2.40
B.S. NOx (g/bhp-hr): Post-Catalyst	1.13	1.08	1.20	0.03	2.79
B.S. THC (g/bhp-hr): Pre-Catalyst	8.61	8.42	8.86	0.11	1.26
B.S. THC (g/bhp-hr): Post-Catalyst	9.04	8.79	9.35	0.12	1.28
B.S. Methane (g/bhp-hr): Pre-Catalyst	4.29	4.02	4.41	0.06	1.32
B.S. Methane (g/bhp-hr): Post-Catalyst	3.70	3.63	3.79	0.04	1.04
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.26	0.25	0.28	0.01	4.79
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.17	0.16	0.18	0.01	3.36
O2 (ppm): Pre-Catalyst	9.90	9.90	9.90	0.00	0.00
O2 (ppm): Post-Catalyst	9.82	9.80	9.90	0.04	0.39
CO (ppm): Pre-Catalyst	625.82	622.50	629.60	1.57	0.25
CO (ppm): Post-Catalyst	42.62	42.10	43.30	0.25	0.58
CO2 (ppm): Pre-Catalyst	6.23	6.23	6.29	0.01	0.11
CO2 (ppm): Post-Catalyst	6.35	6.33	6.36	0.01	0.13
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	51.95	49.90	54.00	1.22	2.36
NOx (ppm - Corrected): Post-Catalyst	55.50	52.70	58.50	1.52	2.75
NOx (ppm): Pre-Catalyst	96.20	92.90	100.00	2.21	2.29
NOx (ppm): Post-Catalyst	103.74	98.40	109.10	2.75	2.65
THC (ppm): Pre-Catalyst	1852.76	1830.20	1881.40	11.63	0.63
THC (ppm): Post-Catalyst	1965.93	1936.70	1992.80	13.14	0.67
Methane (ppm): Pre-Catalyst	1398.33	1319.20	1403.10	13.15	0.94
Methane (ppm): Post-Catalyst	1218.96	1216.80	1219.90	1.43	0.12
Non-Methane (ppm): Pre-Catalyst	170.82	163.50	178.20	7.30	4.27
Non-Methane (ppm): Post-Catalyst	112.97	109.90	116.60	3.21	2.84
DYNO WATER IN TEMPERATURE (F)	81.69	81.52	81.92	0.09	0.11
DYNO WATER OUT TEMPERATURE (F)	127.68	127.36	127.95	0.13	0.10
JACKET WATER IN TEMPERATURE (F)	173.84	173.59	174.18	0.15	0.08
JACKET WATER OUT TEMPERATURE (F)	179.46	178.00	181.00	0.65	0.36
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	88.07	88.07	88.07	0.00	0.00
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	93.62	93.43	93.83	0.13	0.14
LUBE OIL FLOW (GPM)	130.39	129.86	130.99	0.23	0.18
CO F-Factor: Pre-Catalyst	4.49	4.40	4.60	0.05	1.04
CO F-Factor: Post-Catalyst	0.30	0.30	0.31	0.00	1.08
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	1.13	1.08	1.19	0.03	2.43
NOx F-Factor: Post-Catalyst	1.21	1.15	1.28	0.03	2.70
THC F-Factor: Pre-Catalyst	9.00	8.80	9.27	0.11	1.23
THC F-Factor: Post-Catalyst	9.46	9.21	9.77	0.12	1.26
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3235.54	3233.08	3238.45	2.23	0.07

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 16 QC - 736BHP 1200RPM 10BTDC (Cyinder 6-14BDC)

Data Point Number: Run 16 QC **Date:** 08/05/99 **Time:** 19:35:49

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	69.00	69.00	69.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	68.00	68.00	68.00	0.00	0.00
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.73	5.26	0.10	2.08
AIR MANIFOLD RELATIVE HUMIDITY (%)	37.97	37.00	38.00	0.18	0.47
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01568	0.01464	0.01671		
AIR MANIFOLD TEMPERATURE (F)	99.67	98.00	102.00	0.79	0.79
INTAKE AIR FLOW (scfm)	1713.30	1701.32	1724.44	5.44	0.32
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	697.78	697.41	698.20	0.17	0.02
CYLINDER 1 EXHAUST TEMPERATURE (F)	974.88	973.60	975.78	0.44	0.05
CYLINDER 2 EXHAUST TEMPERATURE (F)	977.67	976.58	978.76	0.44	0.04
CYLINDER 3 EXHAUST TEMPERATURE (F)	977.02	975.98	978.16	0.46	0.05
CYLINDER 4 EXHAUST TEMPERATURE (F)	951.39	949.99	952.57	0.56	0.06
CYLINDER 5 EXHAUST TEMPERATURE (F)	942.28	940.66	943.44	0.51	0.05
CYLINDER 6 EXHAUST TEMPERATURE (F)	917.85	916.46	919.43	0.71	0.08
CYLINDER EXHAUST AVERAGE TEMP (F)	956.84	955.88	957.36	0.28	0.03
EXHAUST HEADER TEMPERATURE (F)	697.78	697.41	698.20	0.17	0.02
PRE TURBO EXHAUST PRESSURE ("Hg)	36.82	36.58	37.15	0.12	0.31
PRE TURBO EXHAUST TEMPERATURE (F)	953.87	952.97	954.35	0.31	0.03
POST TURBO EXHAUST PRESSURE ("Hg)	4.90	4.85	4.97	0.02	0.50
POST TURBO EXHAUST TEMPERATURE (F)	771.02	770.42	771.61	0.26	0.03
TURBO OIL PRESSURE ("Hg)	46.98	46.24	47.61	0.28	0.59
ENGINE SPEED (rpm)	1196.91	1192.48	1201.50	1.67	0.14
ENGINE HORSEPOWER (bhp)	737.41	735.01	740.17	1.04	0.14
ENGINE OIL PRESSURE (psig)	52.16	51.40	52.85	0.36	0.68
ENGINE OIL TEMPERATURE IN (F)	164.99	164.86	165.26	0.11	0.07
ENGINE OIL TEMPERATURE OUT (F)	186.15	185.89	186.49	0.14	0.07
SPECIFIC GRAVITY	0.69	0.69	0.69	0.00	0.00
FUEL TEMPERATURE (F)	91.24	91.05	91.64	0.09	0.09
FUEL PRESSURE ("H2O above amp)	4.20	3.63	4.62	0.25	5.86
FUEL SUPPLY PRESSURE (psig)	46.82	46.71	46.90	0.04	0.09
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	14.58	13.89	15.29	0.33	2.30
ORIFICE STATIC PRESSURE (psig)	46.47	46.37	46.58	0.04	0.08
ORIFICE TEMPERATURE (F)	86.21	86.03	86.35	0.08	0.08
FUEL FLOW (SCFH)	5376.16				
CALCULATED FUEL CONSUMPTION (BSFC)	7579.29				
FUEL HEATING VALUE (Btu)	1039.60	1039.60	1039.60	0.00	0.00
AIR FUEL RATIO	28.89	28.89	28.89	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	9.43	9.26	9.58	0.08	0.83
INTERCOOLER AIR TEMP IN (F)	299.49	298.99	300.18	0.31	0.10
INTERCOOLER AIR TEMP OUT (F)	143.54	142.83	144.02	0.33	0.23
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	68.73	68.49	68.99	0.11	0.16
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	57.83	57.20	58.49	0.31	0.53
INTERCOOLER WATER TEMP IN (F)	131.91	131.33	132.52	0.33	0.25
INTERCOOLER WATER TEMP OUT (F)	144.27	143.63	144.82	0.34	0.24
INTERCOOLER SUPPLY PRESSURE (psi)	2.84	2.82	2.88	0.01	0.47
PRE CATALYST TEMPERATURE (F)	728.21	727.57	728.76	0.28	0.04
POST CATALYST TEMPERATURE (F)	732.58	732.13	732.92	0.22	0.03
CATALYST DIFFERENTIAL PRESSURE ("H2O)	9.12	9.02	9.26	0.05	0.56
B.S. CO (g/bhp-hr): Pre-Catalyst	2.42	2.37	2.48	0.03	1.24
B.S. CO (g/bhp-hr): Post-Catalyst	0.16	0.15	0.16	0.00	2.39
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 16 QC - 736BHP 1200RPM 10BTDC (Cyinder 6-14BDC)

Data Point Number: Run 16 QC **Date:** 08/05/99 **Time:** 19:35:49

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.70	0.68	0.71	0.01	1.16
B.S. NOx (g/bhp-hr): Post-Catalyst	0.74	0.72	0.76	0.01	1.32
B.S. THC (g/bhp-hr): Pre-Catalyst	4.94	4.83	5.05	0.05	1.09
B.S. THC (g/bhp-hr): Post-Catalyst	5.00	4.86	5.12	0.05	1.10
B.S. Methane (g/bhp-hr): Pre-Catalyst	2.22	2.08	2.28	0.04	1.81
B.S. Methane (g/bhp-hr): Post-Catalyst	2.03	1.94	2.09	0.04	1.78
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.15	0.13	0.17	0.01	9.07
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.12	0.10	0.17	0.03	23.92
O2 (ppm): Pre-Catalyst	9.80	9.80	9.80	0.00	0.00
O2 (ppm): Post-Catalyst	9.80	9.80	9.80	0.00	0.00
CO (ppm): Pre-Catalyst	624.69	619.30	629.60	3.06	0.49
CO (ppm): Post-Catalyst	42.13	41.70	42.50	0.17	0.39
CO2 (ppm): Pre-Catalyst	6.23	6.23	6.29	0.01	0.16
CO2 (ppm): Post-Catalyst	6.37	6.36	6.38	0.00	0.07
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	58.72	58.20	59.00	0.22	0.38
NOx (ppm - Corrected): Post-Catalyst	63.33	62.30	64.30	0.49	0.77
NOx (ppm): Pre-Catalyst	109.89	108.90	110.50	0.44	0.40
NOx (ppm): Post-Catalyst	118.75	116.90	120.60	0.88	0.74
THC (ppm): Pre-Catalyst	1846.83	1835.10	1860.70	5.94	0.32
THC (ppm): Post-Catalyst	1897.99	1883.00	1917.20	7.66	0.40
Methane (ppm): Pre-Catalyst	1255.20	1189.90	1260.40	18.37	1.46
Methane (ppm): Post-Catalyst	1164.83	1124.70	1173.80	15.75	1.35
Non-Methane (ppm): Pre-Catalyst	170.94	156.70	187.80	15.48	9.06
Non-Methane (ppm): Post-Catalyst	144.17	116.60	186.70	34.17	23.70
DYNO WATER IN TEMPERATURE (F)	81.58	81.52	81.72	0.09	0.11
DYNO WATER OUT TEMPERATURE (F)	127.65	127.36	128.15	0.16	0.12
JACKET WATER IN TEMPERATURE (F)	174.17	173.79	174.38	0.15	0.09
JACKET WATER OUT TEMPERATURE (F)	180.11	179.00	182.00	0.65	0.36
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	87.13	86.88	87.48	0.29	0.34
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	92.66	92.44	92.83	0.11	0.12
LUBE OIL FLOW (GPM)	130.25	129.86	130.67	0.21	0.16
CO F-Factor: Pre-Catalyst	4.37	4.27	4.48	0.05	1.17
CO F-Factor: Post-Catalyst	0.29	0.29	0.30	0.00	1.13
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	1.26	1.23	1.29	0.01	1.13
NOx F-Factor: Post-Catalyst	1.36	1.33	1.40	0.02	1.37
THC F-Factor: Pre-Catalyst	8.76	8.58	8.96	0.10	1.10
THC F-Factor: Post-Catalyst	8.98	8.74	9.19	0.10	1.09
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3235.48	3233.08	3238.45	2.08	0.06

APPENDIX D

TEST POINTS

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 1 - 736BHP 1200RPM 10BTDC

Data Point Number: Run 1 **Date:** 08/04/99 **Time:** 18:12:00

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	64.00	64.00	64.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.08	12.08	12.08	0.00	0.00
AMBIENT HUMIDITY (%)	80.00	80.00	80.00	0.00	0.00
AIR MANIFOLD PRESSURE ("Hg)	5.02	4.75	5.29	0.09	1.83
AIR MANIFOLD RELATIVE HUMIDITY (%)	37.81	37.00	39.00	0.64	1.70
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01553	0.01462	0.01662		
AIR SUPPLY TEMPERATURE (F)	99.54	98.00	101.00	0.72	0.72
INTAKE AIR FLOW (scfm)	1713.65	1696.80	1731.20	5.99	0.35
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	704.49	703.76	705.14	0.32	0.05
CYLINDER 1 EXHAUST TEMPERATURE (F)	976.91	975.39	978.76	0.70	0.07
CYLINDER 2 EXHAUST TEMPERATURE (F)	977.79	976.38	979.95	0.59	0.06
CYLINDER 3 EXHAUST TEMPERATURE (F)	980.38	978.96	981.54	0.50	0.05
CYLINDER 4 EXHAUST TEMPERATURE (F)	954.29	952.77	956.54	0.68	0.07
CYLINDER 5 EXHAUST TEMPERATURE (F)	945.26	943.64	947.01	0.65	0.07
CYLINDER 6 EXHAUST TEMPERATURE (F)	929.75	927.77	931.93	0.97	0.10
CYLINDER EXHAUST AVERAGE TEMP (F)	960.73	959.55	961.99	0.44	0.05
EXHAUST HEADER TEMPERATURE (F)	704.49	703.76	705.14	0.32	0.05
PRE TURBO EXHAUST PRESSURE ("Hg)	36.51	36.18	36.99	0.14	0.38
PRE TURBO EXHAUST TEMPERATURE (F)	960.98	959.51	962.69	0.63	0.07
POST TURBO EXHAUST PRESSURE ("Hg)	4.82	4.76	4.91	0.03	0.57
POST TURBO EXHAUST TEMPERATURE (F)	797.89	796.61	799.79	0.66	0.08
TURBO OIL PRESSURE ("Hg)	46.91	46.00	47.61	0.28	0.60
ENGINE SPEED (rpm)	1196.57	1192.11	1201.50	1.57	0.13
ENGINE HORSEPOWER (bhp)	737.29	734.46	740.17	1.08	0.15
ENGINE OIL PRESSURE (psig)	52.13	51.32	52.93	0.35	0.67
ENGINE OIL TEMPERATURE IN (F)	164.56	164.06	164.86	0.14	0.08
ENGINE OIL TEMPERATURE OUT (F)	185.74	185.49	186.09	0.12	0.07
SPECIFIC GRAVITY	0.68	0.68	0.68	0.00	0.00
FUEL TEMPERATURE (F)	90.61	90.25	91.05	0.17	0.19
FUEL PRESSURE ("H2O above amp)	4.12	3.42	4.83	0.25	5.95
FUEL SUPPLY PRESSURE (psig)	46.73	46.60	46.88	0.05	0.11
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	14.41	13.74	15.16	0.30	2.10
ORIFICE STATIC PRESSURE (psig)	46.46	46.36	46.57	0.04	0.09
ORIFICE TEMPERATURE (F)	85.59	85.44	85.75	0.06	0.06
FUEL FLOW (SCFH)	5377.60				
CALCULATED FUEL CONSUMPTION (BSFC)	7468.11				
FUEL HEATING VALUE (Btu)	1023.90	1023.90	1023.90	0.00	0.00
AIR FUEL RATIO	29.00	29.00	29.00	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	9.26	9.00	9.51	0.10	1.07
INTERCOOLER AIR TEMP IN (F)	296.95	296.01	298.39	0.43	0.15
INTERCOOLER AIR TEMP OUT (F)	142.24	141.45	143.83	0.63	0.44
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	69.21	68.91	69.41	0.10	0.14
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	62.63	61.71	63.96	0.36	0.57
INTERCOOLER WATER TEMP IN (F)	131.58	130.93	132.91	0.53	0.40
INTERCOOLER WATER TEMP OUT (F)	142.94	142.24	144.42	0.52	0.37
INTERCOOLER SUPPLY PRESSURE (psi)	3.12	3.05	3.18	0.02	0.57
PRE CATALYST TEMPERATURE (F)	734.51	733.72	735.50	0.42	0.06
POST CATALYST TEMPERATURE (F)	739.56	738.68	740.46	0.42	0.06
CATALYST DIFFERENTIAL PRESSURE ("H2O)	9.12	8.98	9.28	0.05	0.58
B.S. CO (g/bhp-hr): Pre-Catalyst	2.38	2.31	2.48	0.03	1.25
B.S. CO (g/bhp-hr): Post-Catalyst	0.15	0.14	0.16	0.00	2.35
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 1 - 736BHP 1200RPM 10BTDC

Data Point Number: Run 1 **Date:** 08/04/99 **Time:** 18:12:00

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.70	0.68	0.73	0.01	1.45
B.S. NOx (g/bhp-hr): Post-Catalyst	0.73	0.71	0.76	0.01	1.55
B.S. THC (g/bhp-hr): Pre-Catalyst	4.65	4.50	4.82	0.06	1.28
B.S. THC (g/bhp-hr): Post-Catalyst	4.78	4.64	4.94	0.06	1.21
B.S. Methane (g/bhp-hr): Pre-Catalyst	2.27	2.21	2.35	0.03	1.17
B.S. Methane (g/bhp-hr): Post-Catalyst	1.94	1.88	2.06	0.03	1.73
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.11	0.10	0.12	0.01	4.86
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.09	0.08	0.09	0.00	4.23
O2 (ppm): Pre-Catalyst	9.80	9.70	9.80	0.00	0.05
O2 (ppm): Post-Catalyst	9.80	9.80	9.80	0.00	0.00
CO (ppm): Pre-Catalyst	620.26	616.10	626.40	2.27	0.37
CO (ppm): Post-Catalyst	41.32	39.80	42.50	0.68	1.64
CO2 (ppm): Pre-Catalyst	6.29	6.24	6.30	0.03	0.40
CO2 (ppm): Post-Catalyst	6.46	6.44	6.47	0.01	0.10
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	59.68	58.70	60.80	0.53	0.89
NOx (ppm - Corrected): Post-Catalyst	63.61	61.80	65.30	0.70	1.09
NOx (ppm): Pre-Catalyst	112.26	110.40	114.40	1.01	0.90
NOx (ppm): Post-Catalyst	119.34	115.90	122.50	1.34	1.12
THC (ppm): Pre-Catalyst	1785.07	1766.90	1810.70	8.22	0.46
THC (ppm): Post-Catalyst	1869.95	1848.90	1897.70	8.49	0.45
Methane (ppm): Pre-Catalyst	1266.40	1266.40	1266.40	0.00	0.00
Methane (ppm): Post-Catalyst	1100.07	1095.90	1141.90	13.23	1.20
Non-Methane (ppm): Pre-Catalyst	148.47	135.50	156.50	5.07	3.41
Non-Methane (ppm): Post-Catalyst	117.90	111.00	122.40	3.73	3.17
DYNO WATER IN TEMPERATURE (F)	80.61	80.33	80.93	0.11	0.14
DYNO WATER OUT TEMPERATURE (F)	127.10	126.76	127.56	0.16	0.12
JACKET WATER IN TEMPERATURE (F)	173.09	172.80	173.59	0.14	0.08
JACKET WATER OUT TEMPERATURE (F)	179.39	178.00	181.00	0.61	0.34
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	81.13	81.13	81.72	0.04	0.05
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	86.69	86.29	87.08	0.18	0.20
LUBE OIL FLOW (GPM)	129.19	128.57	129.70	0.21	0.16
CO F-Factor: Pre-Catalyst	4.26	4.15	4.41	0.05	1.19
CO F-Factor: Post-Catalyst	0.28	0.27	0.30	0.01	2.08
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	1.27	1.22	1.32	0.02	1.37
NOx F-Factor: Post-Catalyst	1.35	1.30	1.42	0.02	1.49
THC F-Factor: Pre-Catalyst	8.17	7.94	8.50	0.10	1.23
THC F-Factor: Post-Catalyst	8.58	8.31	8.87	0.11	1.24
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3236.04	3233.08	3238.45	2.11	0.07

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 2 - 515BHP 1200RPM 10BTDC

Data Point Number: Run 2 **Date:** 08/06/99 **Time:** 03:28:00

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	65.00	65.00	65.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	74.56	74.00	76.00	0.90	1.21
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.87	5.15	0.05	0.98
AIR MANIFOLD RELATIVE HUMIDITY (%)	30.43	30.00	31.00	0.50	1.63
AIR MANIFOLD HUMIDITY RATIO (lb_V/lb_A)	0.01260	0.01176	0.01362		
AIR SUPPLY TEMPERATURE (F)	99.91	98.00	102.00	0.77	0.77
INTAKE AIR FLOW (scfm)	1291.79	1275.56	1304.32	4.47	0.35
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	676.41	675.98	676.77	0.15	0.02
CYLINDER 1 EXHAUST TEMPERATURE (F)	960.47	957.93	962.89	1.00	0.10
CYLINDER 2 EXHAUST TEMPERATURE (F)	953.25	951.78	954.95	0.63	0.07
CYLINDER 3 EXHAUST TEMPERATURE (F)	954.72	952.77	956.74	0.85	0.09
CYLINDER 4 EXHAUST TEMPERATURE (F)	931.17	929.35	935.11	0.96	0.10
CYLINDER 5 EXHAUST TEMPERATURE (F)	913.20	911.30	915.27	0.81	0.09
CYLINDER 6 EXHAUST TEMPERATURE (F)	914.19	912.49	915.86	0.70	0.08
CYLINDER EXHAUST AVERAGE TEMP (F)	937.84	936.56	939.41	0.61	0.07
EXHAUST HEADER TEMPERATURE (F)	676.41	675.98	676.77	0.15	0.02
PRE TURBO EXHAUST PRESSURE ("Hg)	28.80	28.47	29.16	0.14	0.48
PRE TURBO EXHAUST TEMPERATURE (F)	926.74	925.39	928.96	0.54	0.06
POST TURBO EXHAUST PRESSURE ("Hg)	4.99	4.89	5.15	0.05	0.94
POST TURBO EXHAUST TEMPERATURE (F)	750.38	749.39	751.77	0.51	0.07
TURBO OIL PRESSURE ("Hg)	47.36	46.56	48.09	0.29	0.60
ENGINE SPEED (rpm)	1197.04	1193.99	1201.50	1.69	0.14
ENGINE HORSEPOWER (bhp)	515.76	514.14	518.19	0.75	0.15
ENGINE OIL PRESSURE (psig)	52.60	51.96	53.33	0.35	0.67
ENGINE OIL TEMPERATURE IN (F)	163.32	162.68	163.67	0.20	0.12
ENGINE OIL TEMPERATURE OUT (F)	183.18	182.72	183.51	0.15	0.08
SPECIFIC GRAVITY	0.69	0.69	0.69	0.00	0.00
FUEL TEMPERATURE (F)	91.70	91.05	92.04	0.29	0.32
FUEL PRESSURE ("H2O above amp)	6.60	6.15	7.12	0.17	2.59
FUEL SUPPLY PRESSURE (psig)	47.17	47.09	47.27	0.05	0.10
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	8.42	8.04	8.81	0.15	1.81
ORIFICE STATIC PRESSURE (psig)	46.64	46.60	46.68	0.02	0.03
ORIFICE TEMPERATURE (F)	87.86	87.47	88.14	0.18	0.18
FUEL FLOW (SCFH)	4083.22				
CALCULATED FUEL CONSUMPTION (BSFC)	8230.47				
FUEL HEATING VALUE (Btu)	1039.60	1039.60	1039.60	0.00	0.00
AIR FUEL RATIO	28.89	28.89	28.89	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	5.86	5.60	6.12	0.08	1.31
INTERCOOLER AIR TEMP IN (F)	280.87	280.14	281.53	0.28	0.10
INTERCOOLER AIR TEMP OUT (F)	137.14	136.09	138.87	0.77	0.56
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	66.06	65.91	66.24	0.06	0.09
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	55.49	54.46	56.39	0.29	0.53
INTERCOOLER WATER TEMP IN (F)	127.55	126.56	128.95	0.86	0.68
INTERCOOLER WATER TEMP OUT (F)	137.09	136.09	138.87	0.85	0.62
INTERCOOLER SUPPLY PRESSURE (psi)	2.72	2.66	2.78	0.02	0.61
PRE CATALYST TEMPERATURE (F)	705.51	704.75	706.33	0.29	0.04
POST CATALYST TEMPERATURE (F)	709.99	709.51	710.90	0.20	0.03
CATALYST DIFFERENTIAL PRESSURE ("H2O)	5.57	5.48	5.74	0.05	0.88
B.S. CO (g/bhp-hr): Pre-Catalyst	2.48	2.40	2.55	0.02	1.00
B.S. CO (g/bhp-hr): Post-Catalyst	0.11	0.10	0.11	0.00	4.46
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 2 - 515BHP 1200RPM 10BTDC

Data Point Number: Run 2 **Date:** 08/06/99 **Time:** 03:28:00

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.52	0.50	0.55	0.01	2.09
B.S. NOx (g/bhp-hr): Post-Catalyst	0.55	0.53	0.59	0.01	2.10
B.S. THC (g/bhp-hr): Pre-Catalyst	6.15	5.93	6.32	0.06	0.98
B.S. THC (g/bhp-hr): Post-Catalyst	6.14	5.93	6.34	0.08	1.24
B.S. Methane (g/bhp-hr): Pre-Catalyst	2.79	2.61	2.91	0.08	2.87
B.S. Methane (g/bhp-hr): Post-Catalyst	2.48	2.39	2.61	0.05	1.90
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.15	0.14	0.18	0.01	7.14
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.12	0.11	0.13	0.00	3.00
O2 (ppm): Pre-Catalyst	9.82	9.80	9.90	0.04	0.41
O2 (ppm): Post-Catalyst	9.83	9.80	9.90	0.05	0.46
CO (ppm): Pre-Catalyst	590.96	588.10	593.30	1.05	0.18
CO (ppm): Post-Catalyst	26.75	25.50	27.40	0.49	1.84
CO2 (ppm): Pre-Catalyst	6.23	6.23	6.29	0.02	0.24
CO2 (ppm): Post-Catalyst	6.42	6.40	6.45	0.01	0.17
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	40.78	39.50	42.70	0.73	1.80
NOx (ppm - Corrected): Post-Catalyst	44.14	42.60	46.70	0.86	1.95
NOx (ppm): Pre-Catalyst	76.28	74.00	80.00	1.48	1.95
NOx (ppm): Post-Catalyst	82.49	79.50	87.50	1.73	2.09
THC (ppm): Pre-Catalyst	2129.31	2100.60	2150.50	10.36	0.49
THC (ppm): Post-Catalyst	2172.24	2129.40	2195.30	12.81	0.59
Methane (ppm): Pre-Catalyst	1462.42	1404.50	1487.30	37.82	2.59
Methane (ppm): Post-Catalyst	1326.09	1312.00	1361.10	21.45	1.62
Non-Methane (ppm): Pre-Catalyst	160.11	147.00	181.20	11.48	7.17
Non-Methane (ppm): Post-Catalyst	131.12	126.10	135.70	2.72	2.08
DYNO WATER IN TEMPERATURE (F)	74.50	74.38	74.78	0.10	0.13
DYNO WATER OUT TEMPERATURE (F)	108.75	108.31	109.30	0.18	0.16
JACKET WATER IN TEMPERATURE (F)	175.33	174.38	175.97	0.49	0.28
JACKET WATER OUT TEMPERATURE (F)	179.05	177.00	181.00	0.81	0.45
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	81.48	80.93	82.12	0.28	0.35
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	86.56	85.89	87.08	0.31	0.35
LUBE OIL FLOW (GPM)	129.15	127.93	129.86	0.23	0.18
CO F-Factor: Pre-Catalyst	3.14	3.05	3.22	0.03	1.03
CO F-Factor: Post-Catalyst	0.14	0.13	0.15	0.00	2.34
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	0.67	0.64	0.71	0.01	1.85
NOx F-Factor: Post-Catalyst	0.72	0.69	0.77	0.01	1.97
THC F-Factor: Pre-Catalyst	7.67	7.42	7.87	0.08	1.01
THC F-Factor: Post-Catalyst	7.83	7.57	8.07	0.10	1.26
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	2263.13	2261.01	2266.38	1.31	0.06

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 3 - 736BHP 1200RPM 10BTDC

Data Point Number: Run 3 **Date:** 08/05/99 **Time:** 13:23:23

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	69.00	69.00	69.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	63.91	62.00	66.00	0.68	1.06
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.83	5.12	0.05	0.95
AIR MANIFOLD RELATIVE HUMIDITY (%)	37.32	31.00	44.00	4.09	10.97
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01544	0.01218	0.01894		
AIR SUPPLY TEMPERATURE (F)	99.74	98.00	101.00	0.68	0.68
INTAKE AIR FLOW (scfm)	1020.45	1008.84	1031.96	3.99	0.39
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	640.38	639.27	641.45	0.59	0.09
CYLINDER 1 EXHAUST TEMPERATURE (F)	884.23	881.93	886.50	1.05	0.12
CYLINDER 2 EXHAUST TEMPERATURE (F)	880.51	878.56	882.53	1.09	0.12
CYLINDER 3 EXHAUST TEMPERATURE (F)	877.49	875.19	879.75	1.05	0.12
CYLINDER 4 EXHAUST TEMPERATURE (F)	861.64	859.51	864.27	1.07	0.12
CYLINDER 5 EXHAUST TEMPERATURE (F)	850.83	848.40	852.96	1.04	0.12
CYLINDER 6 EXHAUST TEMPERATURE (F)	843.41	841.46	845.42	0.90	0.11
CYLINDER EXHAUST AVERAGE TEMP (F)	866.35	864.90	868.14	0.95	0.11
EXHAUST HEADER TEMPERATURE (F)	640.38	639.27	641.45	0.59	0.09
PRE TURBO EXHAUST PRESSURE ("Hg)	21.26	20.86	21.67	0.13	0.59
PRE TURBO EXHAUST TEMPERATURE (F)	860.64	858.32	862.88	1.10	0.13
POST TURBO EXHAUST PRESSURE ("Hg)	4.98	4.85	5.11	0.04	0.78
POST TURBO EXHAUST TEMPERATURE (F)	725.65	723.60	727.37	0.92	0.13
TURBO OIL PRESSURE ("Hg)	45.32	44.47	45.92	0.28	0.61
ENGINE SPEED (rpm)	1001.59	997.37	1007.14	1.48	0.15
ENGINE HORSEPOWER (bhp)	431.67	430.04	433.64	0.70	0.16
ENGINE OIL PRESSURE (psig)	50.49	49.54	51.24	0.29	0.57
ENGINE OIL TEMPERATURE IN (F)	162.76	162.48	163.27	0.16	0.10
ENGINE OIL TEMPERATURE OUT (F)	180.01	179.54	180.53	0.17	0.09
SPECIFIC GRAVITY	0.69	0.69	0.69	0.00	0.00
FUEL TEMPERATURE (F)	90.05	89.66	90.45	0.17	0.19
FUEL PRESSURE ("H2O above amp)	6.88	6.39	7.44	0.19	2.79
FUEL SUPPLY PRESSURE (psig)	47.45	47.39	47.50	0.03	0.05
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	5.13	4.90	5.42	0.11	2.09
ORIFICE STATIC PRESSURE (psig)	46.85	46.82	46.89	0.01	0.03
ORIFICE TEMPERATURE (F)	84.74	84.55	84.97	0.13	0.13
FUEL FLOW (SCFH)	3204.69				
CALCULATED FUEL CONSUMPTION (BSFC)	7718.01				
FUEL HEATING VALUE (Btu)	1039.60	1039.60	1039.60	0.00	0.00
AIR FUEL RATIO	28.20	28.20	28.20	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	4.79	4.64	4.98	0.06	1.20
INTERCOOLER AIR TEMP IN (F)	232.33	231.53	232.92	0.31	0.14
INTERCOOLER AIR TEMP OUT (F)	135.22	134.30	136.09	0.39	0.28
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	54.27	53.91	54.49	0.12	0.22
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	58.55	56.55	59.77	0.58	0.99
INTERCOOLER WATER TEMP IN (F)	130.31	128.95	131.72	0.59	0.45
INTERCOOLER WATER TEMP OUT (F)	135.70	134.70	136.68	0.38	0.28
INTERCOOLER SUPPLY PRESSURE (psi)	2.83	2.72	2.90	0.03	1.03
PRE CATALYST TEMPERATURE (F)	677.04	675.78	677.96	0.49	0.07
POST CATALYST TEMPERATURE (F)	679.03	677.76	680.34	0.67	0.10
CATALYST DIFFERENTIAL PRESSURE ("H2O)	3.88	3.78	3.97	0.03	0.81
B.S. CO (g/bhp-hr): Pre-Catalyst	2.21	2.14	2.28	0.02	1.12
B.S. CO (g/bhp-hr): Post-Catalyst	0.08	0.07	0.08	0.00	0.63
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 3 - 736BHP 1200RPM 10BTDC

Data Point Number: Run 3 **Date:** 08/05/99 **Time:** 13:23:23

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.46	0.42	0.50	0.02	4.48
B.S. NOx (g/bhp-hr): Post-Catalyst	0.52	0.47	0.56	0.02	4.32
B.S. THC (g/bhp-hr): Pre-Catalyst	6.44	6.20	6.71	0.08	1.32
B.S. THC (g/bhp-hr): Post-Catalyst	6.55	6.29	6.81	0.09	1.39
B.S. Methane (g/bhp-hr): Pre-Catalyst	2.91	2.82	3.13	0.06	1.95
B.S. Methane (g/bhp-hr): Post-Catalyst	2.45	2.35	2.58	0.05	1.91
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.16	0.15	0.17	0.01	3.69
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.13	0.12	0.13	0.00	3.51
O2 (ppm): Pre-Catalyst	9.81	9.80	9.90	0.02	0.23
O2 (ppm): Post-Catalyst	9.81	9.80	9.90	0.02	0.23
CO (ppm): Pre-Catalyst	573.32	569.20	579.30	2.76	0.48
CO (ppm): Post-Catalyst	21.89	20.80	22.50	0.43	1.99
CO2 (ppm): Pre-Catalyst	6.37	6.35	6.41	0.03	0.45
CO2 (ppm): Post-Catalyst	6.40	6.37	6.43	0.02	0.28
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Post-Catalyst	43.58	40.20	46.80	1.82	4.17
NOx (ppm): Pre-Catalyst	72.83	68.00	77.60	2.90	3.98
NOx (ppm): Post-Catalyst	81.67	76.10	87.50	3.20	3.91
THC (ppm): Pre-Catalyst	2424.37	2383.10	2473.20	23.04	0.95
THC (ppm): Post-Catalyst	2458.73	2412.40	2517.20	26.90	1.09
Methane (ppm): Pre-Catalyst	1661.01	1648.30	1732.20	29.68	1.79
Methane (ppm): Post-Catalyst	1391.59	1373.30	1427.90	25.43	1.83
Non-Methane (ppm): Pre-Catalyst	183.78	178.70	193.50	5.49	2.99
Non-Methane (ppm): Post-Catalyst	147.29	141.60	151.00	4.01	2.72
DYNO WATER IN TEMPERATURE (F)	73.27	72.79	73.79	0.18	0.24
DYNO WATER OUT TEMPERATURE (F)	101.87	101.56	102.16	0.12	0.12
JACKET WATER IN TEMPERATURE (F)	176.45	175.97	176.96	0.19	0.11
JACKET WATER OUT TEMPERATURE (F)	178.83	178.00	181.00	0.67	0.38
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	82.71	82.71	82.71	0.00	0.00
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	86.93	86.68	87.28	0.15	0.18
LUBE OIL FLOW (GPM)	129.34	128.57	130.02	0.24	0.19
CO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
CO F-Factor: Post-Catalyst	0.09	0.09	0.10	0.00	2.18
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Post-Catalyst	0.56	0.52	0.61	0.02	4.21
THC F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
THC F-Factor: Post-Catalyst	6.95	6.67	7.23	0.10	1.43
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	2263.62	2261.01	2266.38	1.02	0.04

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 4 - 617BHP 1000RPM 10BTDC

Data Point Number: Run 4 **Date:** 08/06/99 **Time:** 05:36:00

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	62.09	61.00	63.00	1.00	1.61
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	78.00	78.00	78.00	0.00	0.00
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.83	5.16	0.06	1.25
AIR MANIFOLD RELATIVE HUMIDITY (%)	36.14	35.00	37.00	0.44	1.22
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01475	0.01336	0.01582		
AIR SUPPLY TEMPERATURE (F)	99.33	97.00	101.00	0.71	0.72
INTAKE AIR FLOW (scfm)	1377.07	1364.10	1391.73	4.44	0.32
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	656.93	656.53	657.72	0.20	0.03
CYLINDER 1 EXHAUST TEMPERATURE (F)	908.34	906.34	917.05	1.20	0.13
CYLINDER 2 EXHAUST TEMPERATURE (F)	910.31	907.93	916.06	1.09	0.12
CYLINDER 3 EXHAUST TEMPERATURE (F)	912.96	911.30	915.66	0.64	0.07
CYLINDER 4 EXHAUST TEMPERATURE (F)	893.00	890.86	896.22	0.92	0.10
CYLINDER 5 EXHAUST TEMPERATURE (F)	886.83	885.31	890.46	0.68	0.08
CYLINDER 6 EXHAUST TEMPERATURE (F)	873.36	871.42	876.18	0.73	0.08
CYLINDER EXHAUST AVERAGE TEMP (F)	897.46	896.32	900.05	0.55	0.06
EXHAUST HEADER TEMPERATURE (F)	656.93	656.53	657.72	0.20	0.03
PRE TURBO EXHAUST PRESSURE ("Hg)	30.55	30.29	30.90	0.11	0.37
PRE TURBO EXHAUST TEMPERATURE (F)	905.05	903.76	907.33	0.57	0.06
POST TURBO EXHAUST PRESSURE ("Hg)	5.16	5.09	5.26	0.03	0.53
POST TURBO EXHAUST TEMPERATURE (F)	725.77	724.59	727.37	0.44	0.06
TURBO OIL PRESSURE ("Hg)	44.90	44.07	45.52	0.25	0.55
ENGINE SPEED (rpm)	1001.52	997.74	1006.77	1.41	0.14
ENGINE HORSEPOWER (bhp)	616.64	614.20	620.27	1.01	0.16
ENGINE OIL PRESSURE (psig)	50.11	49.38	50.83	0.26	0.51
ENGINE OIL TEMPERATURE IN (F)	162.39	161.88	162.68	0.16	0.10
ENGINE OIL TEMPERATURE OUT (F)	181.10	180.73	181.53	0.14	0.08
SPECIFIC GRAVITY	0.69	0.69	0.69	0.00	0.00
FUEL TEMPERATURE (F)	90.11	89.86	90.45	0.14	0.16
FUEL PRESSURE ("H2O above amp)	6.21	5.69	6.65	0.17	2.70
FUEL SUPPLY PRESSURE (psig)	47.16	47.07	47.27	0.04	0.08
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	9.61	9.32	10.01	0.11	1.15
ORIFICE STATIC PRESSURE (psig)	46.57	46.52	46.61	0.02	0.04
ORIFICE TEMPERATURE (F)	86.15	85.97	86.31	0.07	0.07
FUEL FLOW (SCFH)	4368.50				
CALCULATED FUEL CONSUMPTION (BSFC)	7364.88				
FUEL HEATING VALUE (Btu)	1039.60	1039.60	1039.60	0.00	0.00
AIR FUEL RATIO	29.00	29.00	29.00	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	6.59	6.35	6.98	0.10	1.49
INTERCOOLER AIR TEMP IN (F)	282.31	281.33	283.31	0.37	0.13
INTERCOOLER AIR TEMP OUT (F)	138.55	137.08	139.66	0.59	0.43
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	66.48	66.33	66.66	0.06	0.09
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	55.48	54.78	56.23	0.24	0.43
INTERCOOLER WATER TEMP IN (F)	128.54	127.16	129.14	0.48	0.37
INTERCOOLER WATER TEMP OUT (F)	138.69	137.28	139.86	0.62	0.45
INTERCOOLER SUPPLY PRESSURE (psi)	2.72	2.67	2.77	0.02	0.59
PRE CATALYST TEMPERATURE (F)	685.22	684.11	686.29	0.36	0.05
POST CATALYST TEMPERATURE (F)	688.42	687.68	689.07	0.24	0.04
CATALYST DIFFERENTIAL PRESSURE ("H2O)	6.04	5.95	6.17	0.04	0.62
B.S. CO (g/bhp-hr): Pre-Catalyst	2.65	2.58	2.70	0.02	0.73
B.S. CO (g/bhp-hr): Post-Catalyst	0.13	0.12	0.13	0.00	2.42
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 4 - 617BHP 1000RPM 10BTDC

Data Point Number: Run 4 **Date:** 08/06/99 **Time:** 05:36:00

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.79	0.76	0.82	0.01	1.70
B.S. NOx (g/bhp-hr): Post-Catalyst	0.81	0.76	0.86	0.02	1.91
B.S. THC (g/bhp-hr): Pre-Catalyst	6.69	6.53	6.86	0.06	0.91
B.S. THC (g/bhp-hr): Post-Catalyst	6.56	6.40	6.71	0.05	0.81
B.S. Methane (g/bhp-hr): Pre-Catalyst	3.06	2.98	3.24	0.06	1.95
B.S. Methane (g/bhp-hr): Post-Catalyst	2.72	2.66	2.77	0.02	0.62
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.13	0.12	0.15	0.01	5.74
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.11	0.10	0.12	0.00	2.35
O2 (ppm): Pre-Catalyst	9.80	9.80	9.80	0.00	0.00
O2 (ppm): Post-Catalyst	9.80	9.80	9.80	0.00	0.00
CO (ppm): Pre-Catalyst	590.78	587.40	596.20	2.02	0.34
CO (ppm): Post-Catalyst	30.19	29.00	30.70	0.45	1.48
CO2 (ppm): Pre-Catalyst	6.24	6.23	6.29	0.02	0.28
CO2 (ppm): Post-Catalyst	6.41	6.39	6.43	0.01	0.13
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	57.58	55.80	59.00	0.89	1.54
NOx (ppm - Corrected): Post-Catalyst	60.43	56.70	62.70	1.08	1.79
NOx (ppm): Pre-Catalyst	107.78	104.40	110.50	1.69	1.57
NOx (ppm): Post-Catalyst	113.17	106.00	117.40	2.09	1.84
THC (ppm): Pre-Catalyst	2166.34	2144.40	2193.10	11.80	0.54
THC (ppm): Post-Catalyst	2165.01	2144.00	2192.80	9.63	0.44
Methane (ppm): Pre-Catalyst	1498.36	1484.20	1560.80	26.37	1.76
Methane (ppm): Post-Catalyst	1358.65	1358.10	1361.10	1.16	0.09
Non-Methane (ppm): Pre-Catalyst	130.64	125.50	144.30	7.06	5.40
Non-Methane (ppm): Post-Catalyst	113.20	107.30	116.90	2.75	2.43
DYNO WATER IN TEMPERATURE (F)	76.15	75.97	76.37	0.12	0.16
DYNO WATER OUT TEMPERATURE (F)	116.09	115.85	116.45	0.12	0.10
JACKET WATER IN TEMPERATURE (F)	175.42	174.98	175.77	0.14	0.08
JACKET WATER OUT TEMPERATURE (F)	179.48	178.00	181.00	0.62	0.35
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	76.87	76.76	77.36	0.23	0.29
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	81.65	81.33	82.12	0.16	0.20
LUBE OIL FLOW (GPM)	128.27	127.60	129.22	0.23	0.18
CO F-Factor: Pre-Catalyst	3.36	3.30	3.42	0.02	0.64
CO F-Factor: Post-Catalyst	0.17	0.16	0.18	0.00	1.56
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	1.01	0.97	1.04	0.02	1.63
NOx F-Factor: Post-Catalyst	1.06	0.98	1.11	0.02	1.90
THC F-Factor: Pre-Catalyst	8.35	8.14	8.56	0.07	0.86
THC F-Factor: Post-Catalyst	8.34	8.13	8.53	0.07	0.80
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3233.74	3230.40	3238.45	1.73	0.05

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 5 - 736BHP 1200RPM 10BTDC

Data Point Number: Run 5 **Date:** 08/05/99 **Time:** 21:17:27

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	67.00	67.00	67.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	71.48	70.00	72.00	0.88	1.23
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.84	5.12	0.04	0.87
AIR MANIFOLD RELATIVE HUMIDITY (%)	36.54	33.00	39.00	2.28	6.25
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01508	0.01297	0.01725		
AIR SUPPLY TEMPERATURE (F)	99.69	98.00	102.00	0.73	0.73
INTAKE AIR FLOW (scfm)	1853.11	1832.14	1878.38	9.42	0.51
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	684.74	682.33	686.69	1.43	0.21
CYLINDER 1 EXHAUST TEMPERATURE (F)	969.77	964.87	974.79	2.06	0.21
CYLINDER 2 EXHAUST TEMPERATURE (F)	970.74	966.85	975.39	1.88	0.19
CYLINDER 3 EXHAUST TEMPERATURE (F)	967.54	964.87	970.43	1.27	0.13
CYLINDER 4 EXHAUST TEMPERATURE (F)	931.55	925.98	934.51	1.58	0.17
CYLINDER 5 EXHAUST TEMPERATURE (F)	911.69	904.55	917.45	4.32	0.47
CYLINDER 6 EXHAUST TEMPERATURE (F)	901.28	894.83	906.73	3.53	0.39
CYLINDER EXHAUST AVERAGE TEMP (F)	942.10	938.75	944.50	1.18	0.12
EXHAUST HEADER TEMPERATURE (F)	684.74	682.33	686.69	1.44	0.21
PRE TURBO EXHAUST PRESSURE ("Hg)	40.48	39.92	41.00	0.28	0.68
PRE TURBO EXHAUST TEMPERATURE (F)	936.68	932.33	940.27	2.34	0.25
POST TURBO EXHAUST PRESSURE ("Hg)	5.55	5.43	5.66	0.05	0.91
POST TURBO EXHAUST TEMPERATURE (F)	748.26	744.23	752.17	2.57	0.34
TURBO OIL PRESSURE ("Hg)	47.11	46.24	47.77	0.29	0.61
ENGINE SPEED (rpm)	1196.68	1189.85	1204.89	2.19	0.18
ENGINE HORSEPOWER (bhp)	737.14	732.92	741.72	1.40	0.19
ENGINE OIL PRESSURE (psig)	52.23	51.56	53.01	0.34	0.65
ENGINE OIL TEMPERATURE IN (F)	163.96	163.67	164.46	0.15	0.09
ENGINE OIL TEMPERATURE OUT (F)	185.06	184.50	185.49	0.21	0.11
SPECIFIC GRAVITY	0.69	0.69	0.69	0.00	0.00
FUEL TEMPERATURE (F)	91.21	90.85	91.64	0.16	0.17
FUEL PRESSURE ("H2O above amp)	0.68	-0.09	1.44	0.26	38.70
FUEL SUPPLY PRESSURE (psig)	46.79	46.67	46.92	0.04	0.09
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	15.44	14.57	16.27	0.35	2.29
ORIFICE STATIC PRESSURE (psig)	46.40	46.30	46.51	0.04	0.09
ORIFICE TEMPERATURE (F)	87.53	86.80	88.25	0.37	0.37
FUEL FLOW (SCFH)	5522.29				
CALCULATED FUEL CONSUMPTION (BSFC)	7788.17				
FUEL HEATING VALUE (Btu)	1039.60	1039.60	1039.60	0.00	0.00
AIR FUEL RATIO	30.39	30.20	30.70	0.24	0.80
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	10.73	10.34	11.01	0.11	1.04
INTERCOOLER AIR TEMP IN (F)	303.01	302.16	303.95	0.36	0.12
INTERCOOLER AIR TEMP OUT (F)	145.46	142.64	147.40	1.42	0.98
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	67.88	67.66	68.16	0.11	0.17
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	56.24	55.59	57.04	0.28	0.50
INTERCOOLER WATER TEMP IN (F)	130.34	126.76	133.11	2.06	1.58
INTERCOOLER WATER TEMP OUT (F)	144.17	140.65	146.60	1.83	1.27
INTERCOOLER SUPPLY PRESSURE (psi)	2.76	2.70	2.81	0.02	0.62
PRE CATALYST TEMPERATURE (F)	711.15	707.13	715.66	2.02	0.28
POST CATALYST TEMPERATURE (F)	717.83	715.07	720.03	1.63	0.23
CATALYST DIFFERENTIAL PRESSURE ("H2O)	10.15	9.95	10.33	0.08	0.80
B.S. CO (g/bhp-hr): Pre-Catalyst	3.09	2.85	3.37	0.13	4.23
B.S. CO (g/bhp-hr): Post-Catalyst	0.22	0.20	0.24	0.01	4.51
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 5 - 736BHP 1200RPM 10BTDC

Data Point Number: Run 5 **Date:** 08/05/99 **Time:** 21:17:27

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.49	0.46	0.52	0.01	2.70
B.S. NOx (g/bhp-hr): Post-Catalyst	0.53	0.49	0.58	0.02	2.87
B.S. THC (g/bhp-hr): Pre-Catalyst	7.07	6.46	7.73	0.35	4.91
B.S. THC (g/bhp-hr): Post-Catalyst	7.10	6.50	7.78	0.33	4.64
B.S. Methane (g/bhp-hr): Pre-Catalyst	3.14	2.88	3.54	0.17	5.40
B.S. Methane (g/bhp-hr): Post-Catalyst	2.80	2.67	3.02	0.09	3.15
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.18	0.16	0.21	0.01	5.44
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.15	0.14	0.16	0.01	4.35
O2 (ppm): Pre-Catalyst	10.51	10.40	10.60	0.03	0.33
O2 (ppm): Post-Catalyst	10.44	10.40	10.50	0.05	0.47
CO (ppm): Pre-Catalyst	740.59	699.80	780.80	26.47	3.57
CO (ppm): Post-Catalyst	53.70	50.70	57.00	1.90	3.54
CO2 (ppm): Pre-Catalyst	5.86	5.80	5.92	0.03	0.59
CO2 (ppm): Post-Catalyst	5.96	5.91	6.01	0.03	0.43
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	40.88	39.20	43.50	0.92	2.24
NOx (ppm - Corrected): Post-Catalyst	44.36	41.90	48.30	1.16	2.62
NOx (ppm): Pre-Catalyst	71.73	68.50	76.10	1.51	2.11
NOx (ppm): Post-Catalyst	78.16	73.10	84.80	1.95	2.50
THC (ppm): Pre-Catalyst	2456.84	2291.80	2642.50	106.33	4.33
THC (ppm): Post-Catalyst	2479.61	2307.50	2661.20	97.61	3.94
Methane (ppm): Pre-Catalyst	1652.63	1557.80	1800.00	81.15	4.91
Methane (ppm): Post-Catalyst	1483.29	1450.20	1548.50	35.74	2.41
Non-Methane (ppm): Pre-Catalyst	185.58	175.10	210.40	9.20	4.96
Non-Methane (ppm): Post-Catalyst	154.96	149.10	165.70	4.33	2.79
DYNO WATER IN TEMPERATURE (F)	81.04	80.73	81.52	0.14	0.18
DYNO WATER OUT TEMPERATURE (F)	126.87	126.56	127.36	0.12	0.10
JACKET WATER IN TEMPERATURE (F)	173.81	172.99	174.78	0.37	0.21
JACKET WATER OUT TEMPERATURE (F)	179.47	178.00	181.00	0.65	0.36
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	85.19	85.10	85.69	0.21	0.25
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	90.75	90.45	91.25	0.17	0.19
LUBE OIL FLOW (GPM)	129.90	129.05	130.83	0.27	0.21
CO F-Factor: Pre-Catalyst	5.68	5.25	6.19	0.25	4.44
CO F-Factor: Post-Catalyst	0.41	0.38	0.45	0.02	4.46
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	0.90	0.86	0.97	0.02	2.49
NOx F-Factor: Post-Catalyst	0.98	0.91	1.08	0.03	2.85
THC F-Factor: Pre-Catalyst	12.78	11.60	14.04	0.65	5.12
THC F-Factor: Post-Catalyst	12.84	11.74	14.06	0.62	4.81
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3234.95	3233.08	3238.45	1.96	0.06

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 6 - 736BHP 1200RPM 10BTDC

Data Point Number: Run 6 **Date:** 08/05/99 **Time:** 22:52:00

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	65.50	65.00	67.00	0.87	1.33
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	74.00	74.00	74.00	0.00	0.00
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.82	5.18	0.07	1.44
AIR MANIFOLD RELATIVE HUMIDITY (%)	37.62	33.00	40.00	2.08	5.53
AIR MANIFOLD HUMIDITY RATIO (lb_V/lb_A)	0.01551	0.01298	0.01713		
AIR SUPPLY TEMPERATURE (F)	99.62	98.00	101.00	0.70	0.70
INTAKE AIR FLOW (scfm)	1611.80	1596.43	1626.88	5.04	0.31
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	722.55	721.41	723.99	0.77	0.11
CYLINDER 1 EXHAUST TEMPERATURE (F)	1001.80	999.39	1003.96	0.80	0.08
CYLINDER 2 EXHAUST TEMPERATURE (F)	1003.35	1001.58	1005.74	0.79	0.08
CYLINDER 3 EXHAUST TEMPERATURE (F)	1006.78	1004.95	1008.52	0.76	0.08
CYLINDER 4 EXHAUST TEMPERATURE (F)	979.03	977.17	980.74	0.61	0.06
CYLINDER 5 EXHAUST TEMPERATURE (F)	970.16	968.05	972.01	0.82	0.08
CYLINDER 6 EXHAUST TEMPERATURE (F)	957.32	954.95	960.11	1.02	0.11
CYLINDER EXHAUST AVERAGE TEMP (F)	986.40	985.01	987.69	0.64	0.06
EXHAUST HEADER TEMPERATURE (F)	722.55	721.41	723.99	0.77	0.11
PRE TURBO EXHAUST PRESSURE ("Hg)	34.24	33.95	34.66	0.13	0.39
PRE TURBO EXHAUST TEMPERATURE (F)	987.75	985.51	989.47	0.98	0.10
POST TURBO EXHAUST PRESSURE ("Hg)	4.47	4.40	4.59	0.03	0.68
POST TURBO EXHAUST TEMPERATURE (F)	805.61	803.76	807.13	0.85	0.10
TURBO OIL PRESSURE ("Hg)	46.91	46.08	47.45	0.26	0.56
ENGINE SPEED (rpm)	1196.88	1193.61	1201.13	1.57	0.13
ENGINE HORSEPOWER (bhp)	737.15	733.93	740.17	1.05	0.14
ENGINE OIL PRESSURE (psig)	52.15	51.48	52.93	0.34	0.66
ENGINE OIL TEMPERATURE IN (F)	164.84	164.46	165.26	0.15	0.09
ENGINE OIL TEMPERATURE OUT (F)	186.06	185.69	186.49	0.17	0.09
SPECIFIC GRAVITY	0.69	0.69	0.69	0.00	0.00
FUEL TEMPERATURE (F)	91.42	91.05	91.84	0.14	0.16
FUEL PRESSURE ("H2O above amp)	8.53	7.97	9.08	0.21	2.48
FUEL SUPPLY PRESSURE (psig)	46.87	46.75	46.99	0.05	0.10
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	14.44	13.68	15.29	0.30	2.10
ORIFICE STATIC PRESSURE (psig)	46.41	46.29	46.51	0.04	0.09
ORIFICE TEMPERATURE (F)	88.11	87.90	88.23	0.06	0.06
FUEL FLOW (SCFH)	5336.84				
CALCULATED FUEL CONSUMPTION (BSFC)	7526.58				
FUEL HEATING VALUE (Btu)	1039.60	1039.60	1039.60	0.00	0.00
AIR FUEL RATIO	27.65	27.20	27.70	0.15	0.55
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	8.39	8.02	8.68	0.09	1.13
INTERCOOLER AIR TEMP IN (F)	297.35	296.61	298.39	0.35	0.12
INTERCOOLER AIR TEMP OUT (F)	139.51	138.87	140.06	0.27	0.19
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	69.41	69.24	69.58	0.07	0.11
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	56.33	55.59	56.87	0.25	0.45
INTERCOOLER WATER TEMP IN (F)	128.16	127.36	128.95	0.32	0.25
INTERCOOLER WATER TEMP OUT (F)	140.32	139.66	141.05	0.27	0.19
INTERCOOLER SUPPLY PRESSURE (psi)	2.76	2.70	2.81	0.02	0.62
PRE CATALYST TEMPERATURE (F)	758.86	755.94	773.40	2.51	0.33
POST CATALYST TEMPERATURE (F)	760.19	758.92	761.49	0.73	0.10
CATALYST DIFFERENTIAL PRESSURE ("H2O)	8.50	8.38	8.68	0.05	0.60
B.S. CO (g/bhp-hr): Pre-Catalyst	2.43	2.36	2.50	0.03	1.18
B.S. CO (g/bhp-hr): Post-Catalyst	0.14	0.13	0.14	0.00	2.68
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 6 - 736BHP 1200RPM 10BTDC

Data Point Number: Run 6 **Date:** 08/05/99 **Time:** 22:52:00

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	1.22	1.17	1.31	0.03	2.21
B.S. NOx (g/bhp-hr): Post-Catalyst	1.25	1.19	1.35	0.03	2.46
B.S. THC (g/bhp-hr): Pre-Catalyst	4.01	3.87	4.15	0.05	1.36
B.S. THC (g/bhp-hr): Post-Catalyst	3.92	3.80	4.06	0.05	1.30
B.S. Methane (g/bhp-hr): Pre-Catalyst	1.83	1.76	1.99	0.05	2.83
B.S. Methane (g/bhp-hr): Post-Catalyst	1.60	1.55	1.65	0.02	1.15
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.09	0.09	0.11	0.01	6.25
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.07	0.07	0.08	0.00	2.71
O2 (ppm): Pre-Catalyst	9.10	9.00	9.20	0.03	0.34
O2 (ppm): Post-Catalyst	9.01	9.00	9.10	0.03	0.38
CO (ppm): Pre-Catalyst	669.78	663.70	677.00	2.41	0.36
CO (ppm): Post-Catalyst	39.54	39.10	40.10	0.15	0.38
CO2 (ppm): Pre-Catalyst	6.65	6.59	6.71	0.01	0.14
CO2 (ppm): Post-Catalyst	6.83	6.80	6.86	0.01	0.20
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	103.01	99.90	108.70	1.98	1.93
NOx (ppm - Corrected): Post-Catalyst	106.81	103.10	113.50	2.32	2.17
NOx (ppm): Pre-Catalyst	205.32	199.10	215.60	3.88	1.89
NOx (ppm): Post-Catalyst	214.15	206.90	227.30	4.47	2.09
THC (ppm): Pre-Catalyst	1604.71	1576.90	1625.60	12.59	0.78
THC (ppm): Post-Catalyst	1593.83	1565.90	1614.70	11.87	0.74
Methane (ppm): Pre-Catalyst	1109.55	1094.90	1180.70	28.79	2.59
Methane (ppm): Post-Catalyst	983.53	983.40	986.50	0.63	0.06
Non-Methane (ppm): Pre-Catalyst	117.02	109.10	130.30	5.51	4.71
Non-Methane (ppm): Post-Catalyst	91.10	86.30	95.90	2.49	2.73
DYNO WATER IN TEMPERATURE (F)	80.73	80.53	81.13	0.13	0.16
DYNO WATER OUT TEMPERATURE (F)	126.61	126.17	127.16	0.13	0.10
JACKET WATER IN TEMPERATURE (F)	174.81	174.38	175.18	0.16	0.09
JACKET WATER OUT TEMPERATURE (F)	180.27	178.00	182.00	0.68	0.38
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	84.25	83.90	84.50	0.29	0.35
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	89.82	89.46	90.06	0.17	0.19
LUBE OIL FLOW (GPM)	129.68	129.05	130.18	0.22	0.17
CO F-Factor: Pre-Catalyst	4.37	4.26	4.50	0.05	1.16
CO F-Factor: Post-Catalyst	0.26	0.25	0.27	0.00	1.23
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	2.20	2.11	2.36	0.05	2.20
NOx F-Factor: Post-Catalyst	2.28	2.18	2.46	0.06	2.41
THC F-Factor: Pre-Catalyst	7.10	6.87	7.34	0.09	1.33
THC F-Factor: Post-Catalyst	7.01	6.79	7.26	0.09	1.29
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3234.42	3230.40	3238.45	1.77	0.05

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 7 - 515BHP 1200RPM 10BTDC

Data Point Number: Run 7 **Date:** 08/06/99 **Time:** 02:10:00

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	65.00	65.00	65.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	74.00	74.00	74.00	0.00	0.00
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.83	5.11	0.04	0.87
AIR MANIFOLD RELATIVE HUMIDITY (%)	31.00	31.00	31.00	0.00	0.00
AIR MANIFOLD HUMIDITY RATIO (lb_V/lb_A)	0.01283	0.01218	0.01364		
AIR SUPPLY TEMPERATURE (F)	99.89	98.00	102.00	0.74	0.74
INTAKE AIR FLOW (scfm)	1212.41	1200.56	1225.94	4.01	0.33
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	694.41	693.83	695.03	0.28	0.04
CYLINDER 1 EXHAUST TEMPERATURE (F)	987.26	984.91	988.88	0.72	0.07
CYLINDER 2 EXHAUST TEMPERATURE (F)	979.36	976.97	981.14	0.85	0.09
CYLINDER 3 EXHAUST TEMPERATURE (F)	980.42	978.36	982.53	0.71	0.07
CYLINDER 4 EXHAUST TEMPERATURE (F)	956.07	953.76	957.73	0.79	0.08
CYLINDER 5 EXHAUST TEMPERATURE (F)	937.32	935.31	939.08	0.79	0.08
CYLINDER 6 EXHAUST TEMPERATURE (F)	941.55	938.68	944.24	1.16	0.12
CYLINDER EXHAUST AVERAGE TEMP (F)	963.67	961.80	964.94	0.68	0.07
EXHAUST HEADER TEMPERATURE (F)	694.41	693.83	695.03	0.28	0.04
PRE TURBO EXHAUST PRESSURE ("Hg)	27.29	26.90	27.82	0.18	0.66
PRE TURBO EXHAUST TEMPERATURE (F)	950.34	948.40	952.17	0.79	0.08
POST TURBO EXHAUST PRESSURE ("Hg)	4.94	4.82	5.09	0.05	1.05
POST TURBO EXHAUST TEMPERATURE (F)	776.46	774.79	777.96	0.68	0.09
TURBO OIL PRESSURE ("Hg)	47.33	46.56	48.01	0.27	0.57
ENGINE SPEED (rpm)	1196.90	1193.23	1202.63	1.84	0.15
ENGINE HORSEPOWER (bhp)	515.81	513.85	518.48	0.89	0.17
ENGINE OIL PRESSURE (psig)	52.52	51.88	53.41	0.35	0.66
ENGINE OIL TEMPERATURE IN (F)	163.78	163.47	164.06	0.13	0.08
ENGINE OIL TEMPERATURE OUT (F)	183.74	183.31	184.10	0.14	0.08
SPECIFIC GRAVITY	0.69	0.69	0.69	0.00	0.00
FUEL TEMPERATURE (F)	91.77	91.44	92.04	0.11	0.12
FUEL PRESSURE ("H2O above amp)	7.68	7.15	8.17	0.16	2.11
FUEL SUPPLY PRESSURE (psig)	47.14	47.09	47.22	0.03	0.06
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	8.24	7.87	8.76	0.14	1.75
ORIFICE STATIC PRESSURE (psig)	46.65	46.61	46.69	0.01	0.03
ORIFICE TEMPERATURE (F)	88.12	87.99	88.23	0.04	0.04
FUEL FLOW (SCFH)	4039.63				
CALCULATED FUEL CONSUMPTION (BSFC)	8141.74				
FUEL HEATING VALUE (Btu)	1039.60	1039.60	1039.60	0.00	0.00
AIR FUEL RATIO	27.70	27.70	27.70	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	5.38	5.17	5.86	0.11	2.03
INTERCOOLER AIR TEMP IN (F)	278.70	278.15	279.15	0.24	0.09
INTERCOOLER AIR TEMP OUT (F)	138.40	136.68	139.06	0.66	0.48
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	65.46	65.16	65.91	0.13	0.20
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	55.67	54.62	56.39	0.30	0.53
INTERCOOLER WATER TEMP IN (F)	129.00	127.36	130.14	0.57	0.44
INTERCOOLER WATER TEMP OUT (F)	138.24	136.09	139.06	0.70	0.50
INTERCOOLER SUPPLY PRESSURE (psi)	2.72	2.66	2.77	0.01	0.54
PRE CATALYST TEMPERATURE (F)	728.39	727.17	740.26	1.19	0.16
POST CATALYST TEMPERATURE (F)	731.12	730.34	732.13	0.35	0.05
CATALYST DIFFERENTIAL PRESSURE ("H2O)	5.13	5.03	5.26	0.05	0.92
B.S. CO (g/bhp-hr): Pre-Catalyst	2.50	2.44	2.58	0.03	1.00
B.S. CO (g/bhp-hr): Post-Catalyst	0.10	0.09	0.10	0.00	1.65
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 7 - 515BHP 1200RPM 10BTDC

Data Point Number: Run 7 **Date:** 08/06/99 **Time:** 02:10:00

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.93	0.89	0.97	0.01	1.50
B.S. NOx (g/bhp-hr): Post-Catalyst	0.98	0.93	1.01	0.01	1.52
B.S. THC (g/bhp-hr): Pre-Catalyst	4.90	4.78	5.07	0.05	1.02
B.S. THC (g/bhp-hr): Post-Catalyst	4.91	4.79	5.08	0.05	1.03
B.S. Methane (g/bhp-hr): Pre-Catalyst	2.24	2.17	2.41	0.06	2.62
B.S. Methane (g/bhp-hr): Post-Catalyst	1.98	1.93	2.06	0.02	0.97
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.13	0.12	0.14	0.01	5.44
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.09	0.08	0.11	0.01	6.17
O2 (ppm): Pre-Catalyst	9.20	9.10	9.20	0.01	0.09
O2 (ppm): Post-Catalyst	9.09	9.00	9.10	0.03	0.33
CO (ppm): Pre-Catalyst	639.84	636.70	643.80	1.72	0.27
CO (ppm): Post-Catalyst	26.35	25.90	26.70	0.16	0.61
CO2 (ppm): Pre-Catalyst	6.65	6.65	6.65	0.00	0.00
CO2 (ppm): Post-Catalyst	6.79	6.78	6.80	0.01	0.08
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	73.62	71.70	75.20	0.78	1.06
NOx (ppm - Corrected): Post-Catalyst	77.10	74.60	79.40	0.86	1.11
NOx (ppm): Pre-Catalyst	145.99	142.20	149.10	1.54	1.06
NOx (ppm): Post-Catalyst	154.07	148.80	158.70	1.77	1.15
THC (ppm): Pre-Catalyst	1821.08	1809.50	1835.10	5.75	0.32
THC (ppm): Post-Catalyst	1843.10	1826.90	1861.10	5.69	0.31
Methane (ppm): Pre-Catalyst	1260.48	1245.10	1327.80	29.85	2.37
Methane (ppm): Post-Catalyst	1124.82	1124.70	1170.70	2.31	0.21
Non-Methane (ppm): Pre-Catalyst	145.36	133.40	158.00	7.85	5.40
Non-Methane (ppm): Post-Catalyst	110.19	100.60	119.10	6.29	5.71
DYNO WATER IN TEMPERATURE (F)	74.68	74.38	74.98	0.11	0.14
DYNO WATER OUT TEMPERATURE (F)	108.90	108.51	109.30	0.13	0.12
JACKET WATER IN TEMPERATURE (F)	175.33	174.58	175.97	0.34	0.19
JACKET WATER OUT TEMPERATURE (F)	179.19	178.00	181.00	0.89	0.50
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	82.12	82.12	82.12	0.00	0.00
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	87.73	87.48	88.07	0.12	0.14
LUBE OIL FLOW (GPM)	129.34	128.09	130.18	0.24	0.19
CO F-Factor: Pre-Catalyst	3.17	3.10	3.28	0.03	1.01
CO F-Factor: Post-Catalyst	0.13	0.13	0.13	0.00	1.15
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	1.19	1.14	1.23	0.02	1.44
NOx F-Factor: Post-Catalyst	1.25	1.19	1.29	0.02	1.46
THC F-Factor: Pre-Catalyst	6.12	5.99	6.28	0.06	0.97
THC F-Factor: Post-Catalyst	6.15	6.00	6.37	0.06	1.00
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	2263.30	2261.01	2266.38	1.28	0.06

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 8 - 616BHP 1000RPM 10BTDC

Data Point Number: Run 8 **Date:** 08/06/99 **Time:** 07:27:01

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	63.44	63.00	65.00	0.83	1.30
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	77.53	76.00	78.00	0.85	1.09
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.80	5.20	0.07	1.48
AIR MANIFOLD RELATIVE HUMIDITY (%)	37.03	36.00	38.00	0.44	1.19
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01519	0.01377	0.01624		
AIR SUPPLY TEMPERATURE (F)	99.46	97.00	101.00	0.71	0.71
INTAKE AIR FLOW (scfm)	1474.32	1457.14	1488.16	4.69	0.32
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	640.83	640.46	641.25	0.14	0.02
CYLINDER 1 EXHAUST TEMPERATURE (F)	886.55	884.91	888.08	0.57	0.06
CYLINDER 2 EXHAUST TEMPERATURE (F)	887.83	886.30	889.08	0.58	0.07
CYLINDER 3 EXHAUST TEMPERATURE (F)	888.83	887.49	890.27	0.50	0.06
CYLINDER 4 EXHAUST TEMPERATURE (F)	868.00	865.66	870.03	0.80	0.09
CYLINDER 5 EXHAUST TEMPERATURE (F)	859.99	858.32	861.30	0.61	0.07
CYLINDER 6 EXHAUST TEMPERATURE (F)	846.18	844.63	847.81	0.54	0.06
CYLINDER EXHAUST AVERAGE TEMP (F)	872.89	871.88	874.00	0.38	0.04
EXHAUST HEADER TEMPERATURE (F)	640.83	640.46	641.25	0.14	0.02
PRE TURBO EXHAUST PRESSURE ("Hg)	32.03	31.69	32.34	0.10	0.32
PRE TURBO EXHAUST TEMPERATURE (F)	880.63	879.55	881.73	0.42	0.05
POST TURBO EXHAUST PRESSURE ("Hg)	4.95	4.88	5.02	0.02	0.50
POST TURBO EXHAUST TEMPERATURE (F)	702.31	701.18	703.76	0.41	0.06
TURBO OIL PRESSURE ("Hg)	44.99	44.23	45.60	0.23	0.50
ENGINE SPEED (rpm)	1001.48	996.62	1006.02	1.60	0.16
ENGINE HORSEPOWER (bhp)	616.69	614.20	619.16	1.01	0.16
ENGINE OIL PRESSURE (psig)	50.17	49.46	50.83	0.26	0.52
ENGINE OIL TEMPERATURE IN (F)	161.98	161.49	162.28	0.18	0.11
ENGINE OIL TEMPERATURE OUT (F)	180.78	180.33	181.13	0.15	0.08
SPECIFIC GRAVITY	0.69	0.69	0.69	0.00	0.00
FUEL TEMPERATURE (F)	89.91	89.66	90.25	0.13	0.14
FUEL PRESSURE ("H2O above amp)	2.68	2.01	3.21	0.19	7.25
FUEL SUPPLY PRESSURE (psig)	47.26	47.20	47.33	0.03	0.06
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	9.81	9.57	10.08	0.10	1.01
ORIFICE STATIC PRESSURE (psig)	46.61	46.57	46.68	0.02	0.04
ORIFICE TEMPERATURE (F)	84.05	83.84	84.33	0.13	0.13
FUEL FLOW (SCFH)	4424.18				
CALCULATED FUEL CONSUMPTION (BSFC)	7458.20				
FUEL HEATING VALUE (Btu)	1039.60	1039.60	1039.60	0.00	0.00
AIR FUEL RATIO	30.50	30.50	30.50	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	7.54	7.26	7.80	0.09	1.21
INTERCOOLER AIR TEMP IN (F)	284.60	283.71	285.50	0.29	0.10
INTERCOOLER AIR TEMP OUT (F)	138.68	137.87	139.46	0.36	0.26
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	66.62	66.41	66.83	0.07	0.10
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	54.84	54.14	55.42	0.25	0.45
INTERCOOLER WATER TEMP IN (F)	128.74	127.95	129.14	0.27	0.21
INTERCOOLER WATER TEMP OUT (F)	139.61	138.87	140.25	0.38	0.27
INTERCOOLER SUPPLY PRESSURE (psi)	2.67	2.61	2.70	0.02	0.56
PRE CATALYST TEMPERATURE (F)	662.83	661.89	663.48	0.26	0.04
POST CATALYST TEMPERATURE (F)	668.52	667.84	669.23	0.20	0.03
CATALYST DIFFERENTIAL PRESSURE ("H2O)	6.65	6.51	6.75	0.04	0.57
B.S. CO (g/bhp-hr): Pre-Catalyst	2.58	2.52	2.65	0.02	0.85
B.S. CO (g/bhp-hr): Post-Catalyst	0.14	0.13	0.14	0.00	0.78
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 8 - 616BHP 1000RPM 10BTDC

Data Point Number: Run 8 **Date:** 08/06/99 **Time:** 07:27:01

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.40	0.39	0.41	0.00	0.84
B.S. NOx (g/bhp-hr): Post-Catalyst	0.42	0.41	0.44	0.01	1.23
B.S. THC (g/bhp-hr): Pre-Catalyst	6.96	6.81	7.19	0.06	0.93
B.S. THC (g/bhp-hr): Post-Catalyst	7.11	6.96	7.34	0.07	0.97
B.S. Methane (g/bhp-hr): Pre-Catalyst	3.23	3.08	3.36	0.08	2.41
B.S. Methane (g/bhp-hr): Post-Catalyst	4.05	0.08	10.35	3.04	75.12
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.16	0.14	0.16	0.01	4.16
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.16	0.14	0.16	0.01	4.16
O2 (ppm): Pre-Catalyst	10.50	10.50	10.50	0.00	0.00
O2 (ppm): Post-Catalyst	10.50	10.50	10.50	0.00	0.00
CO (ppm): Pre-Catalyst	641.35	635.50	648.80	3.61	0.56
CO (ppm): Post-Catalyst	35.85	35.30	36.40	0.20	0.56
CO2 (ppm): Pre-Catalyst	5.86	5.80	5.86	0.01	0.14
CO2 (ppm): Post-Catalyst	5.99	5.97	6.01	0.01	0.13
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	34.72	34.30	35.20	0.17	0.48
NOx (ppm - Corrected): Post-Catalyst	37.50	36.70	38.40	0.30	0.79
NOx (ppm): Pre-Catalyst	60.93	60.00	61.60	0.30	0.49
NOx (ppm): Post-Catalyst	65.73	64.20	67.30	0.55	0.84
THC (ppm): Pre-Catalyst	2513.13	2485.40	2564.50	16.30	0.65
THC (ppm): Post-Catalyst	2602.29	2566.00	2656.30	17.00	0.65
Methane (ppm): Pre-Catalyst	1766.67	1713.30	1800.00	41.46	2.35
Methane (ppm): Post-Catalyst	1452.07	46.80	1643.60	402.82	27.74
Non-Methane (ppm): Pre-Catalyst	171.13	159.40	177.90	6.85	4.00
Non-Methane (ppm): Post-Catalyst	171.13	159.40	177.90	6.85	4.00
DYNO WATER IN TEMPERATURE (F)	76.62	76.17	77.16	0.19	0.24
DYNO WATER OUT TEMPERATURE (F)	116.64	116.05	117.24	0.20	0.17
JACKET WATER IN TEMPERATURE (F)	175.23	174.78	175.97	0.27	0.16
JACKET WATER OUT TEMPERATURE (F)	178.81	178.00	181.00	0.72	0.40
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	78.70	77.95	79.14	0.47	0.60
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	83.26	82.52	84.10	0.44	0.53
LUBE OIL FLOW (GPM)	128.62	128.09	129.38	0.23	0.18
CO F-Factor: Pre-Catalyst	3.95	3.85	4.04	0.04	0.99
CO F-Factor: Post-Catalyst	0.22	0.22	0.23	0.00	0.82
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	0.62	0.60	0.63	0.00	0.73
NOx F-Factor: Post-Catalyst	0.66	0.64	0.68	0.01	0.92
THC F-Factor: Pre-Catalyst	10.48	10.21	10.79	0.11	1.04
THC F-Factor: Post-Catalyst	10.85	10.62	11.19	0.11	0.97
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3233.97	3230.40	3238.45	1.75	0.05

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 9 - 736BHP 1200RPM 10BTDC

Data Point Number: Run 9 **Date:** 08/04/99 **Time:** 15:52:00

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	64.00	64.00	64.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.08	12.08	12.08	0.00	0.00
AMBIENT HUMIDITY (%)	72.81	70.00	76.00	1.36	1.86
AIR MANIFOLD PRESSURE ("Hg)	5.02	4.77	5.27	0.09	1.73
AIR MANIFOLD RELATIVE HUMIDITY (%)	37.15	36.00	39.00	0.69	1.86
AIR MANIFOLD HUMIDITY RATIO (lb_V/lb_A)	0.01525	0.01377	0.01663		
AIR SUPPLY TEMPERATURE (F)	99.54	97.00	101.00	0.67	0.67
INTAKE AIR FLOW (scfm)	1702.68	1687.78	1718.23	5.56	0.33
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	703.97	703.16	704.95	0.49	0.07
CYLINDER 1 EXHAUST TEMPERATURE (F)	978.90	977.17	980.74	0.66	0.07
CYLINDER 2 EXHAUST TEMPERATURE (F)	978.45	976.97	979.75	0.58	0.06
CYLINDER 3 EXHAUST TEMPERATURE (F)	980.61	978.76	982.13	0.62	0.06
CYLINDER 4 EXHAUST TEMPERATURE (F)	955.43	953.96	957.53	0.64	0.07
CYLINDER 5 EXHAUST TEMPERATURE (F)	946.35	944.63	947.81	0.64	0.07
CYLINDER 6 EXHAUST TEMPERATURE (F)	932.34	930.15	933.92	0.77	0.08
CYLINDER EXHAUST AVERAGE TEMP (F)	962.01	960.77	962.95	0.40	0.04
EXHAUST HEADER TEMPERATURE (F)	703.97	703.16	704.95	0.49	0.07
PRE TURBO EXHAUST PRESSURE ("Hg)	36.23	35.92	36.66	0.14	0.38
PRE TURBO EXHAUST TEMPERATURE (F)	962.68	961.10	964.08	0.59	0.06
POST TURBO EXHAUST PRESSURE ("Hg)	4.76	4.68	4.84	0.03	0.62
POST TURBO EXHAUST TEMPERATURE (F)	798.64	797.21	800.38	0.58	0.07
TURBO OIL PRESSURE ("Hg)	47.02	46.16	47.69	0.28	0.59
ENGINE SPEED (rpm)	1196.63	1192.48	1202.26	1.61	0.13
ENGINE HORSEPOWER (bhp)	736.85	734.08	739.94	1.04	0.14
ENGINE OIL PRESSURE (psig)	52.17	51.48	52.93	0.35	0.66
ENGINE OIL TEMPERATURE IN (F)	164.14	163.67	164.66	0.16	0.10
ENGINE OIL TEMPERATURE OUT (F)	185.43	184.90	185.69	0.16	0.09
SPECIFIC GRAVITY	0.68	0.68	0.68	0.00	0.00
FUEL TEMPERATURE (F)	385.38	88.47	2649.02	581.05	150.77
FUEL PRESSURE ("H2O above amp)	5.25	4.57	5.82	0.22	4.23
FUEL SUPPLY PRESSURE (psig)	47.09	46.95	47.27	0.07	0.14
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	14.40	13.70	15.25	0.31	2.15
ORIFICE STATIC PRESSURE (psig)	46.52	46.41	46.63	0.05	0.10
ORIFICE TEMPERATURE (F)	83.52	83.18	83.73	0.13	0.13
FUEL FLOW (SCFH)	5389.02				
CALCULATED FUEL CONSUMPTION (BSFC)	7484.76				
FUEL HEATING VALUE (Btu)	1023.40	1023.40	1023.40	0.00	0.00
AIR FUEL RATIO	28.60	28.60	28.60	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	8.99	8.64	9.28	0.09	1.02
INTERCOOLER AIR TEMP IN (F)	298.18	296.61	301.57	0.79	0.27
INTERCOOLER AIR TEMP OUT (F)	131.60	130.93	132.12	0.25	0.19
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	69.30	68.99	69.58	0.09	0.13
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	64.83	63.80	65.74	0.33	0.50
INTERCOOLER WATER TEMP IN (F)	119.39	118.63	120.02	0.24	0.20
INTERCOOLER WATER TEMP OUT (F)	131.21	130.53	131.72	0.23	0.17
INTERCOOLER SUPPLY PRESSURE (psi)	3.23	3.18	3.29	0.02	0.55
PRE CATALYST TEMPERATURE (F)	735.01	733.91	738.08	0.61	0.08
POST CATALYST TEMPERATURE (F)	739.63	738.88	740.46	0.41	0.06
CATALYST DIFFERENTIAL PRESSURE ("H2O)	9.01	8.85	9.17	0.05	0.59
B.S. CO (g/bhp-hr): Pre-Catalyst	2.36	2.29	2.42	0.03	1.15
B.S. CO (g/bhp-hr): Post-Catalyst	0.15	0.14	0.15	0.00	2.68
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 9 - 736BHP 1200RPM 10BTDC

Data Point Number: Run 9 **Date:** 08/04/99 **Time:** 15:52:00

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.67	0.64	0.70	0.01	1.49
B.S. NOx (g/bhp-hr): Post-Catalyst	0.72	0.69	0.77	0.01	1.67
B.S. THC (g/bhp-hr): Pre-Catalyst	4.68	4.52	4.86	0.06	1.36
B.S. THC (g/bhp-hr): Post-Catalyst	4.75	4.59	4.93	0.06	1.29
B.S. Methane (g/bhp-hr): Pre-Catalyst	2.29	2.19	2.46	0.07	2.99
B.S. Methane (g/bhp-hr): Post-Catalyst	1.99	1.87	5.11	0.34	17.30
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.11	0.10	0.13	0.01	5.06
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.09	0.08	0.09	0.00	5.86
O2 (ppm): Pre-Catalyst	9.69	9.60	9.80	0.03	0.35
O2 (ppm): Post-Catalyst	9.70	9.70	9.70	0.00	0.00
CO (ppm): Pre-Catalyst	619.70	615.10	625.40	2.35	0.38
CO (ppm): Post-Catalyst	40.61	39.50	42.00	0.60	1.47
CO2 (ppm): Pre-Catalyst	6.35	6.30	6.36	0.02	0.27
CO2 (ppm): Post-Catalyst	6.52	6.49	6.54	0.01	0.18
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	56.72	55.40	57.80	0.59	1.03
NOx (ppm - Corrected): Post-Catalyst	62.29	60.40	64.30	0.77	1.23
NOx (ppm): Pre-Catalyst	107.35	104.80	109.40	1.12	1.04
NOx (ppm): Post-Catalyst	117.91	114.20	121.80	1.52	1.29
THC (ppm): Pre-Catalyst	1816.34	1791.30	1842.40	12.21	0.67
THC (ppm): Post-Catalyst	1870.44	1841.60	1892.80	10.03	0.54
Methane (ppm): Pre-Catalyst	1288.90	1266.40	1340.80	34.21	2.65
Methane (ppm): Post-Catalyst	1135.13	1095.90	2882.10	194.79	17.16
Non-Methane (ppm): Pre-Catalyst	147.16	138.30	159.40	7.71	5.24
Non-Methane (ppm): Post-Catalyst	115.48	111.00	122.40	3.49	3.03
DYNO WATER IN TEMPERATURE (F)	80.63	80.33	80.93	0.10	0.13
DYNO WATER OUT TEMPERATURE (F)	126.77	126.37	127.36	0.16	0.12
JACKET WATER IN TEMPERATURE (F)	172.77	171.80	173.39	0.38	0.22
JACKET WATER OUT TEMPERATURE (F)	178.99	178.00	181.00	0.73	0.41
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	82.77	82.32	82.91	0.25	0.31
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	88.15	87.67	88.67	0.20	0.23
LUBE OIL FLOW (GPM)	129.44	128.73	130.02	0.22	0.17
CO F-Factor: Pre-Catalyst	4.24	4.13	4.37	0.05	1.14
CO F-Factor: Post-Catalyst	0.28	0.27	0.29	0.01	1.91
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	1.21	1.17	1.26	0.02	1.44
NOx F-Factor: Post-Catalyst	1.33	1.27	1.41	0.02	1.61
THC F-Factor: Pre-Catalyst	8.29	7.99	8.56	0.11	1.37
THC F-Factor: Post-Catalyst	8.53	8.26	8.82	0.11	1.26
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3234.36	3230.40	3238.45	1.80	0.06

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 10 - 735BHP 1200RPM 10BTDC

Data Point Number: Run 10 **Date:** 08/06/99 **Time:** 11:36:00

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	78.13	77.00	79.00	0.99	1.27
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	43.86	40.00	48.00	1.32	3.00
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.75	5.28	0.08	1.58
AIR MANIFOLD RELATIVE HUMIDITY (%)	34.88	33.00	36.00	0.60	1.71
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01429	0.01301	0.01532		
AIR SUPPLY TEMPERATURE (F)	99.47	98.00	101.00	0.65	0.66
INTAKE AIR FLOW (scfm)	1699.32	1687.22	1716.54	5.60	0.33
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	705.03	704.35	705.94	0.34	0.05
CYLINDER 1 EXHAUST TEMPERATURE (F)	980.13	977.77	982.73	0.69	0.07
CYLINDER 2 EXHAUST TEMPERATURE (F)	980.60	977.77	982.73	0.80	0.08
CYLINDER 3 EXHAUST TEMPERATURE (F)	983.02	981.14	984.71	0.65	0.07
CYLINDER 4 EXHAUST TEMPERATURE (F)	956.99	954.75	959.12	0.66	0.07
CYLINDER 5 EXHAUST TEMPERATURE (F)	947.73	945.82	949.79	0.62	0.07
CYLINDER 6 EXHAUST TEMPERATURE (F)	932.66	930.54	934.71	0.84	0.09
CYLINDER EXHAUST AVERAGE TEMP (F)	963.52	961.96	965.07	0.49	0.05
EXHAUST HEADER TEMPERATURE (F)	705.03	704.35	705.94	0.34	0.05
PRE TURBO EXHAUST PRESSURE ("Hg)	36.50	36.23	36.92	0.13	0.35
PRE TURBO EXHAUST TEMPERATURE (F)	964.16	962.49	965.47	0.59	0.06
POST TURBO EXHAUST PRESSURE ("Hg)	4.89	4.81	4.97	0.03	0.53
POST TURBO EXHAUST TEMPERATURE (F)	780.38	778.56	781.73	0.52	0.07
TURBO OIL PRESSURE ("Hg)	46.76	46.00	47.45	0.29	0.61
ENGINE SPEED (rpm)	1196.91	1192.48	1201.13	1.48	0.12
ENGINE HORSEPOWER (bhp)	737.77	734.69	740.17	1.03	0.14
ENGINE OIL PRESSURE (psig)	51.97	51.15	52.77	0.35	0.68
ENGINE OIL TEMPERATURE IN (F)	166.10	165.85	166.45	0.13	0.08
ENGINE OIL TEMPERATURE OUT (F)	187.14	186.68	187.68	0.20	0.10
SPECIFIC GRAVITY	0.66	0.66	0.66	0.00	0.00
FUEL TEMPERATURE (F)	95.30	94.82	95.81	0.18	0.19
FUEL PRESSURE ("H2O above amp)	4.84	4.25	5.56	0.24	4.89
FUEL SUPPLY PRESSURE (psig)	46.43	46.30	46.56	0.04	0.09
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	14.62	14.05	15.52	0.28	1.92
ORIFICE STATIC PRESSURE (psig)	46.27	46.16	46.38	0.04	0.08
ORIFICE TEMPERATURE (F)	92.88	92.53	93.19	0.17	0.17
FUEL FLOW (SCFH)	5471.06				
CALCULATED FUEL CONSUMPTION (BSFC)	7315.59				
FUEL HEATING VALUE (Btu)	986.50	986.50	986.50	0.00	0.00
AIR FUEL RATIO	28.70	28.70	28.70	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	9.40	9.14	9.71	0.10	1.05
INTERCOOLER AIR TEMP IN (F)	298.86	298.00	299.98	0.32	0.11
INTERCOOLER AIR TEMP OUT (F)	152.42	151.37	154.94	0.82	0.54
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	68.82	68.58	69.08	0.09	0.13
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	54.13	53.33	54.94	0.26	0.49
INTERCOOLER WATER TEMP IN (F)	141.09	140.25	143.83	0.80	0.57
INTERCOOLER WATER TEMP OUT (F)	153.56	152.56	156.13	0.81	0.53
INTERCOOLER SUPPLY PRESSURE (psi)	2.64	2.60	2.69	0.01	0.56
PRE CATALYST TEMPERATURE (F)	736.58	735.11	737.68	0.44	0.06
POST CATALYST TEMPERATURE (F)	740.58	739.67	741.65	0.39	0.05
CATALYST DIFFERENTIAL PRESSURE ("H2O)	8.99	8.87	9.15	0.05	0.55
B.S. CO (g/bhp-hr): Pre-Catalyst	2.40	2.35	2.48	0.02	1.02
B.S. CO (g/bhp-hr): Post-Catalyst	0.15	0.15	0.16	0.00	2.99
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 10 - 735BHP 1200RPM 10BTDC

Data Point Number: Run 10 **Date:** 08/06/99 **Time:** 11:36:00

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.83	0.79	0.88	0.02	1.95
B.S. NOx (g/bhp-hr): Post-Catalyst	0.85	0.81	0.90	0.02	1.96
B.S. THC (g/bhp-hr): Pre-Catalyst	4.29	4.15	4.44	0.05	1.23
B.S. THC (g/bhp-hr): Post-Catalyst	4.43	4.29	4.60	0.05	1.21
B.S. Methane (g/bhp-hr): Pre-Catalyst	2.09	1.98	2.23	0.08	3.85
B.S. Methane (g/bhp-hr): Post-Catalyst	2.02	1.98	2.08	0.02	0.97
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.07	0.06	0.08	0.01	9.40
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.06	0.06	0.07	0.00	1.49
O2 (ppm): Pre-Catalyst	9.80	9.80	9.80	0.00	0.00
O2 (ppm): Post-Catalyst	9.73	9.70	9.80	0.04	0.45
CO (ppm): Pre-Catalyst	625.62	620.50	629.60	1.90	0.30
CO (ppm): Post-Catalyst	41.97	41.40	42.50	0.19	0.46
CO2 (ppm): Pre-Catalyst	6.35	6.29	6.35	0.01	0.08
CO2 (ppm): Post-Catalyst	6.50	6.47	6.52	0.01	0.13
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	70.06	67.90	73.50	1.14	1.62
NOx (ppm - Corrected): Post-Catalyst	72.77	70.00	76.70	1.18	1.62
NOx (ppm): Pre-Catalyst	131.74	127.70	138.20	2.19	1.66
NOx (ppm): Post-Catalyst	137.05	131.80	144.60	2.33	1.70
THC (ppm): Pre-Catalyst	1713.36	1679.20	1743.80	12.94	0.76
THC (ppm): Post-Catalyst	1797.47	1766.00	1831.80	11.84	0.66
Methane (ppm): Pre-Catalyst	1097.70	1062.00	1148.60	41.02	3.74
Methane (ppm): Post-Catalyst	1078.57	1075.50	1078.60	0.28	0.03
Non-Methane (ppm): Pre-Catalyst	125.44	116.20	144.30	9.57	7.63
Non-Methane (ppm): Post-Catalyst	111.49	104.80	116.90	3.99	3.58
DYNO WATER IN TEMPERATURE (F)	83.02	82.71	83.51	0.19	0.23
DYNO WATER OUT TEMPERATURE (F)	129.15	128.95	129.34	0.04	0.03
JACKET WATER IN TEMPERATURE (F)	173.86	173.39	174.18	0.17	0.10
JACKET WATER OUT TEMPERATURE (F)	180.46	179.00	182.00	0.61	0.34
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	96.16	95.41	97.20	0.41	0.43
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	101.70	100.97	102.56	0.39	0.39
LUBE OIL FLOW (GPM)	131.66	130.99	132.60	0.27	0.20
CO F-Factor: Pre-Catalyst	4.21	4.12	4.34	0.04	1.00
CO F-Factor: Post-Catalyst	0.28	0.28	0.29	0.00	1.07
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	1.46	1.40	1.55	0.03	1.86
NOx F-Factor: Post-Catalyst	1.52	1.44	1.61	0.03	1.86
THC F-Factor: Pre-Catalyst	7.39	7.14	7.69	0.09	1.28
THC F-Factor: Post-Catalyst	7.74	7.50	8.05	0.10	1.23
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3237.32	3233.08	3241.14	1.78	0.05

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 11 - 735BHP 1200RPM 10BTDC

Data Point Number: Run 11 **Date:** 08/06/99 **Time:** 13:16:59

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	74.91	73.00	75.00	0.41	0.54
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	55.34	50.00	58.00	1.86	3.37
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.73	5.23	0.08	1.68
AIR MANIFOLD RELATIVE HUMIDITY (%)	37.78	35.00	40.00	1.23	3.26
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01547	0.01341	0.01710		
AIR SUPPLY TEMPERATURE (F)	99.39	97.00	101.00	0.72	0.72
INTAKE AIR FLOW (scfm)	1717.89	1700.75	1737.97	7.36	0.43
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	701.16	699.99	702.56	0.76	0.11
CYLINDER 1 EXHAUST TEMPERATURE (F)	972.80	970.62	975.19	1.03	0.11
CYLINDER 2 EXHAUST TEMPERATURE (F)	975.01	972.81	977.57	0.99	0.10
CYLINDER 3 EXHAUST TEMPERATURE (F)	977.14	974.99	979.95	1.14	0.12
CYLINDER 4 EXHAUST TEMPERATURE (F)	951.79	949.20	953.56	0.88	0.09
CYLINDER 5 EXHAUST TEMPERATURE (F)	942.05	939.27	944.24	1.06	0.11
CYLINDER 6 EXHAUST TEMPERATURE (F)	928.06	925.78	931.14	1.13	0.12
CYLINDER EXHAUST AVERAGE TEMP (F)	957.81	956.27	959.61	0.92	0.10
EXHAUST HEADER TEMPERATURE (F)	701.16	699.99	702.56	0.76	0.11
PRE TURBO EXHAUST PRESSURE ("Hg)	36.90	36.44	37.49	0.18	0.49
PRE TURBO EXHAUST TEMPERATURE (F)	958.20	956.34	960.70	1.20	0.13
POST TURBO EXHAUST PRESSURE ("Hg)	4.93	4.83	5.04	0.03	0.67
POST TURBO EXHAUST TEMPERATURE (F)	774.92	773.20	777.17	1.04	0.13
TURBO OIL PRESSURE ("Hg)	47.08	46.32	47.77	0.29	0.61
ENGINE SPEED (rpm)	1196.85	1192.86	1201.13	1.51	0.13
ENGINE HORSEPOWER (bhp)	737.92	735.70	740.71	0.97	0.13
ENGINE OIL PRESSURE (psig)	52.30	51.64	53.01	0.34	0.65
ENGINE OIL TEMPERATURE IN (F)	164.39	163.87	164.66	0.21	0.13
ENGINE OIL TEMPERATURE OUT (F)	184.78	184.30	185.49	0.18	0.10
SPECIFIC GRAVITY	0.66	0.66	0.66	0.00	0.00
FUEL TEMPERATURE (F)	95.62	95.21	96.01	0.17	0.18
FUEL PRESSURE ("H2O above amp)	4.87	4.04	5.50	0.24	4.92
FUEL SUPPLY PRESSURE (psig)	46.32	46.20	46.47	0.05	0.11
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	14.66	13.90	15.39	0.30	2.08
ORIFICE STATIC PRESSURE (psig)	46.25	46.14	46.36	0.04	0.08
ORIFICE TEMPERATURE (F)	91.74	91.51	92.09	0.14	0.14
FUEL FLOW (SCFH)	5483.29				
CALCULATED FUEL CONSUMPTION (BSFC)	7330.47				
FUEL HEATING VALUE (Btu)	986.50	986.50	986.50	0.00	0.00
AIR FUEL RATIO	28.60	28.60	28.60	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	9.40	9.10	9.70	0.11	1.13
INTERCOOLER AIR TEMP IN (F)	299.29	298.19	300.38	0.43	0.14
INTERCOOLER AIR TEMP OUT (F)	142.17	140.06	145.41	1.50	1.06
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	68.70	68.41	68.99	0.09	0.13
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	54.53	53.65	55.42	0.29	0.52
INTERCOOLER WATER TEMP IN (F)	129.01	126.17	133.11	1.98	1.54
INTERCOOLER WATER TEMP OUT (F)	142.05	139.26	145.81	1.82	1.28
INTERCOOLER SUPPLY PRESSURE (psi)	2.66	2.60	2.71	0.02	0.58
PRE CATALYST TEMPERATURE (F)	731.32	729.95	732.92	0.81	0.11
POST CATALYST TEMPERATURE (F)	735.71	734.31	737.68	0.95	0.13
CATALYST DIFFERENTIAL PRESSURE ("H2O)	9.01	8.83	9.19	0.06	0.66
B.S. CO (g/bhp-hr): Pre-Catalyst	2.40	2.33	2.47	0.03	1.14
B.S. CO (g/bhp-hr): Post-Catalyst	0.15	0.15	0.16	0.00	3.04
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 11 - 735BHP 1200RPM 10BTDC

Data Point Number: Run 11 **Date:** 08/06/99 **Time:** 13:16:59

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.69	0.65	0.75	0.02	3.42
B.S. NOx (g/bhp-hr): Post-Catalyst	0.73	0.68	0.81	0.03	3.58
B.S. THC (g/bhp-hr): Pre-Catalyst	4.65	4.45	4.84	0.08	1.66
B.S. THC (g/bhp-hr): Post-Catalyst	4.69	4.49	4.89	0.08	1.75
B.S. Methane (g/bhp-hr): Pre-Catalyst	2.27	2.08	2.38	0.08	3.69
B.S. Methane (g/bhp-hr): Post-Catalyst	2.14	1.99	2.28	0.06	2.58
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.08	0.07	0.09	0.01	6.63
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.07	0.07	0.08	0.00	5.48
O2 (ppm): Pre-Catalyst	9.81	9.80	9.90	0.02	0.24
O2 (ppm): Post-Catalyst	9.79	9.70	9.80	0.03	0.29
CO (ppm): Pre-Catalyst	620.51	616.00	627.30	2.34	0.38
CO (ppm): Post-Catalyst	41.71	40.90	42.30	0.26	0.63
CO2 (ppm): Pre-Catalyst	6.29	6.26	6.32	0.03	0.47
CO2 (ppm): Post-Catalyst	6.47	6.44	6.50	0.02	0.26
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	58.62	55.10	63.00	2.01	3.43
NOx (ppm - Corrected): Post-Catalyst	62.94	58.80	68.80	2.20	3.49
NOx (ppm): Pre-Catalyst	109.71	102.90	118.40	3.99	3.64
NOx (ppm): Post-Catalyst	118.10	109.80	129.50	4.36	3.69
THC (ppm): Pre-Catalyst	1840.30	1801.60	1871.60	15.55	0.85
THC (ppm): Post-Catalyst	1893.61	1839.80	1937.40	20.70	1.09
Methane (ppm): Pre-Catalyst	1179.63	1118.00	1209.50	40.58	3.44
Methane (ppm): Post-Catalyst	1136.87	1089.50	1185.70	24.71	2.17
Non-Methane (ppm): Pre-Catalyst	140.34	127.10	149.30	6.99	4.98
Non-Methane (ppm): Post-Catalyst	129.50	123.10	137.60	5.26	4.06
DYNO WATER IN TEMPERATURE (F)	82.35	81.92	82.71	0.19	0.23
DYNO WATER OUT TEMPERATURE (F)	128.81	128.15	129.14	0.18	0.14
JACKET WATER IN TEMPERATURE (F)	163.69	163.27	164.06	0.17	0.10
JACKET WATER OUT TEMPERATURE (F)	170.06	168.00	172.00	0.71	0.42
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	92.41	91.84	93.03	0.50	0.54
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	98.17	97.20	98.79	0.39	0.40
LUBE OIL FLOW (GPM)	131.16	130.50	131.63	0.22	0.17
CO F-Factor: Pre-Catalyst	4.21	4.09	4.32	0.05	1.07
CO F-Factor: Post-Catalyst	0.28	0.27	0.29	0.00	1.37
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	1.22	1.14	1.32	0.04	3.44
NOx F-Factor: Post-Catalyst	1.31	1.21	1.45	0.05	3.50
THC F-Factor: Pre-Catalyst	7.98	7.65	8.30	0.13	1.57
THC F-Factor: Post-Catalyst	8.20	7.85	8.56	0.14	1.76
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3238.02	3233.08	3241.14	1.28	0.04

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 12 - 735BHP 1200RPM 10BTDC

Data Point Number: Run 12 **Date:** 08/06/99 **Time:** 09:36:11

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	72.93	71.00	73.00	0.36	0.50
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	52.32	48.00	56.00	2.12	4.06
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.76	5.27	0.08	1.56
AIR MANIFOLD RELATIVE HUMIDITY (%)	34.12	33.00	35.00	0.69	2.03
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01398	0.01301	0.01536		
AIR SUPPLY TEMPERATURE (F)	99.49	98.00	102.00	0.70	0.71
INTAKE AIR FLOW (scfm)	1720.32	1704.14	1737.41	6.30	0.37
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	704.45	703.56	705.54	0.54	0.08
CYLINDER 1 EXHAUST TEMPERATURE (F)	976.92	974.39	979.35	0.83	0.08
CYLINDER 2 EXHAUST TEMPERATURE (F)	978.81	977.37	980.74	0.64	0.07
CYLINDER 3 EXHAUST TEMPERATURE (F)	981.55	979.75	983.72	0.76	0.08
CYLINDER 4 EXHAUST TEMPERATURE (F)	954.93	952.57	957.93	0.93	0.10
CYLINDER 5 EXHAUST TEMPERATURE (F)	945.90	943.44	948.20	0.96	0.10
CYLINDER 6 EXHAUST TEMPERATURE (F)	933.05	930.74	934.71	0.84	0.09
CYLINDER EXHAUST AVERAGE TEMP (F)	961.86	960.17	963.61	0.64	0.07
EXHAUST HEADER TEMPERATURE (F)	704.45	703.56	705.54	0.54	0.08
PRE TURBO EXHAUST PRESSURE ("Hg)	36.99	36.63	37.38	0.15	0.40
PRE TURBO EXHAUST TEMPERATURE (F)	963.38	961.30	965.27	0.74	0.08
POST TURBO EXHAUST PRESSURE ("Hg)	4.98	4.90	5.05	0.03	0.58
POST TURBO EXHAUST TEMPERATURE (F)	779.01	776.97	780.74	0.77	0.10
TURBO OIL PRESSURE ("Hg)	46.67	45.84	47.29	0.30	0.64
ENGINE SPEED (rpm)	1196.91	1193.61	1201.13	1.40	0.12
ENGINE HORSEPOWER (bhp)	737.53	735.01	740.17	0.99	0.13
ENGINE OIL PRESSURE (psig)	51.88	51.07	52.60	0.35	0.67
ENGINE OIL TEMPERATURE IN (F)	166.62	166.05	166.84	0.14	0.08
ENGINE OIL TEMPERATURE OUT (F)	188.06	187.68	188.47	0.14	0.07
SPECIFIC GRAVITY	0.66	0.66	0.66	0.00	0.00
FUEL TEMPERATURE (F)	93.38	92.83	94.02	0.27	0.29
FUEL PRESSURE ("H2O above amp)	5.30	4.63	6.07	0.23	4.38
FUEL SUPPLY PRESSURE (psig)	46.61	46.47	46.75	0.06	0.12
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	14.92	14.07	15.66	0.29	1.95
ORIFICE STATIC PRESSURE (psig)	46.32	46.22	46.45	0.04	0.08
ORIFICE TEMPERATURE (F)	90.05	89.23	90.80	0.44	0.44
FUEL FLOW (SCFH)	5542.79				
CALCULATED FUEL CONSUMPTION (BSFC)	7413.90				
FUEL HEATING VALUE (Btu)	986.50	986.50	986.50	0.00	0.00
AIR FUEL RATIO	28.70	28.70	28.70	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	9.45	9.17	9.74	0.10	1.02
INTERCOOLER AIR TEMP IN (F)	299.63	298.79	300.57	0.35	0.12
INTERCOOLER AIR TEMP OUT (F)	142.86	142.24	143.63	0.29	0.20
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	68.84	68.66	69.08	0.08	0.12
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	54.76	53.97	58.00	0.30	0.55
INTERCOOLER WATER TEMP IN (F)	130.09	128.95	131.13	0.62	0.48
INTERCOOLER WATER TEMP OUT (F)	143.14	142.44	143.83	0.37	0.26
INTERCOOLER SUPPLY PRESSURE (psi)	2.65	2.60	2.70	0.02	0.58
PRE CATALYST TEMPERATURE (F)	736.01	734.51	737.49	0.65	0.09
POST CATALYST TEMPERATURE (F)	739.63	738.28	741.06	0.60	0.08
CATALYST DIFFERENTIAL PRESSURE ("H2O)	9.18	9.07	9.34	0.05	0.55
B.S. CO (g/bhp-hr): Pre-Catalyst	2.40	2.35	2.46	0.03	1.04
B.S. CO (g/bhp-hr): Post-Catalyst	0.15	0.15	0.16	0.00	3.22
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 12 - 735BHP 1200RPM 10BTDC

Data Point Number: Run 12 **Date:** 08/06/99 **Time:** 09:36:11

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.71	0.68	0.74	0.01	1.86
B.S. NOx (g/bhp-hr): Post-Catalyst	0.75	0.71	0.79	0.01	1.86
B.S. THC (g/bhp-hr): Pre-Catalyst	4.49	4.33	4.66	0.06	1.43
B.S. THC (g/bhp-hr): Post-Catalyst	4.77	4.60	4.96	0.07	1.52
B.S. Methane (g/bhp-hr): Pre-Catalyst	2.37	2.32	2.43	0.02	1.00
B.S. Methane (g/bhp-hr): Post-Catalyst	2.21	2.11	2.31	0.06	2.51
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.07	0.06	0.08	0.01	6.79
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.06	0.05	0.06	0.00	3.14
O2 (ppm): Pre-Catalyst	9.90	9.80	9.90	0.01	0.08
O2 (ppm): Post-Catalyst	9.85	9.80	9.90	0.05	0.51
CO (ppm): Pre-Catalyst	612.71	608.30	616.60	1.74	0.28
CO (ppm): Post-Catalyst	41.10	40.60	41.70	0.18	0.44
CO2 (ppm): Pre-Catalyst	6.29	6.29	6.35	0.01	0.16
CO2 (ppm): Post-Catalyst	6.41	6.38	6.45	0.02	0.25
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	59.85	57.70	61.50	0.91	1.52
NOx (ppm - Corrected): Post-Catalyst	63.16	60.70	65.50	1.04	1.64
NOx (ppm): Pre-Catalyst	111.21	107.30	114.40	1.83	1.65
NOx (ppm): Post-Catalyst	117.87	113.00	122.50	2.10	1.78
THC (ppm): Pre-Catalyst	1756.44	1723.10	1786.40	16.18	0.92
THC (ppm): Post-Catalyst	1889.00	1853.80	1927.00	15.94	0.84
Methane (ppm): Pre-Catalyst	1221.95	1219.20	1222.40	1.12	0.09
Methane (ppm): Post-Catalyst	1149.75	1124.70	1173.80	23.04	2.00
Non-Methane (ppm): Pre-Catalyst	126.92	116.50	134.90	7.01	5.52
Non-Methane (ppm): Post-Catalyst	107.32	100.60	112.10	3.53	3.29
DYNO WATER IN TEMPERATURE (F)	82.59	81.52	83.31	0.55	0.67
DYNO WATER OUT TEMPERATURE (F)	128.85	127.75	129.14	0.43	0.33
JACKET WATER IN TEMPERATURE (F)	184.06	183.31	184.70	0.38	0.21
JACKET WATER OUT TEMPERATURE (F)	190.19	188.00	192.00	0.73	0.38
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	91.71	90.45	92.44	0.56	0.61
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	97.46	96.21	98.39	0.61	0.62
LUBE OIL FLOW (GPM)	130.98	130.18	134.05	0.34	0.26
CO F-Factor: Pre-Catalyst	4.23	4.14	4.36	0.05	1.08
CO F-Factor: Post-Catalyst	0.28	0.28	0.29	0.00	1.16
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	1.26	1.20	1.31	0.02	1.67
NOx F-Factor: Post-Catalyst	1.33	1.26	1.41	0.02	1.82
THC F-Factor: Pre-Catalyst	7.76	7.48	8.09	0.12	1.58
THC F-Factor: Post-Catalyst	8.31	8.02	8.64	0.12	1.50
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3236.42	3233.08	3238.45	2.07	0.06

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 13 - 736BHP 1200RPM 6BTDC

Data Point Number: Run 13 **Date:** 08/05/99 **Time:** 16:57:00

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	69.00	69.00	69.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	66.08	64.00	68.00	1.23	1.86
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.66	5.34	0.11	2.15
AIR MANIFOLD RELATIVE HUMIDITY (%)	36.12	35.00	37.00	0.51	1.41
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01487	0.01386	0.01573		
AIR SUPPLY TEMPERATURE (F)	99.59	98.00	101.00	0.68	0.69
INTAKE AIR FLOW (scfm)	1808.04	1779.70	1854.70	14.74	0.82
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	733.60	732.53	735.50	0.50	0.07
CYLINDER 1 EXHAUST TEMPERATURE (F)	1012.87	1010.31	1015.07	0.82	0.08
CYLINDER 2 EXHAUST TEMPERATURE (F)	1015.66	1014.08	1018.24	0.72	0.07
CYLINDER 3 EXHAUST TEMPERATURE (F)	1013.77	1011.90	1015.67	0.61	0.06
CYLINDER 4 EXHAUST TEMPERATURE (F)	988.19	984.12	991.06	1.11	0.11
CYLINDER 5 EXHAUST TEMPERATURE (F)	978.56	974.59	980.94	1.31	0.13
CYLINDER 6 EXHAUST TEMPERATURE (F)	963.33	960.31	966.66	1.32	0.14
CYLINDER EXHAUST AVERAGE TEMP (F)	995.40	993.48	997.05	0.54	0.05
EXHAUST HEADER TEMPERATURE (F)	733.60	732.53	735.50	0.50	0.07
PRE TURBO EXHAUST PRESSURE ("Hg)	39.47	38.81	40.59	0.39	0.98
PRE TURBO EXHAUST TEMPERATURE (F)	1000.42	998.60	1002.97	0.71	0.07
POST TURBO EXHAUST PRESSURE ("Hg)	5.52	5.40	5.76	0.07	1.34
POST TURBO EXHAUST TEMPERATURE (F)	807.78	804.75	811.10	1.04	0.13
TURBO OIL PRESSURE ("Hg)	47.16	46.16	47.85	0.27	0.57
ENGINE SPEED (rpm)	1196.92	1190.23	1203.38	1.95	0.16
ENGINE HORSEPOWER (bhp)	737.30	734.08	740.63	1.18	0.16
ENGINE OIL PRESSURE (psig)	52.35	51.48	53.09	0.33	0.64
ENGINE OIL TEMPERATURE IN (F)	164.50	164.06	164.86	0.12	0.08
ENGINE OIL TEMPERATURE OUT (F)	185.53	185.10	185.89	0.15	0.08
SPECIFIC GRAVITY	0.69	0.69	0.69	0.00	0.00
FUEL TEMPERATURE (F)	91.21	90.85	91.64	0.18	0.20
FUEL PRESSURE ("H2O above amp)	4.31	3.34	5.08	0.25	5.87
FUEL SUPPLY PRESSURE (psig)	46.70	46.56	46.82	0.05	0.11
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	16.32	15.50	17.39	0.39	2.40
ORIFICE STATIC PRESSURE (psig)	46.40	46.29	46.48	0.04	0.08
ORIFICE TEMPERATURE (F)	86.36	86.11	86.71	0.12	0.12
FUEL FLOW (SCFH)	5682.94				
CALCULATED FUEL CONSUMPTION (BSFC)	8013.03				
FUEL HEATING VALUE (Btu)	1039.60	1039.60	1039.60	0.00	0.00
AIR FUEL RATIO	28.96	28.39	29.39	0.21	0.74
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	10.09	9.68	10.63	0.15	1.50
INTERCOOLER AIR TEMP IN (F)	304.14	302.36	305.73	0.68	0.22
INTERCOOLER AIR TEMP OUT (F)	142.22	141.25	143.43	0.43	0.30
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	69.35	68.91	69.83	0.14	0.20
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	58.01	57.04	59.13	0.29	0.50
INTERCOOLER WATER TEMP IN (F)	128.43	127.75	128.95	0.29	0.23
INTERCOOLER WATER TEMP OUT (F)	141.66	140.65	142.44	0.31	0.22
INTERCOOLER SUPPLY PRESSURE (psi)	2.84	2.80	2.89	0.02	0.56
PRE CATALYST TEMPERATURE (F)	767.12	765.86	769.43	0.54	0.07
POST CATALYST TEMPERATURE (F)	771.28	770.22	773.80	0.56	0.07
CATALYST DIFFERENTIAL PRESSURE ("H2O)	10.22	9.95	10.59	0.12	1.15
B.S. CO (g/bhp-hr): Pre-Catalyst	4.34	4.07	4.81	0.15	3.49
B.S. CO (g/bhp-hr): Post-Catalyst	0.30	0.28	0.34	0.01	4.02
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 13 - 736BHP 1200RPM 6BTDC

Data Point Number: Run 13 **Date:** 08/05/99 **Time:** 16:57:00

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.74	0.69	0.80	0.02	2.43
B.S. NOx (g/bhp-hr): Post-Catalyst	0.80	0.75	0.86	0.02	2.47
B.S. THC (g/bhp-hr): Pre-Catalyst	9.18	8.23	10.33	0.36	3.95
B.S. THC (g/bhp-hr): Post-Catalyst	9.55	8.58	10.71	0.37	3.84
B.S. Methane (g/bhp-hr): Pre-Catalyst	4.39	4.09	5.44	0.33	7.49
B.S. Methane (g/bhp-hr): Post-Catalyst	3.93	3.73	4.74	0.23	5.77
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.27	0.22	0.30	0.02	6.88
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.17	0.16	0.18	0.01	4.15
O2 (ppm): Pre-Catalyst	10.44	9.80	10.50	0.17	1.64
O2 (ppm): Post-Catalyst	9.81	9.60	9.90	0.05	0.47
CO (ppm): Pre-Catalyst	619.89	600.20	657.60	14.27	2.30
CO (ppm): Post-Catalyst	44.53	41.90	47.90	1.25	2.80
CO2 (ppm): Pre-Catalyst	6.27	6.16	6.35	0.04	0.61
CO2 (ppm): Post-Catalyst	6.38	6.31	6.50	0.03	0.45
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	36.57	33.80	37.80	1.10	3.00
NOx (ppm - Corrected): Post-Catalyst	37.83	35.00	41.20	1.05	2.78
NOx (ppm): Pre-Catalyst	64.65	60.00	70.50	2.03	3.14
NOx (ppm): Post-Catalyst	70.86	64.90	78.30	2.26	3.20
THC (ppm): Pre-Catalyst	1904.26	1766.90	2053.10	52.85	2.78
THC (ppm): Post-Catalyst	2002.69	1863.50	2163.60	53.99	2.70
Methane (ppm): Pre-Catalyst	1377.63	1319.20	1651.50	99.99	7.26
Methane (ppm): Post-Catalyst	1248.54	1216.80	1453.30	68.76	5.51
Non-Methane (ppm): Pre-Catalyst	167.00	145.40	182.00	10.43	6.24
Non-Methane (ppm): Post-Catalyst	109.40	103.50	112.40	2.95	2.70
DYNO WATER IN TEMPERATURE (F)	81.73	81.52	81.92	0.13	0.16
DYNO WATER OUT TEMPERATURE (F)	127.77	127.36	128.35	0.16	0.12
JACKET WATER IN TEMPERATURE (F)	176.53	176.17	176.76	0.13	0.08
JACKET WATER OUT TEMPERATURE (F)	183.05	181.00	185.00	0.73	0.40
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	88.07	88.07	88.07	0.00	0.00
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	93.62	93.23	94.02	0.15	0.16
LUBE OIL FLOW (GPM)	130.42	129.70	136.31	0.37	0.29
CO F-Factor: Pre-Catalyst	4.86	4.35	5.35	0.17	3.53
CO F-Factor: Post-Catalyst	0.33	0.30	0.37	0.01	4.05
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	0.83	0.78	0.87	0.02	2.53
NOx F-Factor: Post-Catalyst	0.86	0.81	0.92	0.02	2.34
THC F-Factor: Pre-Catalyst	10.12	8.65	11.29	0.40	3.98
THC F-Factor: Post-Catalyst	10.04	9.03	11.30	0.40	3.96
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3235.52	3230.40	3238.45	2.10	0.06

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 15 - 736BHP 1200RPM 10BTDC (cylinder 6-6BTDC)

Data Point Number: Run 15 **Date:** 08/05/99 **Time:** 18:15:00

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	69.00	69.00	69.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	68.70	66.00	70.00	1.00	1.45
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.75	5.34	0.10	2.09
AIR MANIFOLD RELATIVE HUMIDITY (%)	37.18	34.00	39.00	1.07	2.88
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01532	0.01342	0.01712		
AIR SUPPLY TEMPERATURE (F)	99.61	98.00	102.00	0.77	0.77
INTAKE AIR FLOW (scfm)	1744.40	1726.69	1762.78	5.90	0.34
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	706.79	705.94	708.32	0.52	0.07
CYLINDER 1 EXHAUST TEMPERATURE (F)	975.99	973.40	985.90	1.86	0.19
CYLINDER 2 EXHAUST TEMPERATURE (F)	977.31	974.99	987.49	1.48	0.15
CYLINDER 3 EXHAUST TEMPERATURE (F)	977.14	974.59	984.91	1.44	0.15
CYLINDER 4 EXHAUST TEMPERATURE (F)	951.37	948.80	960.11	1.62	0.17
CYLINDER 5 EXHAUST TEMPERATURE (F)	942.30	940.47	945.82	1.02	0.11
CYLINDER 6 EXHAUST TEMPERATURE (F)	947.70	945.23	951.18	1.29	0.14
CYLINDER EXHAUST AVERAGE TEMP (F)	961.98	960.37	966.06	1.02	0.11
EXHAUST HEADER TEMPERATURE (F)	706.79	705.94	708.32	0.52	0.07
PRE TURBO EXHAUST PRESSURE ("Hg)	37.63	37.26	38.13	0.15	0.40
PRE TURBO EXHAUST TEMPERATURE (F)	967.21	965.27	971.62	1.18	0.12
POST TURBO EXHAUST PRESSURE ("Hg)	5.08	5.00	5.16	0.03	0.56
POST TURBO EXHAUST TEMPERATURE (F)	780.29	778.56	783.12	0.92	0.12
TURBO OIL PRESSURE ("Hg)	47.07	46.24	47.77	0.27	0.58
ENGINE SPEED (rpm)	1196.86	1192.86	1202.26	1.63	0.14
ENGINE HORSEPOWER (bhp)	737.39	734.54	740.02	1.02	0.14
ENGINE OIL PRESSURE (psig)	52.27	51.40	53.01	0.34	0.65
ENGINE OIL TEMPERATURE IN (F)	164.34	163.87	164.86	0.20	0.12
ENGINE OIL TEMPERATURE OUT (F)	185.42	184.90	185.89	0.18	0.10
SPECIFIC GRAVITY	0.69	0.69	0.69	0.00	0.00
FUEL TEMPERATURE (F)	91.15	90.85	91.44	0.12	0.13
FUEL PRESSURE ("H2O above amp)	4.13	3.42	4.82	0.25	6.04
FUEL SUPPLY PRESSURE (psig)	46.78	46.65	46.86	0.04	0.08
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	15.00	14.42	15.70	0.30	2.03
ORIFICE STATIC PRESSURE (psig)	46.46	46.37	46.53	0.04	0.08
ORIFICE TEMPERATURE (F)	86.01	85.64	86.51	0.25	0.25
FUEL FLOW (SCFH)	5452.40				
CALCULATED FUEL CONSUMPTION (BSFC)	7687.02				
FUEL HEATING VALUE (Btu)	1039.60	1039.60	1039.60	0.00	0.00
AIR FUEL RATIO	29.26	28.89	29.39	0.22	0.75
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	9.61	9.31	9.86	0.09	0.98
INTERCOOLER AIR TEMP IN (F)	300.36	299.19	301.77	0.49	0.16
INTERCOOLER AIR TEMP OUT (F)	140.85	139.46	143.03	1.00	0.71
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	68.85	68.58	69.16	0.11	0.17
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	57.93	57.04	58.81	0.29	0.50
INTERCOOLER WATER TEMP IN (F)	128.07	126.56	130.93	1.09	0.85
INTERCOOLER WATER TEMP OUT (F)	140.85	139.06	143.43	1.21	0.86
INTERCOOLER SUPPLY PRESSURE (psi)	2.84	2.77	2.89	0.02	0.62
PRE CATALYST TEMPERATURE (F)	737.76	736.30	740.46	0.82	0.11
POST CATALYST TEMPERATURE (F)	741.89	740.46	744.23	0.74	0.10
CATALYST DIFFERENTIAL PRESSURE ("H2O)	9.45	9.30	9.60	0.05	0.52
B.S. CO (g/bhp-hr): Pre-Catalyst	4.23	4.12	4.38	0.05	1.14
B.S. CO (g/bhp-hr): Post-Catalyst	0.28	0.27	0.29	0.00	1.52
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 15 - 736BHP 1200RPM 10BTDC (cylinder 6-6BTDC)

Data Point Number: Run 15 **Date:** 08/05/99 **Time:** 18:15:00

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	1.04	0.99	1.09	0.02	1.58
B.S. NOx (g/bhp-hr): Post-Catalyst	1.12	1.03	1.18	0.02	1.99
B.S. THC (g/bhp-hr): Pre-Catalyst	8.63	8.34	8.89	0.10	1.21
B.S. THC (g/bhp-hr): Post-Catalyst	9.04	8.76	9.37	0.11	1.24
B.S. Methane (g/bhp-hr): Pre-Catalyst	4.10	3.97	4.41	0.10	2.40
B.S. Methane (g/bhp-hr): Post-Catalyst	3.63	3.49	3.81	0.08	2.21
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.25	0.23	0.27	0.01	4.19
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.17	0.16	0.19	0.01	3.99
O2 (ppm): Pre-Catalyst	9.90	9.90	9.90	0.00	0.00
O2 (ppm): Post-Catalyst	9.82	9.80	9.90	0.04	0.43
CO (ppm): Pre-Catalyst	625.17	618.30	629.60	2.47	0.40
CO (ppm): Post-Catalyst	42.56	41.80	43.20	0.28	0.66
CO2 (ppm): Pre-Catalyst	6.22	6.16	6.29	0.02	0.31
CO2 (ppm): Post-Catalyst	6.35	6.33	6.37	0.01	0.14
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	50.78	48.80	52.60	0.57	1.13
NOx (ppm - Corrected): Post-Catalyst	54.65	50.30	57.10	0.93	1.71
NOx (ppm): Pre-Catalyst	94.19	90.90	97.40	1.05	1.12
NOx (ppm): Post-Catalyst	102.08	94.10	106.50	1.72	1.69
THC (ppm): Pre-Catalyst	1851.76	1820.50	1874.10	10.87	0.59
THC (ppm): Post-Catalyst	1964.48	1929.40	1992.80	12.14	0.62
Methane (ppm): Pre-Catalyst	1331.44	1319.20	1403.10	29.06	2.18
Methane (ppm): Post-Catalyst	1193.07	1170.70	1219.90	24.00	2.01
Non-Methane (ppm): Pre-Catalyst	160.16	152.60	170.70	6.08	3.79
Non-Methane (ppm): Post-Catalyst	115.06	105.70	118.80	3.97	3.45
DYNO WATER IN TEMPERATURE (F)	81.58	81.33	81.72	0.11	0.13
DYNO WATER OUT TEMPERATURE (F)	127.55	126.96	128.15	0.18	0.14
JACKET WATER IN TEMPERATURE (F)	172.83	172.20	173.79	0.30	0.17
JACKET WATER OUT TEMPERATURE (F)	178.71	177.00	181.00	0.69	0.39
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	87.47	86.88	88.07	0.29	0.33
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	92.95	92.44	93.63	0.23	0.25
LUBE OIL FLOW (GPM)	130.32	129.70	131.47	0.22	0.17
CO F-Factor: Pre-Catalyst	4.48	4.35	4.62	0.05	1.13
CO F-Factor: Post-Catalyst	0.30	0.29	0.31	0.00	1.20
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	1.11	1.06	1.16	0.02	1.55
NOx F-Factor: Post-Catalyst	1.19	1.10	1.26	0.02	2.03
THC F-Factor: Pre-Catalyst	9.00	8.74	9.30	0.11	1.19
THC F-Factor: Post-Catalyst	9.47	9.18	9.82	0.11	1.18
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3235.59	3233.08	3238.45	2.00	0.06

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 16 - 736BHP 1200RPM 10BTDC (cyinder 6-14 BTDC)

Data Point Number: Run 16 **Date:** 08/05/99 **Time:** 19:52:00

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	69.00	69.00	69.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	68.00	68.00	68.00	0.00	0.00
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.71	5.29	0.09	1.81
AIR MANIFOLD RELATIVE HUMIDITY (%)	37.26	33.00	40.00	1.84	4.94
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01539	0.01303	0.01760		
AIR SUPPLY TEMPERATURE (F)	99.70	98.00	102.00	0.73	0.73
INTAKE AIR FLOW (scfm)	1715.48	1700.19	1738.53	6.02	0.35
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	698.05	697.41	698.80	0.33	0.05
CYLINDER 1 EXHAUST TEMPERATURE (F)	975.79	973.80	978.16	0.78	0.08
CYLINDER 2 EXHAUST TEMPERATURE (F)	976.66	974.39	979.55	1.04	0.11
CYLINDER 3 EXHAUST TEMPERATURE (F)	976.78	974.59	979.35	0.68	0.07
CYLINDER 4 EXHAUST TEMPERATURE (F)	951.05	949.00	952.77	0.64	0.07
CYLINDER 5 EXHAUST TEMPERATURE (F)	941.73	939.47	943.44	0.89	0.09
CYLINDER 6 EXHAUST TEMPERATURE (F)	918.83	917.25	920.23	0.57	0.06
CYLINDER EXHAUST AVERAGE TEMP (F)	956.81	955.18	958.19	0.56	0.06
EXHAUST HEADER TEMPERATURE (F)	698.05	697.41	698.80	0.33	0.05
PRE TURBO EXHAUST PRESSURE ("Hg)	36.85	36.40	37.26	0.13	0.36
PRE TURBO EXHAUST TEMPERATURE (F)	954.33	952.57	955.54	0.59	0.06
POST TURBO EXHAUST PRESSURE ("Hg)	4.91	4.84	5.01	0.03	0.55
POST TURBO EXHAUST TEMPERATURE (F)	771.21	769.63	772.41	0.53	0.07
TURBO OIL PRESSURE ("Hg)	46.94	46.16	47.53	0.28	0.60
ENGINE SPEED (rpm)	1196.92	1193.23	1201.50	1.47	0.12
ENGINE HORSEPOWER (bhp)	737.33	734.08	740.25	1.09	0.15
ENGINE OIL PRESSURE (psig)	52.12	51.40	52.93	0.34	0.65
ENGINE OIL TEMPERATURE IN (F)	164.84	164.46	165.26	0.16	0.09
ENGINE OIL TEMPERATURE OUT (F)	185.95	185.49	186.68	0.20	0.11
SPECIFIC GRAVITY	0.69	0.69	0.69	0.00	0.00
FUEL TEMPERATURE (F)	91.42	91.05	91.84	0.15	0.16
FUEL PRESSURE ("H2O above amp)	4.17	3.54	4.77	0.24	5.67
FUEL SUPPLY PRESSURE (psig)	46.82	46.69	46.95	0.05	0.10
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	14.59	13.84	15.44	0.34	2.35
ORIFICE STATIC PRESSURE (psig)	46.46	46.36	46.57	0.04	0.10
ORIFICE TEMPERATURE (F)	87.15	86.69	87.47	0.22	0.22
FUEL FLOW (SCFH)	5372.64				
CALCULATED FUEL CONSUMPTION (BSFC)	7575.15				
FUEL HEATING VALUE (Btu)	1039.60	1039.60	1039.60	0.00	0.00
AIR FUEL RATIO	29.28	28.89	29.39	0.21	0.71
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	9.42	9.13	9.66	0.10	1.04
INTERCOOLER AIR TEMP IN (F)	298.87	298.00	299.78	0.34	0.11
INTERCOOLER AIR TEMP OUT (F)	142.34	141.64	143.03	0.39	0.27
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	68.73	68.49	68.99	0.10	0.14
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	57.91	56.87	59.13	0.29	0.51
INTERCOOLER WATER TEMP IN (F)	130.21	128.95	131.33	0.72	0.55
INTERCOOLER WATER TEMP OUT (F)	142.85	142.24	143.83	0.42	0.29
INTERCOOLER SUPPLY PRESSURE (psi)	2.84	2.79	2.90	0.02	0.59
PRE CATALYST TEMPERATURE (F)	730.28	728.36	741.26	2.20	0.30
POST CATALYST TEMPERATURE (F)	732.86	732.13	733.91	0.40	0.05
CATALYST DIFFERENTIAL PRESSURE ("H2O)	9.14	9.00	9.30	0.05	0.58
B.S. CO (g/bhp-hr): Pre-Catalyst	2.43	2.36	2.51	0.03	1.26
B.S. CO (g/bhp-hr): Post-Catalyst	0.16	0.15	0.16	0.00	2.50
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Run 16 - 736BHP 1200RPM 10BTDC (cylinder 6-14 BTDC)

Data Point Number: Run 16 **Date:** 08/05/99 **Time:** 19:52:00

Duration (minutes): 33.00

Description	Average	Min	Max	STDV	Variance
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.69	0.65	0.74	0.02	2.54
B.S. NOx (g/bhp-hr): Post-Catalyst	0.73	0.69	0.79	0.02	2.79
B.S. THC (g/bhp-hr): Pre-Catalyst	4.97	4.76	5.16	0.08	1.55
B.S. THC (g/bhp-hr): Post-Catalyst	5.04	4.85	5.25	0.08	1.51
B.S. Methane (g/bhp-hr): Pre-Catalyst	2.31	2.15	2.41	0.07	2.90
B.S. Methane (g/bhp-hr): Post-Catalyst	2.03	1.91	2.10	0.04	1.73
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.13	0.12	0.15	0.01	8.84
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.10	0.09	0.11	0.00	4.58
O2 (ppm): Pre-Catalyst	9.82	9.80	9.90	0.04	0.44
O2 (ppm): Post-Catalyst	9.80	9.80	9.90	0.01	0.05
CO (ppm): Pre-Catalyst	627.01	621.50	631.60	2.14	0.34
CO (ppm): Post-Catalyst	42.14	41.60	42.60	0.18	0.42
CO2 (ppm): Pre-Catalyst	6.23	6.16	6.23	0.01	0.13
CO2 (ppm): Post-Catalyst	6.36	6.34	6.38	0.01	0.13
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	58.00	55.50	61.20	1.33	2.29
NOx (ppm - Corrected): Post-Catalyst	62.50	59.20	66.60	1.59	2.55
NOx (ppm): Pre-Catalyst	108.40	103.90	113.90	2.43	2.25
NOx (ppm): Post-Catalyst	117.03	110.80	124.50	2.93	2.50
THC (ppm): Pre-Catalyst	1859.18	1820.50	1896.00	16.93	0.91
THC (ppm): Post-Catalyst	1911.35	1866.00	1948.90	17.05	0.89
Methane (ppm): Pre-Catalyst	1307.00	1245.10	1327.80	35.20	2.69
Methane (ppm): Post-Catalyst	1166.46	1124.70	1173.80	13.62	1.17
Non-Methane (ppm): Pre-Catalyst	150.12	136.80	168.30	12.30	8.19
Non-Methane (ppm): Post-Catalyst	118.21	112.10	123.90	3.84	3.25
DYNO WATER IN TEMPERATURE (F)	81.64	81.52	81.72	0.10	0.12
DYNO WATER OUT TEMPERATURE (F)	127.59	127.16	128.15	0.17	0.13
JACKET WATER IN TEMPERATURE (F)	174.13	173.59	174.58	0.17	0.10
JACKET WATER OUT TEMPERATURE (F)	180.21	178.00	182.00	0.71	0.39
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	87.48	87.48	87.48	0.00	0.00
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	92.91	92.64	93.23	0.13	0.14
LUBE OIL FLOW (GPM)	130.29	129.38	130.99	0.24	0.18
CO F-Factor: Pre-Catalyst	4.39	4.26	4.55	0.05	1.24
CO F-Factor: Post-Catalyst	0.29	0.29	0.31	0.00	1.27
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	1.25	1.18	1.35	0.03	2.52
NOx F-Factor: Post-Catalyst	1.35	1.26	1.46	0.04	2.71
THC F-Factor: Pre-Catalyst	8.83	8.45	9.22	0.14	1.56
THC F-Factor: Post-Catalyst	9.06	8.71	9.43	0.14	1.54
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3235.47	3230.40	3238.45	2.10	0.06

Colorado State University: Engines & Energy Conversion Laboratory

Test Program: EPA RICE Testing:

Description: Reference Method Analyzers Daily Calibrations

Date: August 5, 1999

Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Engine Type: Waukesha

Test Points: Calibrations between Runs 5 & 6 and 15 & 16

QC_Aug.,5_1999_22:09:47 Description: Post Run 5 - Span Check

Gas	Slope	Intercept	Cal_Gas	Zero_Avg	Span_Avg	Range	ppm_or_%	% Error
Pre_CO	100.54	-0.047	450	0	4.481	1000	450.499	0.0499
Pre_CO2	25.005	-0.061	9.04	0.002	0.366	25	9.101	0.244
Pre_O2	24.627	0.004	12	0	0.487	25	11.99	-0.04
Pre_Methane	1255.399	-1263.228	1800	1.006	2.44	5000	1800	0
Pre_Non_Methane	140.071	-158.141	181	1.129	2.38	500	175.183	-1.1634
Pre_NOx	49.955	-0.74	304	0.005	6.141	500	306.054	0.4106
Pre_THC	498.544	-0.019	2750	0	5.656	5000	2819.533	1.39066
Post_CO	40.411	-0.002	43.8	0.014	1.098	200	44.384	0.292
Post_CO2	2	-0.001	5.16	0	2.561	10	5.122	-0.38
Post_O2	4.993	0	12	0	2.396	25	11.961	-0.156
Post_Methane	1257.239	-1254.745	1800	0.998	2.415	5000	1781.934	-0.36132
Post_Non_Methane	130.454	-136.043	181	1.043	2.418	500	179.407	-0.3186
Post_NOx	99.559	0.023	305	0	3.073	500	305.94	0.188
Post_THC	998.645	-0.078	2760	0	2.746	5000	2742.601	-0.14796

QC_Aug.,5_1999_22:01:55 Description: Post Run 5 - Zero Check

Gas	Slope	Intercept	Cal_Gas	Zero_Avg	Span_Avg	Range	ppm_or_%	% Error
Pre_CO	100.54	-0.047	0	0	0	1000	0	0
Pre_CO2	25.005	-0.061	0	0.002	0.001	25	-0.047	-0.188
Pre_O2	24.627	0.004	0	0	0.002	25	0.06	0.24
Pre_Methane	1255.399	-1263.228	0	1.006	1.07	5000	80.167	1.60334
Pre_Non_Methane	140.071	-158.141	0	1.129	1.168	500	5.423	1.0846
Pre_NOx	49.955	-0.74	0	0.005	0.017	500	0.112	0.0224
Pre_THC	498.544	-0.019	0	0	0	5000	0	0
Post_CO	40.411	-0.002	0	0.014	0.024	200	0.948	0.4745
Post_CO2	2	-0.001	0	0	0	10	0	0
Post_O2	4.993	0	0	0	0	25	0	0
Post_Methane	1257.239	-1254.745	0	0.998	0.998	5000	0.205	0.0041
Post_Non_Methane	130.454	-136.043	0	1.043	1.046	500	0.441	0.0882
Post_NOx	99.559	0.023	0	0	0	500	0	0
Post_THC	998.645	-0.078	0	0	0	5000	0	0

QC_Aug.,5_1999_19:31:03 Description: Post Run 15 - Span Check

Gas	Slope	Intercept	Cal_Gas	Zero_Avg	Span_Avg	Range	ppm_or_%	% Error
Pre_CO	100.54	-0.047	450	0	4.479	1000	450.299	0.0299
Pre_CO2	25.005	-0.061	9.04	0.002	0.365	25	9.067	0.108
Pre_O2	24.627	0.004	12	0	0.486	25	11.969	-0.124
Pre_Methane	1255.399	-1263.228	1800	1.006	2.501	5000	1876.028	1.52056
Pre_Non_Methane	140.071	-158.141	181	1.129	2.421	500	180.983	-0.0034
Pre_NOx	49.955	-0.74	304	0.005	6.141	500	306.021	0.4042
Pre_THC	498.544	-0.019	2750	0	5.518	5000	2750.812	0.01624
Post_CO	40.411	-0.002	43.8	0.014	1.1	200	44.466	0.333
Post_CO2	2	-0.001	5.16	0	2.558	10	5.115	-0.45
Post_O2	4.993	0	12	0	2.395	25	11.981	-0.156
Post_Methane	1257.239	-1254.745	1800	0.998	2.426	5000	1794.933	-0.10134
Post_Non_Methane	130.454	-136.043	181	1.043	2.412	500	178.594	-0.4812
Post_NOx	99.559	0.023	305	0	3.026	500	301.243	-0.7514
Post_THC	998.645	-0.078	2760	0	2.744	5000	2739.999	-0.20002

QC_Aug.,5_1999_19:17:06 Description: Post Run 15 - Zero Check

Gas	Slope	Intercept	Cal_Gas	Zero_Avg	Span_Avg	Range	ppm_or_%	% Error
Pre_CO	100.54	-0.047	0	0	0	1000	0	0
Pre_CO2	25.005	-0.061	0	0.002	0	25	-0.053	-0.212
Pre_O2	24.627	0.004	0	0	0.002	25	0.06	0.24
Pre_Methane	1255.399	-1263.228	0	1.006	1.006	5000	0.204	0.00408
Pre_Non_Methane	140.071	-158.141	0	1.129	1.073	500	-7.87	-1.574
Pre_NOx	49.955	-0.74	0	0.005	0.017	500	0.096	0.0192
Pre_THC	498.544	-0.019	0	0	0	5000	0	0
Post_CO	40.411	-0.002	0	0.014	0.023	200	0.931	0.4655
Post_CO2	2	-0.001	0	0	0	10	0	0
Post_O2	4.993	0	0	0	0	25	0	0
Post_Methane	1257.239	-1254.745	0	0.998	0.998	5000	0.051	0.00102
Post_Non_Methane	130.454	-136.043	0	1.043	1.075	500	4.185	0.837
Post_NOx	99.559	0.023	0	0	0	500	0	0
Post_THC	998.645	-0.078	0	0	0	5000	0	0

Colorado State University: Engines & Energy Conversion Laboratory

Test Program: EPA RICE Testing:

Description: Reference Method Analyzers Daily Calibrations

Date: August 6, 1999

Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Engine Type: Waukesha

Test Points: Post Test Runs 8 and 4

QC_Aug.,6_1999_08:45:18 — Description: Post Test Run 8 - Span Check

Gas	Slope	Intercept	Cal_Gas	Zero_Avg	Span_Avg	Range	ppm_or_%	% Error
Pre_CO	100.54	-0.047	450	0	4.477	1000	450.094	0.0094
Pre_CO2	25.005	-0.061	9.04	0.002	0.366	25	9.1	0.24
Pre_O2	24.627	0.004	12	0	0.486	25	11.969	-0.124
Pre_Methane	1313.917	-1406.015	1800	1.07	2.44	5000	1800	0
Pre_Non_Methane	123.888	-129.274	181	1.043	2.479	500	177.833	-0.6334
Pre_NOx	49.955	-0.74	304	0.005	6.234	500	310.699	1.3398
Pre_THC	498.544	-0.019	2750	0	5.499	5000	2741.273	-0.17454
Post_CO	40.411	-0.002	43.6	0.014	1.095	200	44.229	0.2145
Post_CO2	2	-0.001	5.16	0	2.581	10	5.161	0.01
Post_O2	4.993	0	12	0	2.403	25	11.998	-0.008
Post_Methane	1257.239	-1254.745	1800	0.998	2.415	5000	1781.882	-0.36236
Post_Non_Methane	130.454	-136.043	181	1.043	2.455	500	184.187	0.6374
Post_NOx	99.559	0.023	305	0	3.027	500	301.34	-0.732
Post_THC	998.645	-0.078	2750	0	2.742	5000	2738.129	-0.23742

QC_Aug.,6_1999_06:34:17 — Description: Post Test Run 4 - Span Check

Gas	Slope	Intercept	Cal_Gas	Zero_Avg	Span_Avg	Range	ppm_or_%	% Error
Pre_CO	100.54	-0.047	450	0	4.477	1000	450.094	0.0094
Pre_CO2	25.005	-0.061	9.04	0.002	0.366	25	9.1	0.24
Pre_O2	24.627	0.004	12	0	0.486	25	11.969	-0.124
Pre_Methane	1313.917	-1406.015	1800	1.07	2.44	5000	1800	0
Pre_Non_Methane	123.888	-129.274	181	1.043	2.479	500	177.833	-0.6334
Pre_NOx	49.955	-0.74	304	0.005	6.171	500	307.51	0.702
Pre_THC	498.544	-0.019	2750	0	5.499	5000	2741.273	-0.17454
Post_CO	40.411	-0.002	43.6	0.014	1.095	200	44.229	0.2145
Post_CO2	2	-0.001	5.16	0	2.581	10	5.161	0.01
Post_O2	4.993	0	12	0	2.403	25	11.998	-0.008
Post_Methane	1257.239	-1254.745	1800	0.998	2.415	5000	1781.882	-0.36236
Post_Non_Methane	130.454	-136.043	181	1.043	2.455	500	184.187	0.6374
Post_NOx	99.559	0.023	305	0	3.076	500	306.228	0.2456
Post_THC	998.645	-0.078	2750	0	2.742	5000	2738.129	-0.23742

QC_Aug.,6_1999_06:19:16 — Description: Post Test Run 4 - Zero Check

Gas	Slope	Intercept	Cal_Gas	Zero_Avg	Span_Avg	Ra[illegible]	[illegible]	% Error
Pre_CO	100.54	-0.047	0	0	0	[illegible]	[illegible]	0
Pre_CO2	25.005	-0.061	0	0.002	0.001	[illegible]	[illegible]	0.152
Pre_O2	24.627	0.004	0	0	0.002	[illegible]	[illegible]	0.24
Pre_Methane	1313.917	-1406.015	0	1.07	1.07	[illegible]	[illegible]	0
Pre_Non_Methane	123.888	-129.274	0	1.043	1.068	[illegible]	[illegible]	0.6067
Pre_NOx	49.955	-0.74	0	0.005	0.027	[illegible]	[illegible]	0.122
Pre_THC	498.544	-0.019	0	0	0	[illegible]	[illegible]	0
Post_CO	40.411	-0.002	0	0.014	0.007	200	0.265	-0.1325
Post_CO2	2	-0.001	0	0	0	10	0	0
Post_O2	4.993	0	0	0	0	25	0	0
Post_Methane	1257.239	-1254.745	0	0.998	0.998	5000	0.461	0.00922
Post_Non_Methane	130.454	-136.043	0	1.043	1.028	500	1.912	0.3824
Post_NOx	99.559	0.023	0	0	0	500	0	0
Post_THC	998.645	-0.078	0	0	0	5000	0	0

QC_Aug.,6_1999_03:05:01 — Description: Post Test Run 7 - Span Check

Gas	Slope	Intercept	Cal_Gas	Zero_Avg	Span_Avg	Range	ppm_or_%	% Error
Pre_CO	100.54	-0.047	450	0	4.474	1000	449.722	-0.0278
Pre_CO2	25.005	-0.061	9.04	0.002	0.366	25	9.099	0.236
Pre_O2	24.627	0.004	12	0	0.486	25	11.969	-0.124
Pre_Methane	1255.399	-1263.228	1800	1.006	2.44	5000	1800	0
Pre_Non_Methane	123.888	-129.274	181	1.043	2.504	500	181	0
Pre_NOx	49.955	-0.74	304	0.005	6.185	500	308.207	0.8414
Pre_THC	498.544	-0.019	2750	0	5.487	5000	2735.631	-0.28738
Post_CO	40.411	-0.002	43.8	0.014	1.102	200	44.522	0.361
Post_CO2	2	-0.001	5.16	0	2.583	10	5.165	0.05
Post_O2	4.993	0	12	0	2.403	25	11.998	-0.008
Post_Methane	1257.239	-1254.745	1800	0.998	2.415	5000	1781.882	-0.36236
Post_Non_Methane	130.454	-136.043	181	1.043	2.474	500	186.731	1.1462
Post_NOx	99.559	0.023	305	0	3.073	500	305.977	0.1954
Post_THC	998.645	-0.078	2750	0	2.745	5000	2741.219	-0.17562

QC_Aug.,6_1999_02:53016 — Description: Post Test Run 7 - Zero Check

Gas	Slope	Intercept	Cal_Gas	Zero_Avg	Span_Avg	Ra[illegible]	[illegible]	% Error
Pre_CO	100.54	-0.047	0	0	0	[illegible]	[illegible]	0
Pre_CO2	25.005	-0.061	0	0.002	0	[illegible]	[illegible]	-0.208
Pre_O2	24.627	0.004	0	0	0.002	[illegible]	[illegible]	0.24
Pre_Methane	1255.399	-1263.228	0	1.006	1.008	[illegible]	[illegible]	0.03372
Pre_Non_Methane	0	0	0	1.043	1.044	[illegible]	[illegible]	0
Pre_NOx	49.955	-0.74	0	0.005	0.027	[illegible]	[illegible]	0.1212
Pre_THC	498.544	-0.019	0	0	0	[illegible]	[illegible]	0
Post_CO	40.411	-0.002	0	0.014	0.024	200	0.972	0.486
Post_CO2	2	-0.001	0	0	0	10	0	0
Post_O2	4.993	0	0	0	0	25	0	0
Post_Methane	1257.239	-1254.745	0	0.998	0.999	5000	0.717	0.01434
Post_Non_Methane	130.454	-136.043	0	1.043	1.062	500	5.099	1.0198
Post_NOx	99.559	0.023	0	0	0	500	0	0
Post_THC	998.645	-0.078	0	0	0	5000	0	0

Colorado State University: Engines & Energy Conversion Laboratory

Test Program: EPA RICE Testing:

Description: Reference Method Analyzers Daily Calibrations

Date: August 4, 1999

Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Engine Type: Waukesha

Test Points: Calibrations between Runs 9 and 1

QC_Aug.,4_1999_23:22:47 Description: NOx Sample Bias

Gas	Slope	Intercept	Cal_Gas	Zero_Avg	Span_Avg	Range	ppm_or_%	% Error
Pre_CO	100.54	-0.047	450	0	4.458	1000	448.13	-0.187
Pre_CO2	24.834	-0.061	9.04	0.002	0.376	25	9.282	0.968
Pre_O2	24.627	0.004	12	0	0.495	25	12.2	0.8
Pre_Methane	1268.052	-1273.329	2750	1.004	3.176	5000	2754.077	0.08154
Pre_Non_Methane	130.478	-140.889	278	1.08	3.266	500	285.559	1.5118
Pre_NOx	49.955	-0.74	304	0.015	6.06	500	302.005	-0.399
Pre_THC	498.544	-0.019	2750	0	5.606	5000	2795.036	0.90072
Post_CO	40.411	-0.002	43.8	0	1.097	200	44.338	0.269
Post_CO2	2	-0.001	5.16	0	2.574	10	5.148	-0.12
Post_O2	4.993	0	12	0	2.401	25	11.989	-0.044
Post_Methane	1256.513	-1254.532	2750	0.998	3.182	5000	2744.118	-0.11764
Post_Non_Methane	129.16	-136.903	278	1.06	3.187	500	274.698	-0.6604
Post_NOx	99.559	0.023	305	0	3.067	500	305.32	0.064
Post_THC	998.645	-0.078	2750	0	2.754	5000	2749.878	-0.00244

QC_Aug.,4_1999_23:19:00 Description: Daily Calibration - Span Check

Gas	Slope	Intercept	Cal_Gas	Zero_Avg	Span_Avg	Range	ppm_or_%	% Error
Pre_CO	100.54	-0.047	450	0	4.458	1000	448.13	-0.187
Pre_CO2	24.834	-0.061	9.04	0.002	0.376	25	9.282	0.968
Pre_O2	24.627	0.004	12	0	0.495	25	12.2	0.8
Pre_Methane	1268.052	-1273.329	2750	1.004	3.176	5000	2754.077	0.08154
Pre_Non_Methane	130.478	-140.889	278	1.08	3.268	500	285.559	1.5118
Pre_NOx	49.955	-0.74	304	0.015	6.09	500	303.451	0.1078
Pre_THC	498.544	-0.019	2750	0	5.606	5000	2795.036	0.90072
Post_CO	40.411	-0.002	43.8	0	1.097	200	44.338	0.269
Post_CO2	2	-0.001	5.16	0	2.574	10	5.148	-0.12
Post_O2	4.993	0	12	0	2.401	25	11.989	-0.044
Post_Methane	1256.513	-1254.532	2750	0.998	3.182	5000	2744.118	-0.11764
Post_Non_Methane	129.16	-136.903	278	1.06	3.187	500	274.698	-0.6604
Post_NOx	99.559	0.023	305	0	3.057	500	304.358	-0.1264
Post_THC	998.645	-0.078	2750	0	2.754	5000	2749.878	-0.00244

QC_Aug.,4_1999_17:19:53 Description: Post Run - Span Check

Gas	Slope	Intercept	Cal_Gas	Zero_Avg	Span_Avg	Range	ppm_or_%	% Error
Pre_CO	100.54	-0.047	450	0	4.454	1000	447.733	-0.2267
Pre_CO2	24.834	-0.061	9.04	0.002	0.366	25	9.039	-0.004
Pre_O2	24.627	0.004	12	0	0.488	25	12.029	0.116
Pre_Methane	1268.052	-1273.329	2750	1.004	3.176	5000	2753.458	0.06916
Pre_Non_Methane	130.478	-140.889	278	1.08	3.237	500	281.517	0.7034
Pre_NOx	49.955	-0.74	304	0.015	6.157	500	306.808	0.5616
Pre_THC	498.544	-0.019	2750	0	5.46	5000	2722.012	-0.55976
Post_CO	40.411	-0.002	43.8	0	1.105	200	44.658	0.4295
Post_CO2	2	-0.001	5.16	0	2.583	10	5.164	0.04
Post_O2	4.993	0	12	0	2.403	25	11.999	-0.004
Post_Methane	1256.513	-1254.532	2750	0.998	3.182	5000	2744.118	-0.11764
Post_Non_Methane	129.16	-136.903	278	1.06	3.222	500	279.215	0.243
Post_NOx	99.559	0.023	305	0	3.061	500	304.777	-0.0446
Post_THC	998.645	-0.078	2750	0	2.751	5000	2747.602	-0.04796

QC_Aug.,4_1999_23:08:15 Description: Daily Calibration - Zero Check

Gas	Slope	Intercept	Cal_Gas	Zero_Avg	Span_Avg	Range	ppm_or_%	% Error
Pre_CO	100.54	-0.047	0	0	0	1000	0	0
Pre_CO2	24.834	-0.061	0	0.002	0.002	25	0	0
Pre_O2	24.627	0.004	0	0	0	25	0	0
Pre_Methane	1268.052	-1273.329	0	1.004	1.065	5000	77.517	1.55034
Pre_Non_Methane	130.478	-140.889	0	1.08	1.085	500	0.68	0.136
Pre_NOx	49.955	-0.74	0	0.015	0.015	500	0.004	0.0008
Pre_THC	498.544	-0.019	0	0	0	5000	0	0
Post_CO	40.411	-0.002	0	0	0.011	200	0.454	0.227
Post_CO2	2	-0.001	0	0	0	10	0	0
Post_O2	4.993	0	0	0	0.001	25	0.006	0.024
Post_Methane	1256.513	-1254.532	0	0.998	0.998	5000	-0.665	-0.0133
Post_Non_Methane	129.16	-136.903	0	1.06	1.079	500	2.524	0.5048
Post_NOx	99.559	0.023	0	0	0	500	0	0
Post_THC	998.645	-0.078	0	0	0	5000	0	0

QC_Aug.,4_1999_16:58:38 Description: Post Run - Zero Check

Gas	Slope	Intercept	Cal_Gas	Zero_Avg	Span_Avg	Range	ppm_or_%	% Error
Pre_CO	100.54	-0.047	0	0	0	1000	0	0
Pre_CO2	24.834	-0.061	0	0.002	0.002	25	0	0
Pre_O2	24.627	0.004	0	0	0	25	0	0
Pre_Methane	1268.052	-1273.329	0	1.004	1.065	5000	77.466	1.54932
Pre_Non_Methane	130.478	-140.889	0	1.08	1.131	500	6.714	1.3428
Pre_NOx	49.955	-0.74	0	0.015	0.015	500	0	0
Pre_THC	498.544	-0.019	0	0	0	5000	0	0
Post_CO	40.411	-0.002	0	0	0.015	200	0.596	0.298
Post_CO2	2	-0.001	0	0	0	10	0	0
Post_O2	4.993	0	0	0	0	25	0.001	0.004
Post_Methane	1256.513	-1254.532	0	0.998	0.998	5000	-0.818	-0.01636
Post_Non_Methane	129.16	-136.903	0	1.06	1.057	500	-0.358	-0.0716
Post_NOx	99.559	0.023	0	0	0	500	0	0
Post_THC	998.645	-0.078	0	0	0	5000	0	0

Colorado State University: Engines & Energy Conversion Laboratory

Test Program: EPA RICE Testing:

Description: Reference Method Analyzers Daily Calibrations

Date: August 3, 1999

Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Engine Type: Waukesha

Test Points: Daily Calibrations

QC_Aug.,3_1999_09:52:58 Description: NOx Sample Bias

Gas	Slope	Intercept	Cal_Gas	Zero_Avg	Span_Avg	Range	ppm_or_%	% Error
Pre_CO	99.314	-0.047	450	0	4.532	1000	450	0
Pre_CO2	24.669	-0.059	9.04	0.002	0.369	25	9.04	0
Pre_O2	24.567	0.004	12	0	0.488	25	12	0
Pre_Methane	1298.888	-1370.902	2750	1.055	3.173	5000	2750	0
Pre_Non_Methane	127.878	-132.505	278	1.036	3.21	500	278	0
Pre_NOx	49.788	-0.251	304	0.005	6.057	500	301.294	0.5412
Pre_THC	499.226	-0.02	2750	0	5.509	5000	2750	0
Post_CO	40.216	-0.002	43.8	0	1.089	200	43.8	0
Post_CO2	2.021	-0.061	5.16	0.03	2.583	10	5.16	0
Post_O2	5	-0.014	12	0.003	2.403	25	12	0
Post_Methane	1246.612	-1242.007	2750	0.996	3.202	5000	2750	0
Post_Non_Methane	130.068	-140.089	278	1.077	3.214	500	278	0
Post_NOx	99.448	0.023	305	[illegible]	3.066	500	306.895	0.378
Post_THC	998.898	-0.078	2750	0	2.753	5000	2750	0

CAL_Aug.,30_1999_09:46:45 Description: Daily Calibration

Gas	Slope	Intercept	Cal_Gas	Zero_Avg	Span_Avg	Range	ppm_or_%	% Error
Pre_CO	99.314	-0.047	450	0	4.532	1000	450	0
Pre_CO2	24.669	-0.059	9.04	0.002	0.369	25	9.04	0
Pre_O2	24.567	0.004	12	0	0.488	25	12	0
Pre_Methane	1298.888	-1370.902	2750	1.055	3.173	5000	2750	0
Pre_Non_Methane	127.878	-132.505	278	1.038	3.21	500	278	0
Pre_NOx	49.788	-0.251	304	0.005	6.111	500	304	0
Pre_THC	499.226	-0.02	2750	0	5.509	5000	2750	0
Post_CO	40.216	-0.002	43.8	0	1.089	[illegible]	[illegible]	0
Post_CO2	2.021	-0.061	5.16	0.03	2.583	[illegible]	[illegible]	0
Post_O2	5	-0.014	12	0.003	2.403	[illegible]	[illegible]	0
Post_Methane	1246.612	-1242.007	2750	0.996	3.202	[illegible]	[illegible]	0
Post_Non_Methane	130.068	-140.089	278	1.077	3.214	[illegible]	[illegible]	0
Post_NOx	99.448	0.023	305	0	3.067	[illegible]	[illegible]	0
Post_THC	998.896	-0.078	2750	0	2.753	[illegible]	[illegible]	0

Colorado State University: Engines & Energy Conversion Laboratory

Test Program: EPA RICE Testing:

Description: Reference Method Analyzers Daily Calibrations

Date: August 2, 1999

Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Engine Type: Waukesha

Test Points: NOx Sample Bias and Converter

QC_Aug.,2_1999_20:00:02 — Description: NOx Sample Bias

Gas	Slope	Intercept	Cal_Gas	Zero_Avg	Span_Avg	Range	ppm_or_%	% Error
Pre_CO	101.032	-0.047	157	0	1.465	1000	148.002	-0.8998
Pre_CO2	25.041	-0.056	5.16	0.002	0.212	25	5.265	0.42
Pre_O2	24.811	0.004	4.38	0	0.176	25	4.365	-0.06
Pre_Methane	1286.474	-1360.626	2750	1.058	1.795	5000	949.059	-36.01882
Pre_Non_Methane	129.786	-140.506	278	1.083	1.769	500	89.086	-37.7828
Pre_NOx	49.854	-0.248	304	0.005	6.149	500	305.067	-0.2134
Pre_THC	498.787	-0.019	901	0	1.784	5000	889.999	-0.22002
Post_CO	40.181	-0.002	16.8	0	0.411	200	16.507	-0.1465
Post_CO2	1.998	-0.001	1.99	0	0.957	10	1.911	-0.79
Post_O2	5.004	-0.024	4.38	0.005	0.879	25	4.374	-0.024
Post_Methane	0	0	2750	1.008	0	5000	0	-55
Post_Non_Methane	0	0	278	1.034	0	500	0	-55.6
Post_NOx	99.519	0.023	305	0	2.998	500	298.352	-1.3298
Post_THC	889.328	-0.077	901	0	0.906	5000	896.516	-0.08968

QC_Aug.,2_1999_19:50:36 — Description: NOx Converter Check

Gas	Slope	Intercept	Cal_Gas	Zero_Avg	Span_Avg	Range	ppm_or_%	% Error
Pre_CO	101.032	-0.047	157	0	1.465	1000	148.002	-0.8998
Pre_CO2	25.041	-0.056	5.16	0.002	0.212	25	5.265	0.42
Pre_O2	24.811	0.004	4.38	0	0.176	25	4.365	-0.06
Pre_Methane	1286.474	-1360.626	901	1.058	1.795	5000	949.059	0.96118
Pre_Non_Methane	129.786	-140.506	91.1	1.083	1.769	500	89.086	-0.4028
Pre_NOx	49.854	-0.248	440.7	0.005	[illegible]	500	441.176	0.0092
Pre_THC	498.787	-0.019	901	0	1.784	5000	889.999	-0.22002
Post_CO	40.181	-0.002	16.8	0	0.411	200	16.507	-0.1465
Post_CO2	1.998	-0.001	1.99	0	0.957	10	1.911	-0.79
Post_O2	5.004	-0.024	4.38	0.005	0.879	25	4.374	-0.024
Post_Methane	0	0	2750	1.008	0	5000	0	-55
Post_Non_Methane	0	0	278	1.034	0	500	0	-55.6
Post_NOx	99.519	0.023	440.7	0	4.279	500	425.628	-2.9748
Post_THC	989.328	-0.077	901	0	0.806	5000	896.516	-0.08968

Colorado State University: Engines & Energy Conversion Laboratory

Test Program: EPA RICE Testing:

Description: Reference Method Analyzers Daily Calibrations

Date: August 2, 1999

Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Engine Type: Waukesha

Test Points: Daily Calibrations

QC_Aug.,2_1999_17:14:39	Description: Calibration							
Gas	Slope	Intercept	Cal_Gas	Zero_Avg	Span_Avg	Range	ppm_or_%	% Error
Pre_CO	101.032	-0.047	450	0	4.454	1000	450	0
Pre_CO2	25.041	-0.056	9.04	0.002	0.363	25	9.04	0
Pre_O2	43.627	0.007	21.1	0	0.483	25	21.1	0
Pre_Methane	1286.474	-1360.626	2750	1.058	3.195	5000	2750	0
Pre_Non_Methane	129.786	-140.506	278	1.083	3.225	500	278	0
Pre_NOx	49.654	-0.248	304	0.005	6.127	500	304	0
Pre_THC	498.787	-0.019	2750	0	5.513	5000	2750	0
Post_CO	39.978	-0.002	109	0	2.727	200	109	0
Post_CO2	1.998	-0.001	5.16	0	2.583	10	5.16	0
Post_O2	5.004	-0.024	12	0.005	2.403	25	12	0
Post_Methane	0	0	2750	1.008	0	5000	0	-55
Post_Non_Methane	0	0	278	1.034	0	500	0	-55.6
Post_NOx	99.519	0.023	305	0	3.065	500	305	0
Post_THC	324.14	-0.025	901	0	2.78	5000	901	0

SAMPLE SYSTEM
RESPONSE TIME

STATION Colorado State

DATE 8-2-99

Pre-Catalyst Sample System	
TIME OF DAY	20:05:00
DURATION	1:10 MIN.
ANALYSER TYPE	SERVOMEX O_2 PMT
INITIAL READING	12%
FINAL READING	20.8%
Post-Catalyst Sample System	
TIME OF DAY	20:09:00
DURATION	1:10 MIN.
ANALYSER TYPE	NGA-2000 O_2 PMT
INITIAL READING	12%
FINAL READING	20.8%

SAMPLE LINE
LEAK CHECK

STATION Colorado State

DATE 8-2-99

PRE-Catalyst Leak Check	
TIME OF DAY	2:22:00 PM
DURATION	1 MIN.
INITIAL VACUUM	21.5 in. Hg
FINAL VACUUM	21.5 in. Hg
POST-Catalyst Leak Check	
TIME OF DAY	7:30:00 PM
DURATION	1 MIN.
INITIAL VACUUM	22 in. Hg
FINAL VACUUM	22 in. Hg

APPENDIX F

FTIR CALIBRATIONS

Colorado State University: Engines & Energy Conversion Laboratory

Test Program: EPA RICE Testing

Description: FTIR Daily Calibrations - Nicolet Rega 7000

Date: August 4, 1999 through August 6, 1999

Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Engine Type: Waukesha

Test Points: Pre Catalyst

4-Aug-99	COLO			CO2			NO			CH4			H2CO			NOX		
	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error
Pre Test																		
H2CO													10.262	10.33	-0.66			
H2CO Integrity													10.351	10.33	0.20			
H2CO Recovery													10.351	10.262	0.87			
CO	292.321	303	-3.52															
Multi Gas	191.858	190	0.98	65041.15	68000	-4.35	249.507	260	-4.04	1278.384	1300	-1.66				251.414	263	-4.41
Post Test																		
H2CO													10.306	10.33	-0.23			
H2CO Recovery													10.05455	10.33	-2.67			
H2CO Integrity													10.05455	10.306	-2.44			
CO	291.509	303	-3.79															
Multi Gas	190.976	190	0.51	65031.53	68000	-4.37	249.098	260	-4.19	1274.849	1300	-1.93				251.044	263	-4.55

5-Aug-99	COLO			CO2			NO			CH4			H2CO			NOX		
	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error
Pre Test																		
H2CO													10.408	10.33	0.76			
H2CO Integrity													10.147	10.33	-1.77			
H2CO Recovery													10.147	10.408	-2.51			
CO	295.577	303	-2.45															
Multi Gas	192.6118	190	1.37	64879.65	68000	-4.59	250.9864	260	-3.47	1293.981	1300	-0.46				252.9173	263	-3.83

6-Aug-99	COLO			CO2			NO			CH4			H2CO			NOX		
	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error
Pre Test																		
H2CO													10.277	10.33	-0.51			
H2CO Integrity													10.356	10.33	0.25			
H2CO Recovery													10.356	10.277	0.77			
CO	292.558	303	-3.45															
Multi Gas	190.934	190	0.49	65732.69	68000	-3.33	248.284	260	-4.51	1273.48	1300	-2.04				250.274	263	-4.84
Post Test																		
H2CO													10.277	10.66	-3.59			
H2CO Integrity													9.965	10.33	-3.53			
H2CO Recovery													9.965	10.277	-3.04			
CO	290.146	303	-4.24															
Multi Gas	189.77	190	-0.12	65755.8	68000	-3.30	247.916	260	-4.65	1267.999	1300	-2.46				250.03	263	-4.93

Colorado State University: Engines & Energy Conversion Laboratory

Test Program: EPA RICE Testing

Description: FTIR Daily Calibrations - Nicolet Magna 560

Date: August 4, 1999 through August 6, 1999

Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Engine Type: Waukesha

Test Points: Post Catalyst

4-Aug-99	COLO			CO2			NO			CH4			H2CO			NOX		
	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error
Pre Test																		
H2CO													10.682	10.66	0.21			
H2CO Integrity													10.686	10.66	0.24			
H2CO Recovery													10.686	10.682	0.04			
CO	46	43.8	5.02															
Multi Gas	187.282	190	-1.43	63606.63	68000	-6.46	250.328	260	-3.72	1291.738	1300	-0.64				252.824	263	-3.87
Post Test																		
H2CO													10.682	10.66	0.21			
H2CO Integrity													10.804	10.66	1.35			
H2CO Recovery													10.804	10.682	1.14			
CO	46.324	43.8	5.76															
Multi Gas	188.45	190	-0.82	65919.63	68000	-3.06	252.434	260	-2.91	1309.72	1300	0.75				255.006	263	-3.04

5-Aug-99	COLO			CO2			NO			CH4			H2CO			NOX		
	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error
Pre Test																		
H2CO													10.602	10.66	-0.54			
H2CO Integrity													10.466	10.66	-1.82			
H2CO Recovery													10.466	10.602	-1.28			
CO	46.084	43.8	5.21															
Multi Gas	186.998	190	-1.58	64019.27	68000	-5.85	250.716	260	-3.57	1279.418	1300	-1.58				252.9	263	-3.84

6-Aug-99	COLO			CO2			NO			CH4			H2CO			NOX		
	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error	Measured (PPM)	Actual (PPM)	Percent Error
Pre Test																		
H2CO													10.73	10.66	0.66			
H2CO Integrity													10.64	10.66	-0.19			
H2CO Recovery													10.64	10.73	-0.84			
CO	45.894	43.8	4.78															
Multi Gas	187.022	190	-1.57	64474.5	68000	-5.18	250.346	260	-3.71	1279.378	1300	-1.59				252.774	263	-3.89
Post Test																		
H2CO													10.71	10.66	0.47			
H2CO Integrity													10.594	10.66	-0.62			
H2CO Recovery													10.594	10.71	-1.08			
CO	45.732	43.8	4.41															
Multi Gas	185.73	190	-2.25	64132.74	68000	-5.69	248.166	260	-4.55	1280.9	1300	-1.47				250.652	263	-4.70

FTIR
SAMPLE SYSTEM
LEAK CHECK

STATION Colorado State

DATE 8-2-99

PRE-Catalyst Leak Check	
TIME OF DAY	23:01:00 _M
DURATION	1 MIN.
INITIAL FLOW RATE	10 mL/min ~~in. Hg~~
FINAL FLOW RATE	0 mL/min in. ~~Hg~~
POST-Catalyst Leak Check	
TIME OF DAY	23:02:00 _M
DURATION	1 MIN.
INITIAL FLOW RATE	10 mL/min in. ~~Hg~~
FINAL FLOW RATE	0 mL/min in. ~~Hg~~

F T I R
SAMPLE SYSTEM
LEAK CHECK

STATION Colorado State

DATE 8-2-99

Pre-Catalyst Sample System	
TIME OF DAY	20:52:15
DURATION	1 MIN.
INITIAL PRESSURE	112.2 in.Torr
FINAL PRESSURE	112.8 in. Torr
TIME OF DAY	21:09:10
DURATION	1 MIN.
INITIAL PRESSURE	125.6 in. Torr
FINAL PRESSURE	128.1 in. Torr

APPENDIX G

FTIR VALIDATION

	VALIDATION OF FTIR FOR THE ANALYSIS OF FORMALDEHYDE							
Date Conducted: 30 March 1999				OUTLET				
ANALYTE SPIKING: QUAD TRAINS								
FEDERAL REGISTER CALCULATION METHOD								
ENTER VALUE OF SPIKED LEVEL (CS)=				19.3				
Dilution Factor for Unspiked Samples =					0.80			
ENTER SPIKED AND UNSPIKED CONCENTRATIONS (COMPARABLE UNITS ASSUMED)								
	CONCENTRATION IN PPM (WET)							
	SPIKED SAMPLES		UNSPIKED SAMPLES					
RUN #	A	B	C	D	A-B	(A-B)^2	C-D	(C-D)^2
1	24.20	24.70	8.78	7.45	-0.50	0.25	1.33	1.77
2	24.40	23.80	7.45	7.41	0.60	0.36	0.04	0.00
3	24.30	23.60	7.47	7.36	0.70	0.49	0.11	0.01
4	24.20	24.40	7.50	7.30	-0.20	0.04	0.20	0.04
5	24.20	23.90	7.44	7.43	0.30	0.09	0.01	0.00
6	24.60	24.60	7.87	7.38	0.00	0.00	0.49	0.24
AVERAGE:	Sm=	24.24	Mm=	7.57				
STANDARD DEVIATION:								
	SPIKED SDs=		0.32					
	UNSPIKED SDu=		0.41					
	RELATIVE STD RSDs=		1.3%	(acceptable)				
	RELATIVE STD RSDu=		5.5%	(acceptable)				
BIAS:								
	Corrected Unspiked Conc =			6.06				
		B=	-1.114					
	STD OF MEAN SDm=		0.524					
		t-VALUE=	2.127					
	CRITICAL t-VALUE=		2.201					
	(n=12, alpha=95%)							
	Bias not statistically significant, CF not needed.							
	CORRECTION FACTOR		1.061	(Acceptable)				

VALIDATION OF FTIR FOR THE ANALYSIS OF ACETALDEHYDE

Date Conducted: 30 March 1999 OUTLET

ANALYTE SPIKING: QUAD TRAINS

FEDERAL REGISTER CALCULATION METHOD

ENTER VALUE OF SPIKED LEVEL (CS)= 4.8

Dilution Factor for Unspiked Samples = 0.80

ENTER SPIKED AND UNSPIKED CONCENTRATIONS (COMPARABLE UNITS ASSUMED)

CONCENTRATION IN PPM (WET)

	SPIKED SAMPLES		UNSPIKED SAMPLES					
RUN #	A	B	C	D	A-B	(A-B)^2	C-D	(C-D)^2
1	4.50	4.50	0.00	0.00	0.00	0.00	0.00	0.00
2	4.50	4.40	0.00	0.00	0.10	0.01	0.00	0.00
3	4.60	4.50	0.00	0.00	0.10	0.01	0.00	0.00
4	4.30	4.50	0.00	0.00	-0.20	0.04	0.00	0.00
5	4.50	4.20	0.00	0.00	0.30	0.09	0.00	0.00
6	4.30	4.40	0.00	0.00	-0.10	0.01	0.00	0.00

AVERAGE: Sm= 4.43 Mm= 0.00

STANDARD DEVIATION:

SPIKED SDs= 0.12

UNSPIKED SDu= 0.00

RELATIVE STD RSDs= 2.6% (acceptable)

RELATIVE STD RSDu= #DIV/0! #DIV/0!

BIAS:

Corrected Unspiked Conc = 0.00

B= -0.367

STD OF MEAN SDm= 0.115

t-VALUE= 3.175

CRITICAL t-VALUE= 2.201

(n=12, alpha=95%)

Bias is statistically significant

CORRECTION FACTOR 1.083 (Acceptable)

VALIDATION OF FTIR FOR THE ANALYSIS OF ACROLEIN

Date Conducted: 30 March 1999 OUTLET

ANALYTE SPIKING: QUAD TRAINS

FEDERAL REGISTER CALCULATION METHOD

ENTER VALUE OF SPIKED LEVEL (CS)= 17.0

Dilution Factor for Unspiked Samples = 0.80

ENTER SPIKED AND UNSPIKED CONCENTRATIONS (COMPARABLE UNITS ASSUMED)

CONCENTRATION IN PPM (WET)

	SPIKED SAMPLES		UNSPIKED SAMPLES					
RUN #	A	B	C	D	A-B	(A-B)^2	C-D	(C-D)^2
1	17.70	18.10	0.00	0.00	-0.40	0.16	0.00	0.00
2	18.20	17.90	0.00	0.00	0.30	0.09	0.00	0.00
3	18.40	18.40	0.00	0.00	0.00	0.00	0.00	0.00
4	17.40	17.40	0.00	0.00	0.00	0.00	0.00	0.00
5	18.20	17.90	0.00	0.00	0.30	0.09	0.00	0.00
6	17.90	19.00	0.00	0.00	-1.10	1.21	0.00	0.00

AVERAGE: Sm= 18.04 Mm= 0.00

STANDARD DEVIATION:

SPIKED SDs= 0.36

UNSPIKED SDu= 0.00

RELATIVE STD RSDs= 2.0% (acceptable)

RELATIVE STD RSDu= #DIV/0! #DIV/0!

BIAS:

Corrected Unspiked Conc = 0.00

B= 1.042

STD OF MEAN SDm= 0.359

t-VALUE= 2.898

CRITICAL t-VALUE= 2.201
(n=12, alpha=95%)

Bias is statistically significant

CORRECTION FACTOR 0.942 (Acceptable)

Colorado State University: Engines & Energy Conversion Laboratory

Test Program: EPA RICE Testing:

Description: FTIR Daily Calibrations - Nicolet Magna 560

Date: March 30, 1999 Time: 19:58:54 to 22:06:21

Engine Class: Natural Gas Fueled, Spark Ignited, Two-Stroke, Lean Burn Engine

Engine Type: Cooper-Bessemer GMV-4-TF

Test Points: Post Catalyst Validation

time	H2CO	(+-)H2CO	ACROL	(+-)ACROL	MECHO	(+-)MECHC	CRUD	(+-)CRUD	COLO	(+-)COLO	CO2	(+-)CO2	NO	(+-)NO	NO2	(+-)NO2	NOX	(+-)NOX	CH4	(+-)CH4	time
56.82	24.17	0.48	17.95	5.02	4.69	1.34	0.26	0.06	9.09	0.78	28498.45	726.15	120.4	8.62	20.72	17.13	141.12	25.76	630.89	11.05	56.82
116.14	24.72	0.48	17.71	5.11	4.48	1.36	0.25	0.06	9.05	0.77	28720.13	738.62	127.29	8.76	21.25	17.28	148.54	26.03	640.19	11	116.14
176.71	24.44	0.49	18.11	5.09	4.45	1.37	0.25	0.06	9.17	0.78	28781.54	732.85	127.56	8.77	21	17.39	148.56	26.16	641.67	10.94	176.71
236.04	23.95	0.49	18.15	5.08	4.6	1.37	0.26	0.06	9.07	0.76	28514.1	733.13	121.05	8.61	20.68	17.17	141.73	25.78	635.91	10.95	236.04
296.61	8.78	0.43	0	4.35	0	1.2	0	0.07	11.85	0.67	34743.05	665.37	155.63	7.86	24.26	14.82	179.9	22.68	781.22	11.14	296.61
355.94	7.45	0.41	0	4.3	0	1.15	0	0.07	12.17	0.66	35459.67	659.35	169.03	8.03	25.2	14.84	194.23	22.88	796.95	11.41	355.94
416.5	8.27	0.41	0	4.3	0	1.16	0	0.07	11.97	0.68	34957.54	672.25	152.45	7.81	23.85	14.89	176.3	22.71	792.37	11.28	416.5
475.82	23.5	0.47	18.28	5.01	4.71	1.32	0.26	0.06	9.33	0.76	28665.09	722.27	132.13	8.52	21.26	16.73	153.39	25.25	637.44	10.88	475.82
535.12	24.35	0.48	18.22	4.98	4.54	1.36	0.26	0.06	9.24	0.75	28534.46	723.5	125.48	8.57	20.99	16.92	146.47	25.48	639.78	10.84	535.12
595.73	23.83	0.48	17.86	5.06	4.37	1.36	0.25	0.06	9.35	0.75	28734.48	730.87	118.9	8.56	20.51	17.05	139.41	25.61	634.39	10.77	595.73
655.02	19.29	0.46	12.52	4.91	3	1.3	0.15	0.07	9.97	0.72	30699.29	716.74	138.21	8.48	22.1	16.48	160.3	24.95	671.38	10.75	655.02
715.59	7.45	0.41	0	4.27	0	1.16	0	0.07	12.17	0.65	35293.43	656.44	156.4	7.64	24.17	14.6	180.57	22.24	792.82	10.88	715.59
774.9	7.41	0.41	0	4.28	0	1.15	0	0.07	12.21	0.64	35375.21	664.99	153.05	7.61	23.8	14.54	176.85	22.15	804.42	10.75	774.9
835.51	14.72	0.43	8.31	4.58	1.66	1.22	0	0.07	10.57	0.68	32412.89	686.28	148.98	8.1	23.3	15.47	172.28	23.57	728.16	10.64	835.51
896.05	24.18	0.47	17.72	5.07	4.2	1.33	0.25	0.06	9.18	0.74	28671.21	725.03	115.92	8.39	20.45	16.95	136.37	25.33	639.17	10.52	896.05
956.64	24.27	0.47	18.37	5.02	4.55	1.33	0.26	0.06	9.07	0.76	28503.37	724.45	120.56	8.41	20.61	16.88	141.18	25.29	636.89	10.57	956.64
1015.95	23.63	0.47	18.37	5.13	4.45	1.33	0.26	0.06	9.17	0.74	28584.71	735.77	124.08	8.55	20.89	17.04	144.97	25.59	629.76	10.61	1015.95
1076.56	15.77	0.44	9.7	4.71	1.87	1.25	0.08	0.07	10.46	0.73	31889.8	711.12	132.87	8.08	22.3	16.05	155.18	24.13	716.84	10.87	1076.56
1137.1	7.47	0.43	0	4.32	0	1.2	0	0.07	12.11	0.65	35386.03	669.94	160.13	7.75	24.79	14.63	184.92	22.39	818.07	10.81	1137.1
1197.74	7.36	0.42	0	4.34	0	1.19	0	0.07	12.08	0.66	35493.09	664.5	160.32	7.82	24.64	14.73	184.96	22.55	804.77	11.13	1197.74
1256.99	7.17	0.42	0	4.24	0	1.18	0	0.07	12.25	0.67	35240.63	657.85	153.33	7.58	24.04	14.62	177.38	22.21	792.94	11.19	1256.99
1317.59	21.85	0.46	16.94	4.92	4.22	1.3	0.23	0.06	9.24	0.72	29089.8	719.73	130.88	8.29	21.71	16.49	152.58	24.78	647.73	10.93	1317.59
1378.16	24.23	0.48	17.39	5.13	4.33	1.35	0.24	0.06	9.17	0.77	28944.17	738.26	129.07	8.7	21.17	17.24	150.24	25.94	650.77	10.92	1378.16
1437.52	24.46	0.48	17.44	5.14	4.45	1.35	0.26	0.06	9.21	0.78	28596.65	742.58	117.28	8.56	20.31	17.34	137.59	25.9	637.57	10.98	1437.52
1498.03	7.54	0.41	0	4.33	0	1.16	0	0.07	11.98	0.67	35194.52	663.51	161.8	7.87	24.6	14.95	186.41	22.82	789.76	11.54	1498.03
1557.37	7.26	0.41	0	4.39	0	1.17	0	0.07	12.06	0.69	35335.38	675.86	159.61	7.97	24.39	15.13	184.01	23.1	805.09	11.6	1557.37
1617.92	7.44	0.42	0	4.25	0	1.19	0	0.07	12.18	0.69	35167.05	658.12	152.3	7.7	23.81	15.03	176.11	22.73	797.18	11.65	1617.92
1677.31	21.29	0.47	16.49	4.87	3.88	1.31	0.22	0.06	9.55	0.75	29177.61	699.6	135.25	8.45	21.59	16.65	156.84	25.1	655.75	11.24	1677.31
1737.81	24.16	0.48	18.23	5.05	4.48	1.34	0.26	0.06	9.3	0.78	28363.99	728.07	125.51	8.65	20.77	17.42	146.28	26.08	630.4	11.33	1737.81
1797.15	23.87	0.47	17.85	5.18	4.21	1.34	0.25	0.07	9.16	0.81	28604.63	747.33	118.14	8.81	20.35	17.9	138.49	26.7	639.2	11.48	1797.15
1857.7	14.03	0.45	7.89	4.75	0	1.27	0	0.07	10.84	0.74	32804.77	713.91	153.43	8.48	23.68	16.55	177.11	25.03	739.93	11.81	1857.7
1917.09	7.44	0.42	0	4.42	0	1.18	0	0.07	12.02	0.68	35250.89	676.77	160.18	7.98	24.53	15.32	184.71	23.3	787.82	11.82	1917.09
1977.6	7.43	0.42	0	4.38	0	1.19	0	0.07	12.25	0.69	35165.07	672.6	149.07	7.8	23.46	15.27	172.53	23.07	799.19	11.81	1977.6
2038.19	19.88	0.45	15.06	4.92	3.68	1.28	0.19	0.07	9.76	0.76	29871.38	724.41	133.02	8.5	21.64	16.95	154.65	25.45	668.89	11.38	2038.19
2097.49	24.58	0.49	17.92	5.21	4.26	1.38	0.25	0.07	9.26	0.78	28719.55	759.43	121.59	8.89	20.5	17.82	142.09	26.72	635.81	11.2	2097.49
2158.15	24.6	0.49	19	5.21	4.36	1.37	0.26	0.06	9.22	0.79	28385.29	751.04	117.34	8.78	20	17.75	137.34	26.52	633.36	11.25	2158.15
2217.38	7.87	0.43	0	4.52	0	1.21	0	0.07	11.99	0.69	35128.98	690.15	161.6	8.2	24.23	15.75	185.83	23.95	794.65	11.6	2217.38
2278.16	7.38	0.43	0	4.39	0	1.2	0	0.07	12.16	0.68	35287.35	685.42	161.23	8.06	24.46	15.46	185.69	23.52	802.46	11.67	2278.16
2338.53	9.78	0.42	0	4.49	0	1.19	0	0.07	11.68	0.69	33931.62	683.56	145.68	7.92	23.16	15.53	168.84	23.46	769.19	11.57	2338.53
2397.92	23.95	0.48	18.19	5.16	4.5	1.36	0.26	0.06	9.19	0.78	28509.38	741.5	124.02	8.74	20.45	17.59	144.47	26.32	631.57	11.2	2397.92
2457.16	23.78	0.48	18.58	5.17	4.22	1.36	0.26	0.06	9.06	0.77	28416.17	733.79	124.6	8.82	20.42	17.67	145.02	26.49	636.81	11.18	2457.16
2517.76	20.33	0.47	14.32	4.96	3.64	1.32	0.19	0.07	9.79	0.76	29680.98	734.34	123.07	8.62	20.95	17.35	144.02	25.98	665.14	11.31	2517.76
2578.31	7.46	0.42	0	4.51	0	1.19	0	0.07	12.02	0.69	35062.11	691.48	152.58	7.95	23.67	15.52	176.26	23.47	795.78	11.57	2578.31
2637.69	7.44	0.42	0	4.39	0	1.19	0	0.07	12.18	0.68	35186.82	678	162.27	8.07	24.4	15.37	186.67	23.44	800.87	11.62	2637.69
2698.2	7.27	0.42	0	4.36	0	1.19	0	0.07	12.16	0.68	35132.26	680.63	153.2	7.86	23.79	15.21	176.99	23.06	790.46	11.54	2698.2
2757.53	7.39	0.42	0	4.42	0	1.18	0	0.07	12.16	0.69	35198.15	685.92	161.69	8.05	24.6	15.37	186.29	23.42	806.06	11.54	2757.53
2818.09	7.4	0.43	0	4.5	0	1.21	0	0.07	11.92	0.69	35403.61	693.5	167.06	8.31	24.92	15.53	191.98	23.84	793.05	11.53	2818.09
2877.44	7.36	0.43	0	4.48	0	1.2	0	0.07	12.03	0.69	35157.11	679.23	151.8	8.01	23.7	15.42	175.49	23.43	790.17	11.54	2877.44
2938	7.27	0.42	0	4.42	0	1.17	0	0.07	12.14	0.69	35140.95	680.82	155.32	8.01	24.07	15.32	179.4	23.33	797.15	11.55	2938
2997.4	7.3	0.42	0	4.47	0	1.19	0	0.07	12.12	0.7	35396.68	686.88	162.65	8.18	24.71	15.49	187.36	23.67	789.03	11.53	2997.4
3057.91	7.28	0.42	0	4.46	0	1.18	0	0.07	12.04	0.68	35272.5	691.98	151.44	8.03	24	15.48	175.44	23.51	802.58	11.5	3057.91
3118.53	7.26	0.42	0	4.46	0	1.19	0	0.07	12.07	0.69	35190.3	680.62	150.08	7.97	23.83	15.47	173.92	23.44	801.2	11.58	3118.53
3179.03	7.14	0.42	0	4.5	0	1.17	0	0.07	12.16	0.7	35282.46	688.6	158.38	8.1	24.45	15.45	182.83	23.54	796.45	11.57	3179.03
3238.38	7.23	0.42	0	4.52	0	1.19	0	0.07	12.19	0.7	35278.64	698.9	153.32	8.15	24.28	15.71	177.6	23.85	796.24	11.59	3238.38
3298.92	6.48	0.4	0	4.44	0	1.13	0	0.07	10.61	0.68	31403.41	688.88	123.98	7.57	22.76	15.23	146.74	22.8	671.47	9.86	3298.92
3358.32	0.93	0.31	0	2.23	1.25	0.88	0	0.02	0	0.34	696.84	357.35	0	3.5	10.12	9.37	0	12.87	11.11	1.18	3358.32
3417.55	0.96	0.3	0	1.96	0	0.85	0	0.02	0.35	0.3	734.15	313.16	0	3.06	9.18	8.79	0	11.85	8.66	1.09	3417.55
3478.16	2.48	0.32	0	2.46	0.93	0.9	0	0.03	3.22	0.38	8737.88	395.1	32.4	3.81	12.37	9.5	44.77	13.3	152.42	2.88	3478.16

Colorado State University: Engines & Energy Conversion Laboratory

Test Program: EPA RICE Testing:
Description: FTIR Daily Calibrations - Nicolet Magna 560
Date: March 30, 1999 **Time:** 19:58:54 to 22:06:21

Engine Class: Natural Gas Fueled, Spark Ignited, Two-Stroke, Lean Burn Engine
Engine Type: Cooper-Bessemer GMV-4-TF
Test Points: Post Catalyst Validation

C2H4	(+-)C2H4	C2H6	(+-)C2H6	C3H8	(+-)C3H8	THC	(+-)THC	H2O	(+-)H2O	SF6	(+-)SF6	MEOH	(+-)MEOH	NMHC	(+-)NMHC
2.22	1.18	64.62	6.68	13.15	4.3	871.02	70.02	166787.8	2046.62	0.34	0.03	6.16	4.37	871.02	70.02
2.16	1.2	65.69	6.7	13.26	4.31	883.66	70.45	167416.9	2044.03	0.33	0.03	6.14	4.41	883.66	70.45
2.24	1.2	65.69	6.74	13.19	4.34	885.26	70.72	168259.7	1976.62	0.33	0.03	6.21	4.35	885.26	70.72
2.28	1.2	65.34	6.69	13.24	4.31	878.38	69.68	167115.3	2047.14	0.34	0.03	5.91	4.52	878.38	69.68
2.92	1.02	78.13	6.39	13.79	4.11	1067.9	64.92	152436.4	2428.37	0	0.03	0	3.79	1067.9	64.92
3.03	1.01	79.66	6.3	13.54	4.06	1087.84	65.3	150931.8	2447.81	0	0.03	0	3.74	1087.84	65.3
2.99	1.01	79.51	6.34	13.63	4.08	1082.62	65.31	151271.7	2487.89	0	0.03	0	3.77	1082.62	65.31
2.21	1.18	65.41	6.63	13.08	4.26	879.63	69.28	165033.6	2131.47	0.34	0.03	5.51	4.19	879.63	69.28
2.28	1.17	65.66	6.68	13.09	4.3	882.86	69.62	166181.2	2073.26	0.34	0.03	6.05	4.45	882.86	69.62
2.15	1.19	64.95	6.68	13.11	4.3	875.32	70.17	166748.6	2061.66	0.33	0.03	6.55	4.34	875.32	70.17
2.51	1.16	68.18	6.55	12.98	4.21	923.07	68.11	163816.7	2171.92	0.23	0.03	4.43	4.25	923.07	68.11
2.99	1.01	78.79	6.36	13.45	4.09	1081.26	64.68	150492.4	2450.3	0	0.03	0	3.7	1081.26	64.68
3.06	1.01	80.02	6.38	13.55	4.11	1096.94	64.18	150932.9	2469.11	0	0.03	0	3.77	1096.94	64.18
2.61	1.08	73.21	6.43	13.26	4.13	997.12	66.19	158215.4	2312.93	0.15	0.03	0	3.95	997.12	66.19
2.16	1.19	65.11	6.67	13.04	4.29	880.79	68.72	166812.1	2041.68	0.33	0.03	6.7	4.39	880.79	68.72
2.25	1.18	65.06	6.66	13.09	4.3	878.47	69.41	166822.8	2039.81	0.34	0.03	6.24	4.37	878.47	69.41
2.23	1.21	64.41	6.65	12.75	4.28	868.17	69.46	167398.1	2037.56	0.34	0.03	6.4	4.43	868.17	69.46
2.48	1.11	72.28	6.48	13.33	4.17	982.66	67.42	160839.4	2289.19	0.16	0.03	0	4.12	982.66	67.42
3.05	1.02	81.52	6.36	13.68	4.09	1115.42	64.28	150715.2	2493.81	0	0.03	0	3.65	1115.42	64.28
2.97	1.02	80.07	6.4	13.52	4.12	1097.21	65.13	151948.9	2436.69	0	0.03	0	3.84	1097.21	65.13
2.96	1	78.96	6.34	13.61	4.08	1082.12	64.6	150640.9	2451.57	0	0.03	0	3.7	1082.12	64.6
2.17	1.16	66.23	6.58	13	4.23	892.37	68.26	163788	2186.69	0.32	0.03	5.27	4.23	892.37	68.26
2.26	1.21	66.43	6.76	13.02	4.35	896.36	70.51	167773.5	2020.91	0.33	0.03	6.92	4.45	896.36	70.51
2.26	1.21	65.37	6.74	13.02	4.33	879.6	70.51	168248.7	2003.94	0.33	0.03	6.54	4.45	879.6	70.51
2.79	1.02	79.25	6.38	13.51	4.1	1078.49	65.64	152474	2418.5	0	0.03	0	3.76	1078.49	65.64
2.98	1.04	80.69	6.37	13.57	4.1	1098.86	65.55	152981.7	2446.96	0	0.03	0	3.74	1098.86	65.55
3.08	1	79.8	6.35	13.68	4.09	1088.87	65.28	152163.6	2408.3	0	0.03	0	3.72	1088.87	65.28
2.24	1.15	67.32	6.61	13.25	4.25	904.27	68.63	164190.6	2106.27	0.31	0.03	4.85	4.23	904.27	68.63
2.29	1.19	65.08	6.69	13.02	4.3	871.09	70.84	167492.8	2011.09	0.34	0.03	6.42	4.35	871.09	70.84
2.29	1.22	65.7	6.75	13.17	4.34	882.57	71.63	169436	1939.15	0.33	0.03	6.72	4.45	882.57	71.63
2.83	1.12	75.15	6.54	13.42	4.21	1014.81	69.34	161926.5	2246.43	0.12	0.03	0	4.12	1014.81	69.34
2.96	1.04	78.97	6.36	13.38	4.09	1075.69	65.9	153616.5	2430.37	0	0.03	0	3.79	1075.69	65.9
2.94	1.03	80.17	6.35	13.64	4.08	1091.44	66.06	153409.1	2422.38	0	0.03	0	3.83	1091.44	66.06
2.22	1.16	68.48	6.56	13.09	4.22	920.62	69.3	164721.5	2151.22	0.28	0.03	4.32	4.23	920.62	69.3
2.18	1.23	65.57	6.76	13.1	4.35	878.12	71.4	169557	1961.97	0.33	0.03	6.62	4.46	878.12	71.4
2.27	1.23	65.29	6.75	13.19	4.34	875.27	71.42	169485.1	1945.91	0.34	0.03	6.21	4.45	875.27	71.42
2.67	1.07	79.79	6.42	13.63	4.13	1085.11	66.82	156838.7	2367.14	0	0.03	0	3.9	1085.11	66.82
2.95	1.03	80.51	6.4	13.72	4.12	1095.98	65.88	154773.7	2422.72	0	0.03	0	3.8	1095.98	65.88
2.77	1.06	77.67	6.37	13.53	4.1	1052.51	66.66	155670.1	2391.01	0.05	0.03	0	3.96	1052.51	66.66
2.21	1.21	65.48	6.72	13.09	4.32	873.23	70.6	168758.3	1968.75	0.34	0.03	5.44	4.57	873.23	70.6
2.16	1.22	66.01	6.77	13.2	4.35	880.31	71.54	169364.9	1909.08	0.34	0.03	6.41	4.4	880.31	71.54
2.38	1.17	68.78	6.64	13.04	4.27	917.14	70.19	167148.6	2045.86	0.27	0.03	5.16	4.41	917.14	70.19
3.1	1.06	80.27	6.43	13.69	4.13	1088.25	66.77	156318.8	2390.85	0	0.03	0	4.07	1088.25	66.77
3.05	1.03	81.05	6.43	13.7	4.14	1095.35	66.17	154982.6	2389.89	0	0.03	0	3.87	1095.35	66.17
2.97	1.03	79.94	6.38	13.57	4.11	1081.07	66	153904.8	2435.34	0	0.03	0	3.79	1081.07	66
2.92	1.04	81.5	6.4	13.72	4.12	1101.81	66.7	154731.4	2426.3	0	0.03	0	3.8	1101.81	66.7
2.95	1.06	80.12	6.43	13.42	4.13	1083.81	66.9	155954.8	2409.45	0	0.03	0	3.93	1083.81	66.9
2.88	1.06	79.74	6.4	13.53	4.12	1080.08	66.37	155125.8	2389.5	0	0.03	0	3.87	1080.08	66.37
3.03	1.04	80.56	6.41	13.67	4.12	1090.13	65.96	154488.8	2416.65	0	0.03	0	3.82	1090.13	65.96
2.91	1.05	79.29	6.37	13.3	4.1	1077.35	66.29	155306	2409.16	0	0.03	0	3.89	1077.35	66.29
2.81	1.05	80.8	6.39	13.48	4.11	1095.68	66.52	155357.5	2425.8	0	0.03	0	3.89	1095.68	66.52
2.9	1.05	80.66	6.38	13.59	4.11	1094.36	66.46	154874.3	2402.78	0	0.03	0	3.8	1094.36	66.46
3.08	1.06	80.23	6.37	13.19	4.1	1087.4	66.27	154966.2	2427.39	0	0.03	0	3.77	1087.4	66.27
2.87	1.07	80.11	6.4	13.1	4.12	1086.28	67.04	156179.5	2420.65	0	0.03	0	3.93	1086.28	67.04
2.51	1.05	69.27	5.8	11.29	3.73	920.17	61.86	151263.2	2564.15	0	0.03	0	3.81	920.17	61.86
0	0.52	2.91	1.71	1.22	1.1	0	23.89	76832.5	1719.74	0	0.01	0	1.95	0	23.89
0	0.46	2.52	1.51	1.17	0.97	0	21.45	66430.98	1482.3	0	0.01	0	1.67	0	21.45
0	0.58	19.09	2.42	3.5	1.56	216.9	29.92	84791.53	1937.9	0	0.01	0	2.23	216.9	29.92

VALIDATION OF FTIR FOR THE ANALYSIS OF ACROLEIN

Date Conducted: 30 March 1999 INLET

ANALYTE SPIKING: QUAD TRAINS

FEDERAL REGISTER CALCULATION METHOD

ENTER VALUE OF SPIKED LEVEL (CS)= 15.0

Dilution Factor for Unspiked Samples = 0.80

ENTER SPIKED AND UNSPIKED CONCENTRATIONS (COMPARABLE UNITS ASSUMED)

CONCENTRATION IN PPM (WET)

	SPIKED SAMPLES		UNSPIKED SAMPLES					
RUN #	A	B	C	D	A-B	(A-B)^2	C-D	(C-D)^2
1	14.90	14.80	0.00	0.00	0.10	0.01	0.00	0.00
2	14.40	14.60	0.00	0.00	-0.20	0.04	0.00	0.00
3	14.40	14.20	0.00	0.00	0.20	0.04	0.00	0.00
4	14.90	14.80	0.00	0.00	0.10	0.01	0.00	0.00
5	14.60	14.70	0.00	0.00	-0.10	0.01	0.00	0.00
6	14.50	14.70	0.00	0.00	-0.20	0.04	0.00	0.00

AVERAGE: Sm= 14.63 Mm= 0.00

STANDARD DEVIATION:

SPIKED SDs= 0.11

UNSPIKED SDu= 0.00

RELATIVE STD RSDs= 0.8% (acceptable)

RELATIVE STD RSDu= #DIV/0! #DIV/0!

BIAS:

Corrected Unspiked Conc = 0.00

B= -0.375

STD OF MEAN SDm= 0.112

t-VALUE= 3.354

CRITICAL t-VALUE= 2.201
(n=12, alpha=95%)

Bias is statistically significant

CORRECTION FACTOR 1.026 (Acceptable)

	VALIDATION OF FTIR FOR THE ANALYSIS OF FORMALDEHYDE							
Date Conducted: 30 March 1999				INLET				
ANALYTE SPIKING: QUAD TRAINS								
FEDERAL REGISTER CALCULATION METHOD								
ENTER VALUE OF SPIKED LEVEL (CS)=				20.9				
Dilution Factor for Unspiked Samples =					0.80			
ENTER SPIKED AND UNSPIKED CONCENTRATIONS (COMPARABLE UNITS ASSUMED)								
	CONCENTRATION IN PPM (WET)							
	SPIKED SAMPLES		UNSPIKED SAMPLES					
RUN #	A	B	C	D	A-B	(A-B)^2	C-D	(C-D)^2
1	34.70	34.40	15.80	15.90	0.30	0.09	-0.10	0.01
2	34.40	34.30	15.90	16.00	0.10	0.01	-0.10	0.01
3	34.10	34.90	15.80	15.90	-0.80	0.64	-0.10	0.01
4	34.30	35.00	16.00	16.10	-0.70	0.49	-0.10	0.01
5	35.10	35.30	16.00	15.90	-0.20	0.04	0.10	0.01
6	34.90	35.20	16.00	16.00	-0.30	0.09	0.00	0.00
AVERAGE:	Sm=	34.72	Mm=	15.94				
STANDARD DEVIATION:								
	SPIKED SDs=		0.34					
	UNSPIKED SDu=		0.06					
	RELATIVE STD RSDs=		1.0%	(acceptable)				
	RELATIVE STD RSDu=		0.4%	(acceptable)				
BIAS:								
	Corrected Unspiked Conc =			12.75				
		B=	1.063					
	STD OF MEAN SDm=		0.343					
		t-VALUE=	3.102					
	CRITICAL t-VALUE=		2.201					
	(n=12, alpha=95%)							
	Bias is statistically significant							
	CORRECTION FACTOR		0.952	(Acceptable)				
END OF ANALYTE SPIKING SPREADSHEET. PRESS "HOME"-KEY TO RETURN.								

VALIDATION OF FTIR FOR THE ANALYSIS OF ACETALDEHYDE

Date Conducted: 30 March 1999 INLET

ANALYTE SPIKING: QUAD TRAINS

FEDERAL REGISTER CALCULATION METHOD

ENTER VALUE OF SPIKED LEVEL (CS)= 4.5

Dilution Factor for Unspiked Samples = 0.80

ENTER SPIKED AND UNSPIKED CONCENTRATIONS (COMPARABLE UNITS ASSUMED)

CONCENTRATION IN PPM (WET)

	SPIKED SAMPLES		UNSPIKED SAMPLES					
RUN #	A	B	C	D	A-B	(A-B)^2	C-D	(C-D)^2
1	3.90	3.80	0.00	0.00	0.10	0.01	0.00	0.00
2	3.50	3.60	0.00	0.00	-0.10	0.01	0.00	0.00
3	3.70	3.50	0.00	0.00	0.20	0.04	0.00	0.00
4	3.90	3.80	0.00	0.00	0.10	0.01	0.00	0.00
5	3.70	3.70	0.00	0.00	0.00	0.00	0.00	0.00
6	4.00	3.80	0.00	0.00	0.20	0.04	0.00	0.00

AVERAGE: Sm= 3.74 Mm= 0.00

STANDARD DEVIATION:

SPIKED SDs= 0.10

UNSPIKED SDu= 0.00

RELATIVE STD RSDs= 2.6% (acceptable)

RELATIVE STD RSDu= #DIV/0! #DIV/0!

BIAS:

Corrected Unspiked Conc = 0.00

B= -0.758

STD OF MEAN SDm= 0.096

t-VALUE= 7.921

CRITICAL t-VALUE= 2.201
(n=12, alpha=95%)

Bias is statistically significant

CORRECTION FACTOR 1.203 (Acceptable)

Colorado State University: Engines & Energy Conversion Laboratory

Test Program: EPA RICE Testing:
Description: FTIR Daily Calibrations - Nicolet Rega 7000
Date: March 30, 1999 Time: 19:42:34 to 22:02:12

Engine Class: Natural Gas Fueled, Spark Ignited, Two-Stroke, Lean Burn Engine
Engine Type: Cooper-Bessemer GMV-4-TF
Test Points: Pre Catalyst Validation

time	H2CO	(+-)H2CO	ACROL	(+-)ACROL	MECHO	(+-)MECHC	COLO	(+-)COLO	CO2	(+-)CO2	NO	(+-)NO	NO2	(+-)NO2	NOX	(+-)NOX	CH4	(+-)CH4	C2H4	(+-)C2H4	C2H6
58.35	15.67	0.35	0.35	1.23	-0.83	1.19	78.34	0.4	34981.95	444.16	151.73	8.49	29.68	5.9	181.4	14.39	813.94	7.31	8.79	0.25	62.98
114.78	15.81	0.35	0.33	1.21	-0.73	1.21	79.35	0.42	34939.74	438.94	146.32	8.3	29.45	5.92	175.77	14.22	810	7.31	8.9	0.25	62.8
171.22	15.91	0.35	0.44	1.25	-0.68	1.2	78.88	0.41	35105.64	440.82	148.58	8.4	29.41	5.92	177.99	14.33	807.83	7.32	8.99	0.25	62.65
227.65	19.6	0.38	4.93	1.3	0.94	1.29	73.68	0.37	33069.85	454.76	147.39	8.49	27.2	5.93	174.59	14.42	764.25	7.37	8.35	0.26	59.59
284.07	33.85	0.53	17.83	1.86	5.1	1.76	60.81	0.28	27079.87	517.56	110.59	8.23	19.35	7.24	129.95	15.47	631.69	7.7	7.03	0.38	49.65
340.52	31.34	0.51	21.34	1.9	6.64	1.7	58.67	0.27	26152.93	497.61	108.69	7.83	19.94	6.56	128.63	14.39	606.38	7.35	6.93	0.39	47.67
396.95	37.35	0.57	14.18	1.71	3.64	1.86	64.15	0.3	28828.72	528.61	128.95	8.75	20.49	7.21	149.44	15.96	658.87	7.94	7.38	0.35	51.62
453.37	35.24	0.54	14.86	1.73	3.88	1.78	64.18	0.3	28456.12	508.83	118.33	8.34	20.63	7.06	138.96	15.41	654.65	7.82	7.35	0.35	51.13
509.8	34.7	0.54	14.89	1.69	3.85	1.77	63.59	0.29	28389.28	514.38	122.94	8.43	20.87	6.96	143.8	15.38	655.54	7.79	7.28	0.34	51.26
566.23	34.41	0.53	14.83	1.74	3.82	1.76	62.98	0.29	28462.56	518.62	126.95	8.63	20.66	7.09	147.6	15.72	663.25	7.82	7.31	0.35	51.91
622.65	34.78	0.54	15.01	1.73	3.68	1.77	63.62	0.3	28455.76	529.92	121.31	8.47	20.51	7.11	141.82	15.58	659.65	7.83	7.36	0.35	51.69
679.08	27.81	0.46	10.5	1.57	2.34	1.52	68.99	0.35	30548.39	507.85	126.79	8.17	23.51	6.35	150.3	14.53	702	7.56	7.91	0.32	54.63
735.52	15.8	0.35	0.78	1.23	-0.81	1.21	78.6	0.4	34961.12	446.74	158.09	8.71	29.49	5.92	187.58	14.63	801.33	7.3	8.86	0.25	61.94
791.92	15.87	0.35	0.89	1.18	-0.78	1.2	79.85	0.42	34962.05	443.61	153.88	8.65	29.55	5.95	183.42	14.6	800.24	7.32	9.04	0.24	61.94
848.35	21.61	0.39	4.97	1.35	0.83	1.34	74.1	0.38	32737.4	470.01	136.2	8.21	26.39	6.03	162.59	14.25	751.99	7.41	8.54	0.27	58.54
904.78	34.39	0.53	14.35	1.68	3.52	1.76	64.75	0.3	28748.17	518.06	130.84	8.75	21.04	7.03	151.88	15.79	665.51	7.81	7.41	0.34	52.22
961.2	34.32	0.53	14.58	1.73	3.6	1.75	64.63	0.29	28659.14	517.74	120.67	8.39	20.93	7.03	141.6	15.41	664.52	7.81	7.47	0.35	52.16
1017.63	34.32	0.53	14.32	1.71	3.65	1.75	64.54	0.31	28592.88	533.41	116.27	8.35	20.57	7.24	136.83	15.59	657.25	7.79	7.47	0.35	51.61
1074.07	28.03	0.46	10.19	1.6	2.07	1.54	69.17	0.33	30802.59	500.18	136.42	8.61	23.75	6.52	160.18	15.13	696.74	7.59	8.04	0.33	54.38
1130.48	15.92	0.35	0.81	1.25	-0.79	1.2	79.62	0.42	34901.92	447.65	148.03	8.36	29.47	5.94	177.49	14.29	793.53	7.3	9.01	0.25	61.36
1186.92	16	0.36	0.57	1.27	-0.85	1.22	79.69	0.43	35017.88	454.46	142.27	8.2	29.53	5.96	171.8	14.16	804.6	7.31	9.06	0.26	62.22
1243.35	20.77	0.39	4.66	1.4	0.81	1.33	73.25	0.34	33045.71	471.37	148.1	8.6	26.9	6.07	175	14.67	760.18	7.4	8.43	0.28	59.29
1299.78	33.42	0.53	13.76	1.71	3.44	1.74	63.99	0.31	28735.94	513.6	115.54	8.15	21.17	6.93	136.71	15.09	663.75	7.76	7.37	0.35	52.01
1356.2	34.06	0.53	14.41	1.69	3.66	1.74	63.78	0.3	28541.24	516.94	115.94	8.2	21.02	7	136.97	15.2	662.35	7.78	7.34	0.34	51.91
1412.63	34.9	0.54	14.18	1.73	3.51	1.78	63.82	0.29	28542.44	526.57	123.6	8.62	20.44	7.29	144.04	15.91	655.56	7.81	7.42	0.35	51.34
1469.05	33.01	0.51	13.18	1.67	3.35	1.7	65.44	0.31	29055.96	516.29	117.85	8.23	21.45	6.91	139.3	15.14	673.5	7.76	7.53	0.34	52.59
1525.48	16.4	0.36	1.13	1.28	-0.5	1.22	78.65	0.41	34683.26	449.9	141.85	8.15	29.38	5.93	171.24	14.08	797.07	7.3	8.81	0.26	61.48
1581.92	15.79	0.35	0.21	1.25	-0.77	1.19	79.13	0.41	35043.82	443.15	159.31	8.78	29.91	5.93	189.21	14.71	826.49	7.32	8.94	0.25	63.9
1638.33	15.93	0.35	0.73	1.24	-0.7	1.21	78.94	0.41	34982.95	447.36	143.23	8.24	29.55	5.96	172.78	14.2	799.41	7.3	9.07	0.25	61.64
1694.78	20.04	0.38	4.68	1.27	0.39	1.3	74.56	0.38	33074.57	468.69	137.63	8.17	27.29	5.98	164.93	14.15	758.18	7.37	8.57	0.26	58.88
1751.2	34.27	0.53	14.86	1.7	3.88	1.76	63.63	0.3	28625.97	522.25	128.87	8.61	21.25	6.91	150.13	15.53	659.5	7.77	7.3	0.35	51.57
1807.63	34.99	0.54	14.75	1.71	3.83	1.79	63.71	0.29	28417.88	527.61	121.27	8.52	20.64	7.26	141.91	15.78	661.9	7.83	7.31	0.35	51.91
1864.07	32.41	0.51	12.81	1.69	3.03	1.7	65.8	0.31	29222.95	521.99	117.84	8.34	21.48	7.12	139.31	15.45	677.38	7.75	7.58	0.34	53.16
1920.48	16.07	0.35	0.6	1.23	-0.71	1.2	78.95	0.41	34953.13	443.56	152.96	8.53	29.73	5.93	182.69	14.47	793.38	7.28	8.9	0.25	61.47
1976.92	15.94	0.35	0.5	1.25	-0.9	1.21	78.76	0.4	35039.03	448.94	151.01	8.5	29.67	5.95	180.69	14.45	810.49	7.31	8.99	0.25	62.87
2033.35	16.03	0.36	0.4	1.23	-0.94	1.22	80.26	0.42	34943.37	453.36	142.1	8.21	29.7	5.94	171.8	14.14	801.65	7.29	9.19	0.25	62.11
2089.78	29.6	0.48	12.27	1.62	3.09	1.59	66.45	0.3	29727.87	505.1	133.68	8.53	23.06	6.56	156.73	15.09	686.36	7.61	7.68	0.33	53.96
2146.22	35.07	0.54	14.58	1.66	3.7	1.78	64.71	0.29	28471.76	526.04	124.72	8.56	21.12	7.04	145.84	15.59	655.34	7.79	7.32	0.34	51.54
2202.63	35.29	0.55	14.67	1.81	3.66	1.8	64.3	0.3	28298.01	531.13	113.94	8.33	20.58	7.36	134.52	15.69	658.24	7.84	7.45	0.37	51.79
2259.07	29.37	0.48	10.25	1.53	2.44	1.6	67.83	0.32	30430.24	507.04	132.54	8.49	23.41	6.61	155.95	15.1	703.45	7.64	7.84	0.31	55.06
2315.5	15.98	0.35	0.91	1.17	-0.83	1.2	78.51	0.41	35051.9	445.71	157.56	8.75	29.88	5.97	187.44	14.71	797.75	7.29	9.02	0.24	61.82
2371.92	15.9	0.35	0.36	1.21	-0.82	1.19	79.7	0.4	34907.65	444.84	142.97	8.17	29.91	5.96	172.88	14.13	799.84	7.29	8.94	0.25	61.96
2428.35	21.47	0.4	5.37	1.41	0.76	1.37	73.75	0.37	32722.43	473.34	135.31	8.21	26.81	6.07	162.12	14.28	757.06	7.4	8.53	0.29	59.03
2484.78	34.87	0.54	14.5	1.72	4.03	1.77	64.32	0.3	28558.05	519.87	123.62	8.58	20.92	7.1	144.54	15.68	661.32	7.81	7.36	0.35	52.01
2541.2	35.16	0.54	14.67	1.75	3.79	1.77	64.03	0.31	28264.66	532.02	112.35	8.3	20.32	7.35	132.67	15.65	652.46	7.8	7.4	0.36	51.37
2597.63	29.36	0.48	11.1	1.57	2.66	1.58	69.3	0.33	30208.42	505.47	126.4	8.35	23.2	6.62	149.59	14.97	696.99	7.62	7.9	0.32	54.6
2654.05	16.02	0.35	0.37	1.24	-0.84	1.21	79.3	0.42	35017.59	450.79	156.69	8.68	29.76	5.96	186.45	14.64	805.67	7.29	9.06	0.25	62.56
2710.48	15.96	0.35	0.82	1.21	-0.73	1.2	79.92	0.43	34882.01	445.4	146.25	8.28	29.98	5.92	176.23	14.21	808.74	7.28	9.11	0.24	62.76
2766.92	20.97	0.39	5.47	1.37	0.66	1.33	74.92	0.36	32766.15	470.74	134.8	8.11	27.02	6.01	161.82	14.12	752.19	7.37	8.52	0.28	58.89
2823.35	34.56	0.53	14.86	1.74	3.93	1.76	63.84	0.3	28539.39	520.62	123.28	8.56	20.93	7.17	144.21	15.73	656.29	7.79	7.38	0.35	51.77
2879.77	35.1	0.54	14.91	1.75	3.99	1.79	63.19	0.29	28471.51	531.85	121.03	8.49	20.98	7.21	142.01	15.7	658.72	7.81	7.34	0.36	51.93
2936.2	31.75	0.51	12.87	1.69	3.29	1.68	66.58	0.31	29290.34	505.28	117.27	8.13	22.35	6.75	139.62	14.87	678.69	7.69	7.65	0.34	53.44
2992.63	16.19	0.35	0.45	1.26	-0.72	1.2	79.22	0.4	34819.19	452.05	142.08	8.19	29.54	5.96	171.61	14.14	797.07	7.29	9	0.26	62.03
3049.05	15.92	0.35	0.83	1.21	-0.79	1.2	78.99	0.39	35043.49	440.42	152.89	8.56	29.79	5.95	182.68	14.51	805.6	7.29	9.02	0.25	62.83
3105.48	15.91	0.35	0.17	1.17	-0.8	1.2	79.69	0.42	34936.94	443.75	144.93	8.31	29.9	5.95	174.83	14.25	797.69	7.27	9	0.24	62.27
3161.92	15.87	0.35	0.61	1.28	-0.63	1.21	79.55	0.41	35096.78	443.81	152.21	8.55	30.2	5.94	182.41	14.49	805.88	7.26	9.01	0.26	63.01
3218.33	15.93	0.35	0.77	1.26	-0.66	1.21	78.76	0.41	35055.92	450.5	155.84	8.69	30.04	5.97	185.88	14.66	802.04	7.29	9.14	0.26	62.63
3274.77	15.94	0.35	0.5	1.25	-0.8	1.21	79.19	0.41	35134.38	435.55	152.19	8.58	30.09	5.96	182.28	14.54	792.24	7.26	9.17	0.25	61.9
3331.2	15.97	0.35	0.61	1.2	-0.87	1.2	79.42	0.4	34945.82	447.43	139.44	8.09	30.16	5.98	169.6	14.07	801.88	7.28	9.1	0.24	62.51
3387.63	15.83	0.35	0.44	1.23	-0.68	1.2	79.81	0.43	35131.55	444.73	155.54	8.69	30.22	5.96	185.76	14.64	795.71	7.27	8.99	0.25	61.94
3444.05	15.87	0.35	0.47	1.26	-0.73	1.19	78.49	0.4	35032.84	438.41	149.6	8.45	30	5.99	179.59	14.44	797.59	7.28	9.08	0.26	62.06
3500.5	15.89	0.35	0.45	1.21	-0.71	1.2	79.12	0.41	34861.55	450.49	138.47	8.06	30.02	5.98	168.49	14.03	799.28	7.26	9.05	0.25	62.1

Colorado State University: Engines & Energy Conversion Laboratory

Test Program: EPA RICE Testing:
Description: FTIR Daily Calibrations - Nicolet Rega 7000
Date: March 30, 1999 **Time:** 19:42:34 to 22:02:12

Engine Class: Natural Gas Fueled, Spark Ignited, Two-Stroke, Lean Burn Engine
Engine Type: Cooper-Bessemer GMV-4-TF
Test Points: Pre Catalyst Validation

time	(+-)C2H6	C3H8	(+-)C3H8	THC	(+-)THC	H2O	(+-)H2O	SF6	(+-)SF6	CH3OH	(+-)CH3OH	(+-)SF6	MEOH	(+-)MEOH	NMHC	(+-)NMHC
58.35	4.96	18.74	4.4	1005.02	38.49	95254.5	1317.16	0	0.01	0.51	0.32	0.03	6.16	4.37	871.02	70.02
114.78	4.96	18.84	4.4	1000.37	33.81	95859.85	1302.99	-0.01	0.01	0.5	0.33	0.03	6.14	4.41	883.68	70.45
171.22	4.98	18.75	4.41	998.77	38.72	97673.82	1311.18	-0.01	0.01	0.44	0.34	0.03	6.21	4.35	885.26	70.72
227.65	5.08	17.9	4.5	947.74	34.66	103725.8	1374.09	0.09	0.01	2.11	0.35	0.03	5.91	4.52	878.38	69.68
284.07	5.55	15.17	4.93	790.56	38.08	128767.7	1652.11	0.36	0.01	8.17	0.44	0.03	0	3.79	1067.9	64.92
340.52	5.35	14.16	4.75	756.38	36.76	120739.5	1578.73	0.43	0.01	6.5	0.42	0.03	0	3.74	1087.84	65.3
396.95	5.67	16.25	5.03	827.23	38.78	128160	1674.58	0.28	0.01	9.49	0.44	0.03	0	3.77	1082.62	65.31
453.37	5.59	15.88	4.96	818.79	38.34	126180.1	1610.4	0.3	0.01	8.25	0.43	0.03	5.51	4.19	879.63	69.28
509.8	5.57	15.9	4.94	821.08	38.11	125078.3	1626.2	0.3	0.01	8.06	0.42	0.03	6.05	4.45	882.86	69.62
566.23	5.57	15.98	4.95	829.27	38.28	126772.2	1642.51	0.3	0.01	8.16	0.44	0.03	6.55	4.34	875.32	70.17
622.65	5.59	15.9	4.96	824.61	38.33	127281	1679.4	0.3	0.01	8.25	0.43	0.03	4.43	4.25	923.07	68.11
679.08	5.32	16.58	4.72	872.98	36.57	115989	1574.28	0.2	0.01	5.49	0.39	0.03	0	3.7	1081.26	64.68
735.52	4.97	18.45	4.41	990.14	33.89	96248.65	1326.79	0	0.01	0.33	0.33	0.03	0	3.77	1096.94	64.18
791.92	4.99	18.47	4.43	989.48	38.78	97823.52	1320.45	0	0.01	0.54	0.34	0.03	0	3.95	997.12	66.19
848.35	5.13	17.65	4.55	932.86	35.01	106798.6	1427.83	0.1	0.01	2.68	0.35	0.03	6.7	4.39	880.79	68.72
904.78	5.57	16.15	4.94	833.05	38.13	125353.2	1636.08	0.29	0.01	7.82	0.43	0.03	6.24	4.37	878.47	69.41
961.2	5.57	16.08	4.94	831.81	38.19	125335.7	1635.6	0.29	0.01	8.06	0.43	0.03	6.4	4.43	868.17	69.46
1017.63	5.57	15.92	4.94	823.25	38.12	127766.3	1690.55	0.29	0.01	8.13	0.43	0.03	0	4.12	982.68	67.42
1074.07	5.35	16.56	4.74	869.63	36.65	117313.9	1551.63	0.19	0.01	5.57	0.39	0.03	0	3.65	1115.42	64.28
1130.48	4.98	18.39	4.42	983.26	38.72	96364.02	1329.99	0	0.01	0.43	0.31	0.03	0	3.84	1097.21	65.13
1186.92	4.97	16.47	4.41	994.46	38.72	97062.92	1351.01	0	0.01	0.49	0.33	0.03	0	3.7	1082.12	64.6
1243.35	5.11	17.74	4.53	942.52	35.04	106584.3	1429.92	0.09	0.01	2.4	0.34	0.03	5.27	4.23	892.37	68.26
1299.78	5.53	16	4.91	830.56	37.94	124252.1	1619.89	0.28	0.01	7.55	0.41	0.03	8.92	4.45	896.36	70.51
1356.2	5.55	15.93	4.92	828.05	38.02	124489.9	1632.14	0.29	0.01	7.92	0.43	0.03	8.54	4.45	879.6	70.51
1412.63	5.58	15.88	4.95	819.74	38.34	128308.3	1670.28	0.29	0.01	8.25	0.44	0.03	0	3.76	1078.49	65.64
1469.05	5.51	16.12	4.89	842.81	37.72	124258.4	1626.38	0.26	0.01	7.38	0.42	0.03	0	3.74	1098.86	65.55
1525.48	4.98	18.29	4.42	983.5	33.84	96306.72	1337.62	0.01	0.01	0.73	0.34	0.03	0	3.72	1088.87	65.28
1581.92	4.94	18.85	4.39	1020.98	38.48	95916.24	1315.13	0	0.01	0.45	0.33	0.03	4.85	4.23	904.27	68.63
1638.33	4.98	18.34	4.42	987.74	33.87	97040.13	1330.03	0	0.01	0.53	0.33	0.03	6.42	4.35	871.09	70.84
1694.78	5.09	17.71	4.51	939.75	34.74	103064.2	1414.86	0.08	0.01	2.18	0.36	0.03	6.72	4.45	882.57	71.63
1751.2	5.55	15.89	4.92	824.44	37.93	124027.4	1647.41	0.3	0.01	7.58	0.43	0.03	0	4.12	1014.81	69.34
1807.63	5.58	15.9	4.95	827.32	38.42	127849.3	1673.46	0.3	0.01	8.13	0.43	0.03	0	3.79	1075.69	65.9
1864.07	5.5	16.15	4.88	846.04	37.87	126206.1	1647.17	0.25	0.01	7.25	0.42	0.03	0	3.83	1091.44	66.06
1920.48	4.97	18.32	4.41	980.06	34.01	95628.07	1316.22	0	0.01	0.64	0.32	0.03	4.32	4.23	920.62	69.3
1976.92	4.97	18.51	4.41	1000.62	34	96921.08	1334.25	-0.01	0.01	0.34	0.33	0.03	6.62	4.46	878.12	71.4
2033.35	4.97	18.4	4.41	989.72	33.99	96666.19	1347.35	-0.01	0.01	0.42	0.34	0.03	6.21	4.45	875.27	71.42
2089.78	5.38	16.35	4.78	854.86	36.8	118508.9	1575.67	0.24	0.01	5.8	0.39	0.03	0	3.9	1085.11	66.82
2146.22	5.57	15.87	4.94	820.75	38.04	125575.1	1663.52	0.3	0.01	8.11	0.44	0.03	0	3.8	1095.98	65.88
2202.63	5.6	15.86	4.97	824.78	38.62	128837	1687.41	0.3	0.01	8.17	0.43	0.03	0	3.96	1052.51	66.66
2259.07	5.37	16.7	4.77	876.54	37.01	118372.4	1577.24	0.21	0.01	5.75	0.4	0.03	5.44	4.57	873.23	70.6
2315.5	4.97	18.39	4.41	985.49	33.96	96234.9	1323.3	0	0.01	0.45	0.34	0.03	6.41	4.4	880.31	71.54
2371.92	4.97	18.42	4.41	988.49	38.67	95191.76	1319.4	0	0.01	0.49	0.31	0.03	5.16	4.41	917.14	70.19
2428.35	5.11	17.69	4.54	938.33	34.9	106207.5	1436.87	0.1	0.01	2.57	0.35	0.03	0	4.07	1088.25	66.77
2484.78	5.58	16.02	4.95	827.26	38.21	126271.8	1644.85	0.3	0.01	7.93	0.42	0.03	0	3.87	1095.35	66.17
2541.2	5.59	15.81	4.96	818.14	36.26	128998	1690.79	0.3	0.01	8.21	0.44	0.03	0	3.79	1081.07	66
2597.63	5.37	16.58	4.77	868.8	36.85	119411.5	1575.74	0.22	0.01	5.81	0.41	0.03	0	3.8	1101.81	66.7
2654.05	4.96	18.64	4.4	997.69	38.67	97265.23	1340.5	0	0.01	0.53	0.33	0.03	0	3.93	1083.81	66.9
2710.48	4.94	18.65	4.39	999.68	38.2	95389.45	1321.56	0	0.01	0.5	0.33	0.03	0	3.87	1080.08	66.37
2766.92	5.1	17.65	4.52	933.35	34.99	105055.8	1426.54	0.1	0.01	2.35	0.35	0.03	0	3.82	1090.13	65.96
2823.35	5.57	15.92	4.94	821.16	38.37	127077.6	1648.96	0.3	0.01	7.78	0.42	0.03	0	3.89	1077.35	66.29
2879.77	5.58	15.96	4.95	825.36	38.38	127072.2	1684.96	0.3	0.01	8	0.43	0.03	0	3.89	1095.68	66.52
2936.2	5.45	16.3	4.84	848.47	37.59	121185.6	1584.22	0.25	0.01	6.82	0.42	0.03	0	3.8	1094.36	66.46
2992.63	4.97	18.42	4.41	985.91	34.07	97090.2	1344.85	0	0.01	0.66	0.33	0.03	0	3.77	1087.4	66.27
3049.05	4.96	18.56	4.4	995.66	38.68	96826.43	1308.72	0	0.01	0.46	0.33	0.03	0	3.93	1086.28	67.04
3105.48	4.95	18.46	4.39	986.5	33.66	96069.77	1317.69	0	0.01	0.53	0.32	0.03	0	3.81	920.17	61.86
3161.92	4.94	16.66	4.38	1000.43	38.41	95429	1315.91	0	0.01	0.51	0.33	0.01	0	1.95	0	23.69
3218.33	4.96	18.5	4.4	992.69	34.04	97591.07	1340.06	0	0.01	0.41	0.34	0.01	0	1.67	0	21.45
3274.77	4.96	18.39	4.4	982.16	38.82	96702.76	1293.59	0	0.01	0.42	0.33	0.01	0	2.23	216.9	29.92
3331.2	4.96	18.42	4.4	992.21	38.7	95366.31	1327.24	0	0.01	0.52	0.33					
3387.63	4.96	18.41	4.4	984.61	38.67	95931.7	1319.44	0	0.01	0.35	0.34					
3444.05	4.96	18.28	4.4	986.8	38.82	97211.45	1303.5	0	0.01	0.44	0.33					
3500.5	4.95	18.29	4.39	986.42	33.86	96108.81	1338.15	0	0.01	0.39	0.32					

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Baseline 8-5 - 736BHP 1200RPM 10BTDC

Data Point Number: Baseline **Date:** 08/05/99 **Time:** 15:11:38

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	73.00	73.00	73.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	61.51	60.00	62.00	0.86	1.40
AIR MANIFOLD PRESSURE ("Hg)	5.01	4.76	5.19	0.09	1.80
AIR MANIFOLD RELATIVE HUMIDITY (%)	37.85	36.00	39.00	1.06	2.81
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01561	0.01422	0.01669		
AIR MANIFOLD TEMPERATURE (F)	99.63	98.00	101.00	0.60	0.60
INTAKE AIR FLOW (scfm)	1747.25	1734.02	1758.27	5.28	0.30
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	699.38	698.99	699.79	0.22	0.03
CYLINDER 1 EXHAUST TEMPERATURE (F)	975.36	973.60	976.97	0.71	0.07
CYLINDER 2 EXHAUST TEMPERATURE (F)	974.40	972.61	975.98	0.74	0.08
CYLINDER 3 EXHAUST TEMPERATURE (F)	974.36	972.61	975.98	0.69	0.07
CYLINDER 4 EXHAUST TEMPERATURE (F)	949.03	947.41	950.98	0.78	0.08
CYLINDER 5 EXHAUST TEMPERATURE (F)	939.66	938.08	941.06	0.51	0.05
CYLINDER 6 EXHAUST TEMPERATURE (F)	928.50	927.17	929.95	0.63	0.07
CYLINDER EXHAUST AVERAGE TEMP (F)	956.92	955.94	957.93	0.52	0.05
EXHAUST HEADER TEMPERATURE (F)	699.38	698.99	699.79	0.22	0.03
PRE TURBO EXHAUST PRESSURE ("Hg)	37.63	37.41	37.92	0.13	0.36
PRE TURBO EXHAUST TEMPERATURE (F)	957.21	955.94	958.52	0.64	0.07
POST TURBO EXHAUST PRESSURE ("Hg)	5.06	5.01	5.12	0.02	0.43
POST TURBO EXHAUST TEMPERATURE (F)	772.01	771.02	773.00	0.52	0.07
TURBO OIL PRESSURE ("Hg)	47.10	46.16	47.77	0.31	0.66
ENGINE SPEED (rpm)	1196.86	1191.73	1200.00	1.48	0.12
ENGINE HORSEPOWER (bhp)	737.44	735.01	739.70	1.09	0.15
ENGINE OIL PRESSURE (psig)	52.19	51.64	52.93	0.32	0.61
ENGINE OIL TEMPERATURE IN (F)	165.17	164.86	165.45	0.16	0.10
ENGINE OIL TEMPERATURE OUT (F)	186.07	185.89	186.49	0.14	0.07
SPECIFIC GRAVITY	0.69	0.69	0.69	0.00	0.00
FUEL TEMPERATURE (F)	91.36	91.05	91.64	0.15	0.16
FUEL PRESSURE ("H2O above amp)	4.07	3.44	4.66	0.21	5.15
FUEL SUPPLY PRESSURE (psig)	46.83	46.75	46.90	0.04	0.08
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	15.19	14.65	15.86	0.31	2.06
ORIFICE STATIC PRESSURE (psig)	46.41	46.35	46.48	0.03	0.07
ORIFICE TEMPERATURE (F)	88.18	88.04	88.30	0.05	0.05
FUEL FLOW (SCFH)	5474.35				
CALCULATED FUEL CONSUMPTION (BSFC)	7717.47				
FUEL HEATING VALUE (Btu)	1039.60	1039.60	1039.60	0.00	0.00
AIR FUEL RATIO	32.70	32.70	32.70	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	9.72	9.43	9.87	0.09	0.90
INTERCOOLER AIR TEMP IN (F)	299.90	299.19	300.38	0.28	0.09
INTERCOOLER AIR TEMP OUT (F)	143.43	142.64	143.83	0.35	0.24
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	68.79	68.49	68.99	0.09	0.14
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	57.90	57.20	58.49	0.28	0.49
INTERCOOLER WATER TEMP IN (F)	131.13	129.74	131.72	0.57	0.43
INTERCOOLER WATER TEMP OUT (F)	143.56	142.44	144.02	0.43	0.30
INTERCOOLER SUPPLY PRESSURE (psi)	2.81	2.77	2.87	0.02	0.62
PRE CATALYST TEMPERATURE (F)	730.58	729.75	731.34	0.40	0.05
POST CATALYST TEMPERATURE (F)	734.79	734.11	735.70	0.35	0.05
CATALYST DIFFERENTIAL PRESSURE ("H2O)	9.50	9.43	9.62	0.04	0.47
B.S. CO (g/bhp-hr): Pre-Catalyst	4.16	4.05	4.26	0.04	1.06
B.S. CO (g/bhp-hr): Post-Catalyst	0.29	0.28	0.30	0.00	1.48
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Baseline 8-5 - 736BHP 1200RPM 10BTDC

Data Point Number: Baseline   **Date:** 08/05/99   **Time:** 15:11:38

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	1.01	0.98	1.09	0.03	2.71
B.S. NOx (g/bhp-hr): Post-Catalyst	1.11	1.09	1.18	0.02	1.45
B.S. THC (g/bhp-hr): Pre-Catalyst	9.34	8.95	9.57	0.12	1.25
B.S. THC (g/bhp-hr): Post-Catalyst	9.37	9.16	9.60	0.10	1.04
B.S. Methane (g/bhp-hr): Pre-Catalyst	4.27	4.20	4.37	0.04	0.91
B.S. Methane (g/bhp-hr): Post-Catalyst	3.48	3.37	3.66	0.08	2.34
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.19	0.18	0.21	0.01	7.36
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.15	0.13	0.16	0.01	5.58
O2 (ppm): Pre-Catalyst	100.00	100.00	100.00	0.00	0.00
O2 (ppm): Post-Catalyst	9.90	9.90	9.90	0.00	0.00
CO (ppm): Pre-Catalyst	621.17	614.40	624.70	3.34	0.54
CO (ppm): Post-Catalyst	43.25	42.80	43.70	0.20	0.47
CO2 (ppm): Pre-Catalyst	6.29	6.29	6.29	0.00	0.00
CO2 (ppm): Post-Catalyst	6.30	6.28	6.32	0.01	0.16
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Post-Catalyst	54.21	53.40	57.40	0.60	1.10
NOx (ppm): Pre-Catalyst	92.24	90.90	97.90	2.27	2.47
NOx (ppm): Post-Catalyst	100.56	99.20	106.50	1.08	1.07
THC (ppm): Pre-Catalyst	2024.33	1969.00	2047.00	17.80	0.88
THC (ppm): Post-Catalyst	2017.11	1987.90	2034.30	9.44	0.47
Methane (ppm): Pre-Catalyst	1400.68	1399.90	1403.10	1.38	0.10
Methane (ppm): Post-Catalyst	1135.08	1120.50	1171.70	23.18	2.04
Non-Methane (ppm): Pre-Catalyst	123.40	117.00	137.80	9.52	7.71
Non-Methane (ppm): Post-Catalyst	96.72	87.90	99.60	4.97	5.14
DYNO WATER IN TEMPERATURE (F)	82.87	82.71	82.91	0.08	0.09
DYNO WATER OUT TEMPERATURE (F)	129.28	129.14	130.14	0.21	0.16
JACKET WATER IN TEMPERATURE (F)	174.86	174.58	174.98	0.13	0.07
JACKET WATER OUT TEMPERATURE (F)	180.32	179.00	182.00	0.54	0.30
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	89.86	89.86	89.86	0.00	0.00
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	95.65	95.41	95.81	0.14	0.15
LUBE OIL FLOW (GPM)	130.72	129.86	131.63	0.28	0.22
CO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
CO F-Factor: Post-Catalyst	0.31	0.30	0.32	0.00	1.03
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Post-Catalyst	1.19	1.16	1.25	0.02	1.35
THC F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
THC F-Factor: Post-Catalyst	9.83	9.60	10.07	0.10	1.00
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3235.75	3233.08	3238.45	1.82	0.06

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Baseline - 735BHP 1200RPM 10BTDC

Data Point Number: Baseline 8/6 **Date:** 08/06/99 **Time:** 14:16:35

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	77.00	77.00	77.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	54.62	54.00	56.00	0.93	1.70
AIR MANIFOLD PRESSURE ("Hg)	5.00	4.87	5.16	0.06	1.18
AIR MANIFOLD RELATIVE HUMIDITY (%)	38.37	38.00	39.00	0.48	1.26
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01585	0.01497	0.01670		
AIR MANIFOLD TEMPERATURE (F)	99.66	98.00	101.00	0.75	0.75
INTAKE AIR FLOW (scfm)	1712.03	1700.19	1724.44	5.23	0.31
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	704.59	704.15	704.95	0.19	0.03
CYLINDER 1 EXHAUST TEMPERATURE (F)	976.17	974.59	977.57	0.65	0.07
CYLINDER 2 EXHAUST TEMPERATURE (F)	977.77	975.19	978.76	0.91	0.09
CYLINDER 3 EXHAUST TEMPERATURE (F)	980.03	978.36	981.54	0.73	0.07
CYLINDER 4 EXHAUST TEMPERATURE (F)	954.39	952.77	956.14	0.79	0.08
CYLINDER 5 EXHAUST TEMPERATURE (F)	945.56	944.24	947.21	0.76	0.08
CYLINDER 6 EXHAUST TEMPERATURE (F)	932.59	931.54	934.12	0.65	0.07
CYLINDER EXHAUST AVERAGE TEMP (F)	961.08	959.71	962.46	0.59	0.06
EXHAUST HEADER TEMPERATURE (F)	704.59	704.15	704.95	0.19	0.03
PRE TURBO EXHAUST PRESSURE ("Hg)	36.76	36.54	36.95	0.11	0.31
PRE TURBO EXHAUST TEMPERATURE (F)	962.40	961.50	963.88	0.60	0.06
POST TURBO EXHAUST PRESSURE ("Hg)	4.91	4.87	5.01	0.03	0.56
POST TURBO EXHAUST TEMPERATURE (F)	778.87	777.96	779.55	0.41	0.05
TURBO OIL PRESSURE ("Hg)	46.84	46.00	47.45	0.28	0.59
ENGINE SPEED (rpm)	1196.86	1193.61	1201.13	1.47	0.12
ENGINE HORSEPOWER (bhp)	737.95	735.76	740.17	0.87	0.12
ENGINE OIL PRESSURE (psig)	52.03	51.40	52.77	0.33	0.63
ENGINE OIL TEMPERATURE IN (F)	165.90	165.65	166.05	0.13	0.08
ENGINE OIL TEMPERATURE OUT (F)	186.81	186.49	187.08	0.14	0.08
SPECIFIC GRAVITY	0.66	0.66	0.66	0.00	0.00
FUEL TEMPERATURE (F)	96.38	96.21	96.41	0.07	0.07
FUEL PRESSURE ("H2O above amp)	4.90	4.08	5.37	0.25	5.09
FUEL SUPPLY PRESSURE (psig)	46.23	46.11	46.32	0.05	0.10
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	14.59	14.06	15.28	0.29	1.98
ORIFICE STATIC PRESSURE (psig)	46.23	46.13	46.31	0.04	0.08
ORIFICE TEMPERATURE (F)	92.95	92.79	93.15	0.09	0.09
FUEL FLOW (SCFH)	5462.78				
CALCULATED FUEL CONSUMPTION (BSFC)	7302.69				
FUEL HEATING VALUE (Btu)	986.50	986.50	986.50	0.00	0.00
AIR FUEL RATIO	28.60	28.60	28.60	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	9.34	9.17	9.51	0.09	0.92
INTERCOOLER AIR TEMP IN (F)	299.16	298.59	299.58	0.30	0.10
INTERCOOLER AIR TEMP OUT (F)	142.43	139.46	144.62	1.67	1.17
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	68.77	68.66	68.91	0.08	0.11
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	54.43	53.65	54.94	0.23	0.42
INTERCOOLER WATER TEMP IN (F)	129.31	125.77	132.32	2.29	1.77
INTERCOOLER WATER TEMP OUT (F)	142.41	138.87	145.02	2.07	1.45
INTERCOOLER SUPPLY PRESSURE (psi)	2.66	2.62	2.71	0.02	0.66
PRE CATALYST TEMPERATURE (F)	735.04	734.31	736.10	0.47	0.06
POST CATALYST TEMPERATURE (F)	739.40	738.88	739.87	0.30	0.04
CATALYST DIFFERENTIAL PRESSURE ("H2O)	8.97	8.89	9.11	0.05	0.55
B.S. CO (g/bhp-hr): Pre-Catalyst	2.39	2.35	2.45	0.03	1.06

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Baseline - 735BHP 1200RPM 10BTDC

Data Point Number: Baseline 8/6 **Date:** 08/06/99 **Time:** 14:16:35

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
B.S. CO (g/bhp-hr): Post-Catalyst	0.15	0.15	0.15	0.00	0.00
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NO (g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (corrected - g/bhp-hr): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
B.S. NOx (g/bhp-hr): Pre-Catalyst	0.71	0.69	0.73	0.01	1.26
B.S. NOx (g/bhp-hr): Post-Catalyst	0.74	0.72	0.77	0.01	1.59
B.S. THC (g/bhp-hr): Pre-Catalyst	4.54	4.44	4.64	0.05	1.12
B.S. THC (g/bhp-hr): Post-Catalyst	4.54	4.43	4.64	0.05	1.06
B.S. Methane (g/bhp-hr): Pre-Catalyst	1.97	1.93	2.01	0.02	1.05
B.S. Methane (g/bhp-hr): Post-Catalyst	2.03	1.99	2.07	0.02	1.05
B.S. Non-Methane (g/bhp-hr): Pre-Catalyst	0.07	0.07	0.08	0.00	6.00
B.S. Non-Methane (g/bhp-hr): Post-Catalyst	0.07	0.07	0.07	0.00	0.00
O2 (ppm): Pre-Catalyst	9.80	9.80	9.80	0.00	0.00
O2 (ppm): Post-Catalyst	9.78	9.70	9.80	0.04	0.37
CO (ppm): Pre-Catalyst	621.84	618.90	624.30	1.51	0.24
CO (ppm): Post-Catalyst	41.09	40.80	41.60	0.19	0.47
CO2 (ppm): Pre-Catalyst	6.32	6.26	6.32	0.02	0.25
CO2 (ppm): Post-Catalyst	6.51	6.50	6.52	0.01	0.11
NO (ppm): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO (ppm): Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx (ppm - Corrected): Pre-Catalyst	60.21	59.10	61.10	0.41	0.68
NOx (ppm - Corrected): Post-Catalyst	64.29	62.80	65.50	0.70	1.09
NOx (ppm): Pre-Catalyst	113.06	111.10	114.20	0.82	0.72
NOx (ppm): Post-Catalyst	120.94	118.10	123.20	1.41	1.16
THC (ppm): Pre-Catalyst	1812.50	1797.90	1823.70	5.61	0.31
THC (ppm): Post-Catalyst	1850.66	1837.30	1864.20	6.06	0.33
Methane (ppm): Pre-Catalyst	1033.00	1033.00	1033.00	0.00	0.00
Methane (ppm): Post-Catalyst	1089.46	1086.40	1089.50	0.36	0.03
Non-Methane (ppm): Pre-Catalyst	131.61	130.00	136.40	2.79	2.12
Non-Methane (ppm): Post-Catalyst	126.96	123.10	130.50	3.55	2.80
DYNO WATER IN TEMPERATURE (F)	82.68	82.52	82.91	0.10	0.12
DYNO WATER OUT TEMPERATURE (F)	129.12	128.95	129.14	0.07	0.05
JACKET WATER IN TEMPERATURE (F)	173.09	172.20	173.99	0.46	0.26
JACKET WATER OUT TEMPERATURE (F)	179.80	178.00	182.00	0.72	0.40
JACKET WATER FLOW (GPM)	0.00	0.00	0.00	0.00	0.00
LUBE OIL COOLING WATER IN TEMPERATURE (F)	94.53	94.22	94.82	0.30	0.32
LUBE OIL COOLING WATER OUT TEMPERATURE (F)	100.07	99.78	100.57	0.23	0.23
LUBE OIL FLOW (GPM)	131.45	130.99	131.95	0.23	0.17
CO F-Factor: Pre-Catalyst	4.19	4.11	4.31	0.04	1.04
CO F-Factor: Post-Catalyst	0.28	0.27	0.28	0.00	1.11
NO F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
NO F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
NOx F-Factor: Pre-Catalyst	1.25	1.22	1.29	0.02	1.20
NOx F-Factor: Post-Catalyst	1.34	1.29	1.38	0.02	1.45
THC F-Factor: Pre-Catalyst	7.81	7.63	8.03	0.09	1.14
THC F-Factor: Post-Catalyst	7.96	7.78	8.16	0.09	1.10
Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Pre-Catalyst	0.00	0.00	0.00	0.00	0.00
Non-Methane F-Factor: Post-Catalyst	0.00	0.00	0.00	0.00	0.00
ENGINE TORQUE	3238.33	3235.77	3241.14	0.72	0.02

Colorado State University
Engine and Energy Conversion Laboratory
FTIR System Verification Results

DRAFT REPORT

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January 1997

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1.0 EXECUTIVE SUMMARY

An independent verification of the Fourier Transform Infrared (FTIR) system at Colorado State University (CSU) Engine and Energy Conversion Laboratory (EECL) was conducted on 16 and 17 January 1997. The verification test was performed on the CSU FTIR system for formaldehyde, acetaldehyde, and acrolein utilizing the validation test procedures according to EPA Method 301. The sample matrix measured in the system evaluation was exhaust gas from the natural gas-fired Cooper GMV 2-cycle large-bore internal combustion (IC) engine operated under lean combustion conditions located at the EECL facility.

The CSU FTIR system met the EPA Method 301 validation criteria for all three analytes (i.e., formaldehyde, acetaldehyde, and acrolein). Relative standard deviation was significantly less than the Method 301 precision criteria of 50 percent in all cases and measurement bias was statistically insignificant for formaldehyde and acetaldehyde. The results indicate that no bias correction factor for formaldehyde and acetaldehyde is required. However, the acrolein data generated using the CSU FTIR system must be multiplied by a bias correction factor of 0.96 before subsequent use. Table 1-1 summarizes the results of the CSU FTIR system verification.

Table 1-1. FTIR System Verification Summary

Analyte	Percent RSD (unspiked)	Percent RSD (spiked)	Bias Significant?	Correction Factor
Formaldehyde	0.6	4.2	No	-
Acetaldehyde	12.0	2.3	No	-
Acrolein	0.0 (1)	0.7	Yes	0.96

(1) Not detected in native sample gas during validation run.
RSD - Relative standard deviation

2.0 INTRODUCTION

Radian International, LLC was retained by Enginuity International, Inc. to conduct an independent verification of the CSU EECL FTIR system using EPA Method 301 validation procedures. The verification testing was conducted for formaldehyde, acetaldehyde, and acrolein in exhaust gases generated from natural gas-fired IC engines. The verification testing of the CSU FTIR system was essentially identical to that used in the EPA-approved validation tests performed by Radian for the Gas Research Institute [1]. The verification testing was conducted at the CSU site during 16 and 17 January 1997.

The following procedure was used for generation of spiked and unspiked samples:

- Measure native stack gas for a 5 minute period;
- Start spike gas flow into sample stream;
- Let system equilibrate for 5 minutes;
- Measure spiked sample stream for 5 minutes;
- Turn off spike gas flow;
- Let system equilibrate for 5 minutes; and
- Repeat cycle.

This cycle is repeated 12 times to provide 12 spiked/unspiked pairs. These pairs were grouped further into six groups of 2 spiked/unspiked pairs to simulate a 'quad train' approach used for the Method 301 statistical calculations.

Spike level was computed from mass balance for formaldehyde, and by dilution measured from the SF_6 dilution tracer for acetaldehyde and acrolein. The equations for computing spike level can be easily derived or can be found in the GRI FTIR validation report [1].

4.0 RESULTS AND DISCUSSION

Tables 4-1, 4-2, and 4-3 present the CSU FTIR system verification results for formaldehyde, acetaldehyde, and acrolein, respectively. These tables are taken directly from the Method 301 validation spreadsheet available from the EPA EMTIC electronic bulletin board. Verification test data were grouped into 'quad train' sets to facilitate the use of the EPA spreadsheet. As previously summarized in Table 1-1, the CSU FTIR system met the EPA Method 301 validation criteria for all three analytes (i.e., formaldehyde, acetaldehyde, and acrolein).

As indicated in Table 4-1 through 4-3, all three analytes were well within the Method 301 precision criteria of 50% RSD. The highest RSD observed is 12 percent for the unspiked acetaldehyde validation. Acrolein unspiked data were set to zero since acrolein was not detected in any of the unspiked validation runs. Formaldehyde and acetaldehyde do not show any statistically significant bias, while acrolein shows a small but statistically significant bias of + 4 percent. This is easily within the Method 301 criteria of +/- 30 percent bias. As a result, formaldehyde and acetaldehyde data from the CSU EECL FTIR system do not require any bias correction, while acrolein results should be multiplied by a bias correction factor of 0.96 before final use.

Table 4-4 presents the calibration data for all flow measurement devices used in the study. As indicated, the difference between pre- and post- validation calibrations is less than 4 percent in all cases.

Table 4-1. Verification Results for Formaldehyde

VALIDATION OF FTIR FOR THE ANALYSIS OF FORMALDEHYDE								
Date Conducted: 16 January 1997								
ANALYTE SPIKING: QUAD TRAINS								
FEDERAL REGISTER CALCULATION METHOD								
ENTER VALUE OF SPIKED LEVEL (CS) =				35.4				
Dilution Factor for Unspiked Samples = 0.70								
ENTER SPIKED AND UNSPIKED CONCENTRATIONS (COMPARABLE UNITS ASSUMED) CONCENTRATION IN PPM (WET)								
	SPIKED SAMPLES		UNSPIKED SAMPLES					
RUN #	A	B	C	D	A-B	(A-B)^2	C-D	(C-D)^2
1	53.59	55.53	18.72	19.05	-1.94	3.76	-0.33	0.11
2	53.27	49.12	18.93	18.79	4.15	17.22	0.14	0.02
3	58.21	52.52	18.70	18.71	5.69	32.38	-0.01	0.00
4	52.33	50.73	18.54	18.54	1.60	2.56	0.00	0.00
5	54.44	54.51	18.61	18.63	-0.07	0.00	-0.02	0.00
6	53.17	51.06	18.57	18.66	2.11	4.45	-0.09	0.01
AVERAGE:	Sm=	53.21	Mm=	18.70				
STANDARD DEVIATION:								
	SPIKED Sds =		2.24					
	UNSPIKED Sdu =		0.11					
	RELATIVE STD RSDs =		4.2%	(acceptable)				
	RELATIVE STD RSDu=		0.6%	(acceptable)				
BIAS:								
	Corrected Unspiked Conc =			13.09				
	B =		4.714					
	STD OF MEAN SDm =		2.246					
	t-VALUE =		2.099					
	CRITICAL t-VALUE =		2.201					
	(n=12, alpha=95%)							
	Bias not statistically significant, CF not needed.							

Table 4-2. Verification Results for Acetaldehyde

VALIDATION OF FTIR FOR THE ANALYSIS OF ACETALDEHYDE								
Date Conducted: 17 January 1997								
ANALYTE SPIKING: QUAD TRAINS								
FEDERAL REGISTER CALCULATION METHOD								
ENTER VALUE OF SPIKED LEVEL (CS)=			10.10					
Dilution Factor for Unspiked Samples =				0.90				
ENTER SPIKED AND UNSPIKED CONCENTRATIONS (COMPARABLE UNITS ASSUMED)								
	CONCENTRATION IN PPM (WET)							
	SPIKED SAMPLES		UNSPIKED SAMPLES					
RUN #	A	B	C	D	A-B	(A-B)^2	C-D	(C-D)^2
1	10.96	11.50	0.35	1.17	-0.54	0.29	-0.82	0.67
2	12.15	12.34	1.87	2.15	-0.19	0.04	-0.28	0.08
3	12.42	12.90	2.59	2.88	-0.48	0.23	-0.29	0.08
4	12.94	12.32	3.05	2.76	0.62	0.38	0.29	0.08
5	12.89	13.01	2.82	2.97	-0.12	0.01	-0.15	0.02
6	13.15	13.18	3.00	3.22	-0.03	0.00	-0.22	0.05
AVERAGE:	Sm=	12.48	Mm =	2.40				
STANDARD DEVIATION:								
	SPIKED Sds =		0.28					
	UNSPIKED Sdu =		0.29					
	RELATIVE STD RSDs =		2.3%	(acceptable)				
	RELATIVE STD RSDu=		12.0%	(acceptable)				
BIAS:								
	Corrected Unspiked Conc =			2.16				
		B =	0.218					
	STD OF MEAN Sdm =		0.403					
		t-VALUE =	0.540					
	CRITICAL t-VALUE =		2.201					
	(n=12, alpha = 95%)							
	Bias not statistically significant, CF not needed.							

Table 4-3. Verification Results for Acrolein

VALIDATION OF FTIR FOR THE ANALYSIS OF ACROLEIN								
Date Conducted: 17 January 1997								
ANALYTE SPIKING: QUAD TRAINS								
FEDERAL REGISTER CALCULATION METHOD								
ENTER VALUE OF SPIKED LEVEL (CS) =		9.30						
Dilution Factor for Unspiked Samples =				0.90				
ENTER SPIKED AND UNSPIKED CONCENTRATIONS (COMPARABLE UNITS ASSUMED)								
CONCENTRATION IN PPM (WET)								
	SPIKED SAMPLES		UNSPIKED SAMPLES					
RUN #	A	B	C	D	A-B	(A-B)^2	C-D	(C-D)^2
1	9.33	9.38	0.00	0.00	-0.05	0.00	0.00	0.00
2	9.67	9.68	0.00	0.00	-0.01	0.00	0.00	0.00
3	9.64	9.75	0.00	0.00	-0.11	0.01	0.00	0.00
4	9.70	9.70	0.00	0.00	0.00	0.00	0.00	0.00
5	9.86	9.72	0.00	0.00	0.14	0.02	0.00	0.00
6	9.91	10.05	0.00	0.00	-0.14	0.02	0.00	0.00
AVERAGE:	Sm=	9.70	Mm=	0.00				
STANDARD DEVIATION:								
	SPIKED SDs=		0.07					
	UNSPIKED SDu=		0.00					
	RELATIVE STD RSDs=		0.7%	(acceptable)				
	RELATIVE STD RSDu=		0.0%	(acceptable)				
BIAS:								
	Corrected Unspiked Conc =			0.00				
	B=		0.399					
	STD OF MEAN SDm=		0.067					
	t-VALUE=		5.956					
	CRITICAL t-VALUE=		2.201					
	(n=12, alpha=95%)							
	Bias is statistically significant							
	Correction Factor=		0.959	(Acceptable)				

Table 4-4. Post-Verification Flow Meter Calibration Results

Rotameter Calibrations			Baro.P=	25.15		
Dynamic Spiking console Channel 1			Std. P=	29.96		
Readout	Time (Sec)	Volume (l)	Flow (l/min)	Flow (SLM) (Post test)	Flow (SLM) (Pre test)	% Difference (post - pre)
0.65	36.09	0.6	1.00	0.84		
0.65	24.08	0.4	1.00	0.84		
0.65	47.96	0.8	1.00	0.84		
average				0.84	0.85	-1.2
1.75	24.43	1	2.46	2.06		
1.75	24.29	1	2.47	2.07		
average				2.07	2.00	3.5
Orifice cal (dp = 0.60 inch H2O)						
	Time (sec)	Volume (l)	Flow (l/min)	Flow (SLM) (Post test)	Pretest cal (SLM)	
	9.81	1.6	9.79	8.21		
	9.58	1.6	10.02	8.41		
	9.71	1.6	9.89	8.30		
average			9.90	8.31	8.30	< 1
Syringe pump						
	Time (min)	Vol (ml)	Post Test Flow (ml/min)		Pretest cal (ml/min)	
	10	3.5	0.35		0.34	2.9

5.0 REFERENCES

1 L.D. Ogle, G.S.-Shareef, and J.P. LaCosse. "Fourier Transform Infrared (FTIR) Method Validation at a Natural Gas-Fired Internal Combustion Engine", *Radian Corporation under Contract to Gas Research Institute*, Document GRI-95/0271, May 1995.

APPENDIX H

CALIBRATION GAS CERTIFICATION SHEETS

RATA CLASS

Dual-Analyzed Calibration Standard

Scott Specialty Gases

500 WEAVER PARK RD,LONGMONT,CO 80501

Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: Interference Free™ EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: P165299
Project No.: 08-52254-003

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure #G1; September, 1997.

Cylinder Number: ALM040676 Certification Date: 1/12/99 Exp. Date: 1/12/2001

Cylinder Pressure***: 1912 PSIG

COMPONENT	CERTIFIED CONCENTRATION		ANALYTICAL ACCURACY**	TRACEABILITY
NITRIC OXIDE	112	PPM	+/- 1%	NIST
NITROGEN - OXYGEN FREE		BALANCE		
NOX	112.	PPM		Reference Value Only

*** Do not use when cylinder pressure is below 150 psig.

** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes.

Product certified as +/- 1% analytical accuracy is directly traceable to NIST standards.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 1685	7/10/01	ALM050868	247.5 PPM	NO/N2

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
FTIR System/8220/AAB9400251	12/24/98	Scott Enhanced FTIR

ANALYZER READINGS

(Z=Zero Gas R=Reference Gas T=Test Gas r=Correlation Coefficient)

NITRIC OXIDE

First Triad Analysis

Date: 01/04/99	Response Unit: PPM	
Z1=-0.110	R1=246.85	T1=111.80
R2=247.55	Z2=-0.031	T2=112.15
Z3=0.0056	T3=112.16	R3=248.10
Avg. Concentration:	112.0	PPM

Second Triad Analysis

Date: 01/12/99	Response Unit: PPM	
Z1=-0.059	R1=247.41	T1=111.87
R2=247.58	Z2=0.1289	T2=112.07
Z3=0.1765	T3=112.13	R3=247.51
Avg. Concentration:	112.0	PPM

Calibration Curve

Concentration=A+Bx+Cx2+Dx3+Ex4	
r=0.999990	
Constants:	A=0.000000
B=1.000000	C=0.000000
D=0.000000	E=0.000000

Special Notes:

APPROVED BY: Devon VonFeldt

Devon VonFeldt

RATA CLASS

Scott Specialty Gases

Dual-Analyzed Calibration Standard

500 WEAVER PARK RD,LONGMONT,CO 80501

Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: Interference Free™ Multi-Component EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: P165299
Project No.: 08-52254-005

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure #G1; September, 1997.

Cylinder Number: ALM043082 Certification Date: 1/19/99 Exp. Date: 1/19/2001

Cylinder Pressure***: 1922 PSIG

COMPONENT	CERTIFIED CONCENTRATION		ANALYTICAL ACCURACY**	TRACEABILITY
NITRIC OXIDE	304	PPM	+/- 1%	NIST
NITROGEN - OXYGEN FREE		BALANCE		
NOX	305.	PPM		Reference Value Only

*** Do not use when cylinder pressure is below 150 psig.

** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes.

Product certified as +/- 1% analytical accuracy is directly traceable to NIST standards.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 1685	7/10/01	ALM050868	247.5 PPM	NO/N2

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
FTIR System/8220/AAB9400251	12/24/98	Scott Enhanced FTIR

ANALYZER READINGS

(Z=Zero Gas R=Reference Gas T=Test Gas r=Correlation Coefficient)

First Triad Analysis — Second Triad Analysis — Calibration Curve

NITRIC OXIDE

First Triad Analysis

Date: 01/08/99	Response Unit: PPM	
Z1=0.2720	R1=247.22	T1=303.89
R2=247.76	Z2=0.2750	T2=304.60
Z3=0.6268	T3=304.60	R3=247.52
Avg. Concentration:	304.3	PPM

Second Triad Analysis

Date: 01/19/99	Response Unit: PPM	
Z1=-0.073	R1=247.27	T1=304.31
R2=247.66	Z2=-0.058	T2=304.77
Z3=0.0358	T3=304.37	R3=247.57
Avg. Concentration:	304.5	PPM

Calibration Curve

Concentration = A + Bx + Cx2 + Dx3 + Ex4

r=0.999990	
Constants:	A=0.000000
B=1.000000	C=0.000000
D=0.000000	E=0.000000

Special Notes:

APPROVED BY: Devon VonFeldt

Devon VonFeldt

COMPLIANCE CLASS

Dual-Analyzed Calibration Standard

Scott Specialty Gases

500 WEAVER PARK RD,LONGMONT,CO 80501 Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: 814671
Project No.: 08-54121-002

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure #G1; September, 1997.

Cylinder Number: ALM016431 **Certification Date:** 3/10/99 **Exp. Date:** 3/09/2002

Cylinder Pressure*:** 1878 PSIG

COMPONENT	CERTIFIED CONCENTRATION		ANALYTICAL ACCURACY**	TRACEABILITY
METHANE	901	PPM	+/- 2%	GMIS
PROPANE	91.1	PPM	+/- 2%	NIST
AIR		BALANCE		

*** Do not use when cylinder pressure is below 150 psig.

** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
CH4/AIR 50PP	2/18/01	ALM014418	50.20 PPM	METHANE
NTRM 1669	10/02/02	ALM006765	497.0 PPM	PROPANE

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
HPGC/5710A/2010A99310	03/08/99	FID
HPGC/5890/3115A34623	03/08/99	FID

APPROVED BY: Virginia E. Chandler

VIRGINIA CHANDLER

COMPLIANCE CLASS

Dual-Analyzed Calibration Standard

Scott Specialty Gases

500 WEAVER PARK RD,LONGMONT,CO 80501

Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: EPA Protocol Gas

Assay Laboratory

P.O. No.: VERBAL PER GARY
Project No.: 08-54121-003

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure #G1; September, 1997.

Cylinder Number: AAL13109 Certification Date: 3/09/99 Exp. Date: 3/08/2002

Cylinder Pressure***: 1906 PSIG

COMPONENT	CERTIFIED CONCENTRATION		ANALYTICAL ACCURACY**	TRACEABILITY
METHANE	1,800	PPM	+/- 2%	GMIS
PROPANE	181	PPM	+/- 2%	NIST
AIR		BALANCE		

*** Do not use when cylinder pressure is below 150 psig.

** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
CH4/AIR 50PP	2/18/01	ALM014418	50.20 PPM	METHANE
NTRM 1669	10/02/02	ALM006765	497.0 PPM	PROPANE

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
HPGC/5710A/2010A99310	03/08/99	FID
HPGC/5890/3115A34623	03/08/99	FID

Special Notes:

APPROVED BY: Virginia E Chandler

VIRGINIA CHANDLER

COMPLIANCE CLASS

Scott Specialty Gases

Dual-Analyzed Calibration Standard

500 WEAVER PARK RD,LONGMONT,CO 80501 Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: Interference Free™ EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: P165299
Project No.: 08-52254-023

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure #G1; September, 1997.

Cylinder Number: ALM027362 Certification Date: 1/15/99 Exp. Date: 1/15/2002

Cylinder Pressure***: 1982 PSIG

COMPONENT	CERTIFIED CONCENTRATION	ANALYTICAL ACCURACY**	TRACEABILITY
CARBON MONOXIDE	43.8 PPM	+/- 2%	NIST
NITROGEN	BALANCE		

*** Do not use when cylinder pressure is below 150 psig.

** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 1678	5/24/01	ALM041017	49.90 PPM	CO/N2

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
FTIR System/8220/AAB9400251	12/31/98	Scott Enhanced FTIR

Special Notes:

APPROVED BY: Devon VonFeldt

Devon VonFeldt

RATA CLASS

Scott Specialty Gases

Dual-Analyzed Calibration Standard

500 WEAVER PARK RD,LONGMONT,CO 80501 Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: Interference Free™ EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: P165299
Project No.: 08-52254-026

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure #G1; September, 1997.

Cylinder Number: ALM025646 Certification Date: 1/15/99 Exp. Date: 1/15/2002
Cylinder Pressure***: 1928 PSIG

COMPONENT	CERTIFIED CONCENTRATION		ANALYTICAL ACCURACY**	TRACEABILITY
CARBON MONOXIDE	303	PPM	+/- 1%	NIST
NITROGEN		BALANCE		

*** Do not use when cylinder pressure is below 150 psig.
** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes.
Product certified as +/- 1% analytical accuracy is directly traceable to NIST standards.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 1680	4/09/99	ALM066528	498.8 PPM	CO/N2

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
FTIR System/8220/AAB9400251	12/31/98	Scott Enhanced FTIR

ANALYZER READINGS

(Z=Zero Gas R=Reference Gas T=Test Gas r=Correlation Coefficient)

First Triad Analysis | Second Triad Analysis | Calibration Curve

CARBON MONOXIDE

First Triad Analysis

Date: 01/08/99	Response Unit: PPM	
Z1=-0.192	R1=498.55	T1=302.68
R2=499.18	Z2=-0.014	T2=302.71
Z3=-0.105	T3=302.59	R3=498.67
Avg. Concentration:	302.7	PPM

Second Triad Analysis

Date: 01/15/99	Response Unit: PPM	
Z1=-0.304	R1=498.97	T1=302.51
R2=499.05	Z2=-0.218	T2=302.29
Z3=-0.226	T3=302.41	R3=498.37
Avg. Concentration:	302.4	PPM

Calibration Curve

Concentration=A+Bx+Cx2+Dx3+Ex4

r=0.999990	
Constants:	A=0.000000
B=1.000000	C=0.000000
D=0.000000	E=0.000000

Special Notes:

APPROVED BY: Devon VonFeldt

Devon VonFeldt

COMPLIANCE CLASS

Dual-Analyzed Calibration Standard

Scott Specialty Gases

500 WEAVER PARK RD,LONGMONT,CO 80501 Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: VERBAL PER GARY
Project No.: 08-54343-003

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure #G1; September, 1997.

Cylinder Number: ALM036214 **Certification Date:** 3/09/99 **Exp. Date:** 3/08/2002

Cylinder Pressure*:** 1373 PSIG

COMPONENT	CERTIFIED CONCENTRATION		ANALYTICAL ACCURACY**	TRACEABILITY
METHANE	4,530	PPM	+/- 2%	GMIS
PROPANE	456	PPM	+/- 2%	NIST
AIR		BALANCE		

*** Do not use when cylinder pressure is below 150 psig.

** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
CH4/AIR 50PP	2/18/01	ALM014418	50.20 PPM	METHANE
NTRM 1669	10/02/02	ALM006765	497.0 PPM	PROPANE

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
HPGC/5710A/2010A99310	03/08/99	FID
HPGC/5890/3115A34623	03/08/99	FID

Special Notes:

APPROVED BY: Virginia E Chandler

VIRGINIA CHANDLER

COMPLIANCE CLASS

Dual-Analyzed Calibration Standard

Scott Specialty Gases

500 WEAVER PARK RD,LONGMONT,CO 80501

Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: Interference Free™ EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: P165299
Project No.: 08-52254-021

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure #G1; September, 1997.

Cylinder Number: ALM004316 **Certification Date:** 1/12/99 **Exp. Date:** 1/12/2002

Cylinder Pressure*:** 1986 PSIG

COMPONENT	CERTIFIED CONCENTRATION	ANALYTICAL ACCURACY**	TRACEABILITY
CARBON MONOXIDE	16.8 PPM	+/- 2%	NIST
NITROGEN	BALANCE		

*** Do not use when cylinder pressure is below 150 psig.

** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 2635	1/27/99	ALM060952	25.20 PPM	CO/N2

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
FTIR System/8220/AAB9400251	12/31/98	Scott Enhanced FTIR

Special Notes:

APPROVED BY: Devon VonFeldt

Devon VonFeldt

RATA CLASS

Dual-Analyzed Calibration Standard

Scott Specialty Gases

500 WEAVER PARK RD,LONGMONT,CO 80501 Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: Interference Free™ EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: P165299
Project No.: 08-52254-034

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure #G1; September, 1997.

Cylinder Number: ALM047090 **Certification Date:** 1/15/99 **Exp. Date:** 1/15/2002

Cylinder Pressure*:** 1970 PSIG

COMPONENT	CERTIFIED CONCENTRATION	ANALYTICAL ACCURACY**	TRACEABILITY
CARBON MONOXIDE	109 PPM	+/- 1%	NIST
NITROGEN	BALANCE		

*** Do not use when cylinder pressure is below 150 psig.

** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes.

Product certified as +/- 1% analytical accuracy is directly traceable to NIST standards.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 1680	4/09/99	ALM066528	498.8 PPM	CO/N2

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
FTIR System/8220/AAB9400251	12/31/98	Scott Enhanced FTIR

ANALYZER READINGS

(Z=Zero Gas R=Reference Gas T=Test Gas r=Correlation Coefficient)

CARBON MONOXIDE

First Triad Analysis

Date: 01/08/99	Response Unit: PPM	
Z1=-0.192	R1=498.55	T1=109.22
R2=499.18	Z2=-0.014	T2=109.23
Z3=-0.105	T3=109.33	R3=498.67
Avg. Concentration:	109.3	PPM

Second Triad Analysis

Date: 01/15/99	Response Unit: PPM	
Z1=-0.304	R1=498.97	T1=109.35
R2=499.05	Z2=-0.218	T2=109.30
Z3=-0.226	T3=109.16	R3=498.37
Avg. Concentration:	109.3	PPM

Calibration Curve

Concentration=A+Bx+Cx2+Dx3+Ex4	
r=0.999990	
Constants:	A=0.000000
B=1.000000	C=0.000000
D=0.000000	E=0.000000

Special Notes:

APPROVED BY: Devon VonFeldt

Devon VonFeldt

RATA CLASS

Scott Specialty Gases

Dual-Analyzed Calibration Standard

500 WEAVER PARK RD,LONGMONT,CO 80501

Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: Interference Free™ EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: P165299
Project No.: 08-52254-025

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure #G1; September, 1997.

Cylinder Number: ALM039419 Certification Date: 1/15/99 Exp. Date: 1/15/2002

Cylinder Pressure***: 1746 PSIG

COMPONENT	CERTIFIED CONCENTRATION		ANALYTICAL ACCURACY**	TRACEABILITY
CARBON MONOXIDE	157	PPM	+/- 1%	NIST
NITROGEN		BALANCE		

*** Do not use when cylinder pressure is below 150 psig.

** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes. Product certified as +/- 1% analytical accuracy is directly traceable to NIST standards.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 1680	4/09/99	ALM066528	498.8 PPM	CO/N2

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
FTIR System/8220/AAB9400251	12/31/98	Scott Enhanced FTIR

ANALYZER READINGS

(Z=Zero Gas R=Reference Gas T=Test Gas r=Correlation Coefficient)

CARBON MONOXIDE

First Triad Analysis

Date: 01/08/99	Response Unit: PPM	
Z1=-0.192	R1=498.55	T1=157.23
R2=499.18	Z2=-0.014	T2=157.29
Z3=-0.105	T3=157.37	R3=498.67
Avg. Concentration:	157.3	PPM

Second Triad Analysis

Date: 01/15/99	Response Unit: PPM	
Z1=-0.304	R1=498.97	T1=157.48
R2=499.05	Z2=-0.218	T2=157.32
Z3=-0.226	T3=157.43	R3=498.37
Avg. Concentration:	157.4	PPM

Calibration Curve

Concentration=A+Bx+Cx2+Dx3+Ex4	
r=0.999990	
Constants:	A=0.000000
B=1.000000	C=0.000000
D=0.000000	E=0.000000

Special Notes:

APPROVED BY: Devon VonFeldt

Devon VonFeldt

RATA CLASS

Scott Specialty Gases

Dual-Analyzed Calibration Standard

500 WEAVER PARK RD,LONGMONT,CO 80501

Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: Interference Free™ EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: P165299
Project No.: 08-52254-031

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure #G1; September, 1997.

Cylinder Number: ALM052548 Certification Date: 1/19/99 Exp. Date: 1/19/2002

Cylinder Pressure***: 1998 PSIG

COMPONENT	CERTIFIED CONCENTRATION	ANALYTICAL ACCURACY**	TRACEABILITY
CARBON DIOXIDE	1.99 %	+/- 1%	NIST
NITROGEN	BALANCE		

*** Do not use when cylinder pressure is below 150 psig.

** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes.

Product certified as +/- 1% analytical accuracy is directly traceable to NIST standards.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 5000	7/17/01	ALM048931	5.032 %	CO2/N2

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
CO2/AIA-220/570497012	01/19/99	NDIR

ANALYZER READINGS

(Z=Zero Gas R=Reference Gas T=Test Gas r=Correlation Coefficient)

First Triad Analysis | Second Triad Analysis | Calibration Curve

CARBON DIOXIDE

First Triad Analysis

Date: 01/19/99	Response Unit: %	
Z1=-0.002	R1=5.0380	T1=1.9920
R2=5.0340	Z2=-0.001	T2=1.9910
Z3=-0.001	T3=1.9940	R3=5.0320
Avg. Concentration:	1.992	%

Calibration Curve

Concentration=A+Bx+Cx2+Dx3+Ex4	
r=0.999999	
Constants:	A=-0.009819
B=0.730591	C=0.046295
D=0.005346	E=0.000000

Special Notes:

APPROVED BY: Devon VonFeldt

Devon VonFeldt

RATA CLASS

Scott Specialty Gases

Dual-Analyzed Calibration Standard

500 WEAVER PARK RD,LONGMONT,CO 80501

Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: Interference Free™ EPA Protocol Gas

Assay Laboratory

P.O. No.: P165299
Project No.: 08-52254-032

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure #G1; September, 1997.

Cylinder Number: 1L3264 Certification Date: 1/15/99 Exp. Date: 1/15/2002

Cylinder Pressure***: 1966 PSIG

COMPONENT	CERTIFIED CONCENTRATION	ANALYTICAL ACCURACY**	TRACEABILITY
CARBON DIOXIDE	5.16 %	+/- 1%	NIST
NITROGEN	BALANCE		

*** Do not use when cylinder pressure is below 150 psig.

** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes.

Product certified as +/- 1% analytical accuracy is directly traceable to NIST standards.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 5000	7/17/01	ALM048931	5.032 %	CO2/N2

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
CO2/AIA-220/570497012	01/15/99	NDIR

ANALYZER READINGS

(Z=Zero Gas R=Reference Gas T=Test Gas r=Correlation Coefficient)

First Triad Analysis — **Second Triad Analysis** — **Calibration Curve**

CARBON DIOXIDE

First Triad Analysis:

Date: 01/15/99 Response Unit: %

Z1=0.0020	R1=5.0490	T1=5.1700
R2=5.0660	Z2=0.0000	T2=5.1550
Z3=0.0170	T3=5.1640	R3=5.0590

Avg. Concentration: 5.163 %

Calibration Curve:

Concentration=A+Bx+Cx2+Dx3+Ex4

r=0.999996

Constants:	
	A=-0.011101
B=1.253540	C=0.004333
D=0.037926	E=0.000000

Special Notes:

APPROVED BY: Devon VonFeldt

Devon VonFeldt

RATA CLASS

Scott Specialty Gases

Dual-Analyzed Calibration Standard

500 WEAVER PARK RD,LONGMONT,CO 80501

Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: Interference Free™ EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: P165299
Project No.: 08-52254-033

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure #G1; September, 1997.

Cylinder Number: AAL14777 **Certification Date:** 1/15/99 **Exp. Date:** 1/15/2002

Cylinder Pressure*:** 1971 PSIG

COMPONENT	CERTIFIED CONCENTRATION	ANALYTICAL ACCURACY**	TRACEABILITY
CARBON DIOXIDE	9.04 %	+/- 1%	NIST
NITROGEN	BALANCE		

*** Do not use when cylinder pressure is below 150 psig.

** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes.
Product certified as +/- 1% analytical accuracy is directly traceable to NIST standards.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 5000	7/17/01	ALM048931	5.032 %	CO2/N2

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
CO2/AIA-220/570497012	01/15/99	NDIR

ANALYZER READINGS

(Z=Zero Gas R=Reference Gas T=Test Gas r=Correlation Coefficient)

CARBON DIOXIDE

First Triad Analysis

Date: 01/15/99	Response Unit: %	
Z1=0.0020	R1=5.0490	T1=9.0470
R2=5.0660	Z2=0.0000	T2=9.0190
Z3=0.0170	T3=9.0430	R3=5.0590
Avg. Concentration:	9.036	%

Second Triad Analysis

Calibration Curve

Concentration=A+Bx+Cx2+Dx3+Ex4	
r=0.999996	
Constants:	A=-0.011101
B=1.253540	C=0.004333
D=0.037926	E=0.000000

Special Notes:

APPROVED BY: Devon VonFeldt

Devon VonFeldt

RATA CLASS

Dual-Analyzed Calibration Standard

Scott Specialty Gases

500 WEAVER PARK RD,LONGMONT,CO 80501

Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: Interference Free™ EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: VERBAL PER GARY
Project No.: 08-54131-014

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure #G1; September, 1997.

Cylinder Number: ALM008282 Certification Date: 3/03/99 Exp. Date: 3/03/2002
Cylinder Pressure***: 1862 PSIG

COMPONENT	CERTIFIED CONCENTRATION	ANALYTICAL ACCURACY**	TRACEABILITY
CARBON DIOXIDE	21.3 %	+/- 1%	NIST
NITROGEN	BALANCE		

*** Do not use when cylinder pressure is below 150 psig.
** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes.
Product certified as +/- 1% analytical accuracy is directly traceable to NIST standards.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 1675	1/01/03	ALM008792	13.96 %	CO2/N2

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
CO2/AIA-220/570497012	02/23/99	NDIR

ANALYZER READINGS

(Z=Zero Gas R=Reference Gas T=Test Gas r=Correlation Coefficient)

First Triad Analysis — Second Triad Analysis — Calibration Curve

CARBON DIOXIDE

First Triad Analysis

Date: 03/03/99	Response Unit: %	
Z1=0.1000	R1=13.850	T1=21.390
R2=13.910	Z2=0.0500	T2=21.270
Z3=0.0300	T3=21.240	R3=13.920
Avg. Concentration:	21.30	%

Calibration Curve

Concentration=A+Bx+Cx2+Dx3+Ex4	
r=0.999968	
Constants:	A=-0.044800
B=6.531250	C=-2.667969
D=0.482666	E=0.000000

Special Notes:

APPROVED BY: Devon VonFeldt

Devon VonFeldt

RATA CLASS

Scott Specialty Gases

Dual-Analyzed Calibration Standard

500 WEAVER PARK RD,LONGMONT,CO 80501 Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: VERBAL PER GARY
Project No.: 08-54131-012

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure #G1; September, 1997.

Cylinder Number: ALM062109 **Certification Date:** 3/02/99 **Exp. Date:** 3/01/2002
Cylinder Pressure*:** 2010 PSIG

COMPONENT	CERTIFIED CONCENTRATION	ANALYTICAL ACCURACY**	TRACEABILITY
OXYGEN	4.38 %	+/- 1%	NIST
NITROGEN	BALANCE		

*** Do not use when cylinder pressure is below 150 psig.

** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes. Product certified as +/- 1% analytical accuracy is directly traceable to NIST standards.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 2658	1/02/01	ALM031952	9.680 %	OXYGEN

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
PARAMAG O2/SERVOMEX/244/701/1446	02/20/99	PARAMAGNETIC

ANALYZER READINGS

(Z=Zero Gas R=Reference Gas T=Test Gas r=Correlation Coefficient)

First Triad Analysis | Second Triad Analysis | Calibration Curve

OXYGEN

Date: 03/02/99	Response Unit: PCT	
Z1=0.0010	R1=4.3800	T1=9.7000
R2=9.6700	Z2=0.0010	T2=4.3800
Z3=0.0019	T3=4.3700	R3=9.6700
Avg. Concentration:	4.377	%

Calibration Curve:

Concentration=A+Bx+Cx2+Dx3+Ex4	
r=0.999978	
Constants:	A=-0.008155
B=10.046744	C=0.00000
D=0.00000	E=0.00000

Special Notes:

APPROVED BY: Diane Beehler
DIANA BEEHLER

RATA CLASS

Scott Specialty Gases

Dual-Analyzed Calibration Standard

500 WEAVER PARK RD,LONGMONT,CO 80501 Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: P165299
Project No.: 08-52254-029

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure #G1; September, 1997.

Cylinder Number: ALM036531 Certification Date: 1/19/99 Exp. Date: 1/18/2002

Cylinder Pressure***: 1995 PSIG

COMPONENT	CERTIFIED CONCENTRATION	ANALYTICAL ACCURACY**	TRACEABILITY
OXYGEN	12.0 %	+/- 1%	NIST
NITROGEN	BALANCE		

*** Do not use when cylinder pressure is below 150 psig.

** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes.
Product certified as +/- 1% analytical accuracy is directly traceable to NIST standards.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 2659	1/02/01	ALM031719	20.72 %	OXYGEN

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
PARAMAG O2/SERVOMEX/244/701/1446	01/12/99	PARAMAGNETIC

ANALYZER READINGS

(Z=Zero Gas R=Reference Gas T=Test Gas r=Correlation Coefficient)

First Triad Analysis | Second Triad Analysis | Calibration Curve

OXYGEN

First Triad Analysis

Date: 01/19/99 Response Unit: PCT

Z1=0.0005	R1=20.720	T1=12.030
R2=20.720	Z2=0.0007	T2=12.010
Z3=0.0008	T3=20.720	R3=12.000

Avg. Concentration: 12.02 %

Calibration Curve

Concentration=A+Bx+Cx2+Dx3+Ex4

r=0.999999

Constants: A=-0.005293

B=24.996153 C=0.00000

D=0.00000 E=0.00000

Special Notes:

APPROVED BY: Diana Beehl

DIANA BEEHLER

RATA CLASS

Scott Specialty Gases

Dual-Analyzed Calibration Standard

500 WEAVER PARK RD,LONGMONT,CO 80501

Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: EPA Protocol Gas

Assay Laboratory

P.O. No.: P165299

Project No.: 08-52254-030

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure #G1; September, 1997.

Cylinder Number: AAL2794 **Certification Date:** 1/19/99 **Exp. Date:** 1/18/2002

Cylinder Pressure*:** 1995 PSIG

COMPONENT	CERTIFIED CONCENTRATION	ANALYTICAL ACCURACY**	TRACEABILITY
OXYGEN	21.1 %	+/- 1%	NIST
NITROGEN	BALANCE		

*** Do not use when cylinder pressure is below 150 psig.

** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes.

Product certified as +/- 1% analytical accuracy is directly traceable to NIST standards.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 2659	1/02/01	ALM031719	20.72 %	OXYGEN

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
PARAMAG O2/SERVOMEX/244/701/1446	01/12/99	PARAMAGNETIC

ANALYZER READINGS

(Z=Zero Gas R=Reference Gas T=Test Gas r=Correlation Coefficient)

First Triad Analysis | **Second Triad Analysis** | **Calibration Curve**

OXYGEN

First Triad Analysis:

Date: 01/19/99 Response Unit: PCT

Z1=0.0005	R1=20.720	T1=21.110
R2=20.720	Z2=0.0007	T2=21.110
Z3=0.0008	T3=21.100	R3=20.720

Avg. Concentration: 21.11 %

Calibration Curve:

Concentration=A+Bx+Cx2+Dx3+Ex4

r=0.999999

Constants:	A=-0.005293
B=24.996153	C=0.00000
D=0.00000	E=0.00000

Special Notes:

Diana Beehler

APPROVED BY: ____________________

DIANA BEEHLER

CHECK CLASS

Noncertified Calibration Standard

Scott Specialty Gases
500 WEAVER PARK RD, LONGMONT, CO 80501
Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF CONFORMANCE: Check Class Calibration Standard

Product Information
Project No.: 08-52623-001
Item No.: 08023333 YA
P.O. No.: DPO763155
Folio #:
Cylinder Number: 1A8708
Cylinder Size: A
Certification Date: 1/12/1999

Customer

COLORADO STATE UNIVERSITY
ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS, CO 80524

CERTIFIED CONCENTRATION

Component Name	Concentration (Moles)		Accuracy (+/-%)
OXYGEN	40.	%	
NITROGEN		BALANCE	

APPROVED BY: Diana Beehl
DIANA BEEHLER

DATE: 1/12/99

Scott Specialty Gases

Shipped From: 500 WEAVER PARK RD
LONGMONT CO 80501
Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ANALYSIS

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

PROJECT #: 08-54125-002
PO#: VERBAL PER GARY
ITEM #: 0801543 AL
DATE: 2/16/99

CYLINDER #: ALM044013
FILL PRESSURE: 2000 PSIG

PURE MATERIAL: HYDROGEN CAS# 1333-74-0

GRADE: ZERO GAS

PURITY: 99.99%

IMPURITY	MAXIMUM CONCENTRATIONS	ACTUAL CONCENTRATIONS
THC	0.5 PPM	< 0.5 PPM

CGA 350 2000 PSIG

ANALYST: Wayne Johnson
WAYNE JOHNSON

Scott Specialty Gases

Shipped From: 500 WEAVER PARK RD
LONGMONT CO 80501
Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ANALYSIS

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

PROJECT #: 08-54125-002
PO#: VERBAL PER GARY
ITEM #: 0801543 AL
DATE: 2/16/99

CYLINDER #: ALM007853
FILL PRESSURE: 2000 PSIG

PURE MATERIAL: HYDROGEN CAS# 1333-74-0

GRADE: ZERO GAS

PURITY: 99.99%

IMPURITY	MAXIMUM CONCENTRATIONS	ACTUAL CONCENTRATIONS
THC	0.5 PPM	< 0.5 PPM

CGA 350 2000 PSIG

ANALYST: Wayne Johnson
WAYNE JOHNSON

Scott Specialty Gases

Shipped From: 500 WEAVER PARK RD
LONGMONT CO 80501
Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ANALYSIS

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

PROJECT #: 08-52623-002
PO#: DPO763155
ITEM #: 08022333 5A
DATE: 1/12/99

CYLINDER #: 1C1367
FILL PRESSURE: 2255 PSIG

ANALYTICAL ACCURACY: +/-2%
PRODUCT EXPIRATION: 1/08/2002

BLEND TYPE : CERTIFIED WORKING STD

COMPONENT	REQUESTED GAS CONC MOLES	ANALYSIS (MOLES)
HYDROGEN	40. %	40.0 %
HELIUM	BALANCE	BALANCE

CGA 350 2255 PSIG

ANALYST: STEVE SHOCKITES

Scott Specialty Gases

Shipped From: 500 WEAVER PARK RD
LONGMONT CO 80501
Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ANALYSIS

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

PROJECT #: 08-52623-002
PO#: DPO763155
ITEM #: 08022333 5A
DATE: 1/12/99

CYLINDER #: A2171
FILL PRESSURE: 2248 PSIG

ANALYTICAL ACCURACY: +/-2%
PRODUCT EXPIRATION: 1/08/2002

BLEND TYPE : CERTIFIED WORKING STD

COMPONENT	REQUESTED GAS CONC MOLES	ANALYSIS (MOLES)
HYDROGEN	40. %	39.9 %
HELIUM	BALANCE	BALANCE

CGA 350 2248 PSIG

ANALYST: STEVE SHOCKITES

Scott Specialty Gases

Shipped From: 500 WEAVER PARK RD
LONGMONT CO 80501
Phone: 888-253-1635 Fax: 303-772-7673

C E R T I F I C A T E   O F   A N A L Y S I S

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

PROJECT #: 08-58340-002
PO#: 404179
ITEM #: 0801809 A
DATE: 6/10/99

CYLINDER #: A017675
FILL PRESSURE: 2200 PSIG

PURE MATERIAL: NITROGEN CAS# 7727-37-9

GRADE: ULTRA-HI PURITY

PURITY: 99.9995%

IMPURITY	MAXIMUM CONCENTRATIONS	ACTUAL CONCENTRATIONS
THC	0.5 PPM	< 0.5 PPM
O2	0.5 PPM	< 0.5 PPM
CO	1 PPM	< 1 PPM
CO2	1 PPM	< 1 PPM
H2O	2 PPM	< 2 PPM

CGA 580 2200 PSIG

ANALYST: Wayne Johnson
WAYNE JOHNSON

Scott Specialty Gases

Shipped From: 500 WEAVER PARK RD
LONGMONT CO 80501
Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ANALYSIS

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

PROJECT #: 08-58340-003
PO#: 404179
ITEM #: 0801817 A
DATE: 6/10/99

CYLINDER #: 1A017096
FILL PRESSURE: 2200 PSIG

PURE MATERIAL: NITROGEN CAS# 7727-37-9

GRADE: HIGH PURITY

PURITY: 99.99%

CGA 580 2200 PSIG

ANALYST: Wayne Johnson
WAYNE JOHNSON

Scott Specialty Gases

Shipped From: 500 WEAVER PARK RD
LONGMONT CO 80501
Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ANALYSIS

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

PROJECT #: 08-58340-001
PO#: 404179
ITEM #: 0801022 A
DATE: 6/10/99

CYLINDER #: 1A9448
FILL PRESSURE: 2200 PSIG

PURE MATERIAL: AIR CAS# 132259-10-0

GRADE: HYDROCARBONFREE

IMPURITY	MAXIMUM CONCENTRATIONS	ACTUAL CONCENTRATIONS
O2 CONTENT	=20 TO 21%	= 20 TO 21%
CO	<0.5PPM	< 0.5 PPM
CO2	<1PPM	< 1 PPM
H2O	<5PPM	< 5 PPM
THC(CH4)	<0.1PPM	< 0.1 PPM

CGA 590 2200 PSIG

ANALYST: Wayne Johnson
WAYNE JOHNSON

Scott Specialty Gases

Shipped From: 500 WEAVER PARK RD
LONGMONT CO 80501
Phone: 888-253-1635 Fax: 303-772-7673

C E R T I F I C A T E   O F   A N A L Y S I S

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

PROJECT #: 08-58340-001
PO#: 404179
ITEM #: 0801022 A
DATE: 6/10/99

CYLINDER #: A3837
FILL PRESSURE: 2200 PSIG

PURE MATERIAL: AIR

CAS# 132259-10-0

GRADE: HYDROCARBONFREE

IMPURITY	MAXIMUM CONCENTRATIONS	ACTUAL CONCENTRATIONS
O2 CONTENT	=20 TO 21%	= 20 TO 21%
CO	<0.5PPM	< 0.5 PPM
CO2	<1PPM	< 1 PPM
H2O	<5PPM	< 5 PPM
THC(CH4)	<0.1PPM	< 0.1 PPM

CGA 590 2200 PSIG

ANALYST: Wayne Johnson
WAYNE JOHNSON

Scott Specialty Gases

Shipped From: 500 WEAVER PARK RD
LONGMONT CO 80501
Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ANALYSIS

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

PROJECT #: 08-58340-001
PO#: 404179
ITEM #: 0801022 A
DATE: 6/10/99

CYLINDER #: A5839
FILL PRESSURE: 2200 PSIG

PURE MATERIAL: AIR

CAS# 132259-10-0

GRADE: HYDROCARBONFREE

IMPURITY	MAXIMUM CONCENTRATIONS	ACTUAL CONCENTRATIONS
O2 CONTENT	=20 TO 21%	= 20 TO 21%
CO	<0.5PPM	< 0.5 PPM
CO2	<1PPM	< 1 PPM
H2O	<5PPM	< 5 PPM
THC(CH4)	<0.1PPM	< 0.1 PPM

CGA 590 2200 PSIG

ANALYST: Wayne Johnson
WAYNE JOHNSON

Scott Specialty Gases

Shipped From: 500 WEAVER PARK RD
LONGMONT CO 80501
Phone: 888-253-1635 Fax: 303-772-7673

C E R T I F I C A T E   O F   A N A L Y S I S

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

PROJECT #: 08-58340-001
PO#: 404179
ITEM #: 0801022 A
DATE: 6/10/99

CYLINDER #: 1A021928
FILL PRESSURE: 2200 PSIG

PURE MATERIAL: AIR

CAS# 132259-10-0

GRADE: HYDROCARBONFREE

IMPURITY	MAXIMUM CONCENTRATIONS	ACTUAL CONCENTRATIONS
O2 CONTENT	=20 TO 21%	= 20 TO 21%
CO	<0.5PPM	< 0.5 PPM
CO2	<1PPM	< 1 PPM
H2O	<5PPM	< 5 PPM
THC(CH4)	<0.1PPM	< 0.1 PPM

CGA 590 2200 PSIG

ANALYST: Wayne Johnson
WAYNE JOHNSON

Scott Specialty Gases

Shipped From: 500 WEAVER PARK RD
LONGMONT CO 80501
Phone: 888-253-1635 Fax: 303-772-7673

C E R T I F I C A T E O F A N A L Y S I S

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

PROJECT #: 08-57603-001
PO#: 798673
ITEM #: 080153501 AL
DATE: 5/25/99

CYLINDER #: ALM025658
FILL PRESSURE: 2000 PSIG

PURE MATERIAL: HELIUM CAS# 7440-59-7

GRADE: NGG1

PURITY: 99.999%

CGA 580 2000 PSIG

ANALYST: Wayne Johnson
WAYNE JOHNSON

Scott Specialty Gases

Shipped From: 500 WEAVER PARK RD
LONGMONT CO 80501
Phone: 888-253-1635 Fax: 303-772-7673

C E R T I F I C A T E   O F   A N A L Y S I S

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

PROJECT #: 08-57603-001
PO#: 798673
ITEM #: 080153501 AL
DATE: 5/25/99

CYLINDER #: ALM061145
FILL PRESSURE: 2000 PSIG

PURE MATERIAL: HELIUM CAS# 7440-59-7

GRADE: NGG1

PURITY: 99.999%

CGA 580 2000 PSIG

ANALYST: Wayne Johnson
WAYNE JOHNSON

Scott Specialty Gases

Shipped From: 500 WEAVER PARK RD
LONGMONT CO 80501
Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ANALYSIS

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

PROJECT #: 08-57603-001
PO#: 798673
ITEM #: 080153501 AL
DATE: 5/25/99

CYLINDER #: 1L1183
FILL PRESSURE: 2000 PSIG

PURE MATERIAL: HELIUM CAS# 7440-59-7

GRADE: NGG1

PURITY: 99.999%

CGA 580 2000 PSIG

ANALYST: Wayne Johnson
WAYNE JOHNSON

RATA CLASS

Scott Specialty Gases

Dual-Analyzed Calibration Standard

500 WEAVER PARK RD,LONGMONT,CO 80501 Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: Interference Free™ EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: VERBAL
Project No.: 08-58340-004

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure #G1; September, 1997.

Cylinder Number: ALM023324 Certification Date: 3/16/99 Exp. Date: 3/15/2001
Cylinder Pressure***: 1932 PSIG

COMPONENT	CERTIFIED CONCENTRATION (Moles)		ANALYTICAL ACCURACY**	TRACEABILITY
NITRIC OXIDE	435	PPM	+/- 1%	Direct NIST and NMi
NITROGEN - OXYGEN FREE		BALANCE		
TOTAL OXIDES OF NITROGEN	435.	PPM		Reference Value Only

*** Do not use when cylinder pressure is below 150 psig.
** Analytical accuracy is based on the requirements of EPA Protocal procedure G1, September 1997.
Product certified as +/- 1% analytical accuracy is directly traceable to NIST or NMI standards.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 1686	7/11/01	ALM051851	504.0 PPM	NO/N2

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
FTIR System/8220/AAB9400251	02/19/99	Scott Enhanced FTIR

ANALYZER READINGS

(Z=Zero Gas R=Reference Gas T=Test Gas r=Correlation Coefficient)

NITRIC OXIDE

First Triad Analysis

Date:03/05/99	Response Unit:PPM	
Z1=-0.098	R1=502.85	T1=433.03
R2=504.68	Z2=0.0835	T2=433.79
Z3=0.2012	T3=434.48	R3=504.47
Avg. Concentration:	433.8	PPM

Second Triad Analysis

Date: 03/16/99	Response Unit: PPM	
Z1=0.1958	R1=502.90	T1=434.87
R2=504.66	Z2=0.2198	T2=435.24
Z3=0.2533	T3=435.51	R3=504.44
Avg. Concentration:	435.2	PPM

Calibration Curve

Concentration=A+Bx+Cx2+Dx3+Ex4	
r=0.999990	
Constants:	A=0.000000
B=1.000000	C=0.000000
D=0.000000	E=0.000000

APPROVED BY: Devon VonFeldt

Devon VonFeldt

COMPLIANCE CLASS

Scott Specialty Gases

Dual-Analyzed Calibration Standard

500 WEAVER PARK RD,LONGMONT,CO 80501 Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: P169978
Project No.: 08-61261-002

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

Certified to exceed the minimum specifications of EPA Prot ol 1 Procedure #G2.

Cylinder Number: ALM002455 **Certification Date:** 8/30/99 **Exp. Date:** 8/29/2002
Cylinder Pressure*:** 2000 PSIG

COMPONENT	CERTIFIED CONCENTRATION (Moles)		ANALYTICAL ACCURACY**	TRACEABILITY
METHANE	910	PPM	+/- 2%	GMIS
PROPANE	91.6	PPM	+/- 2%	GMIS
AIR		BALANCE		

*** Do not use when cylinder pressure is below 150 psig.

** Analytical accuracy is based on the requirements of EPA Protocal procedures , September 1997.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
CH4/AIR 50PP	2/18/01	ALM014418	50.20 PPM	METHANE
GMIS.01%C3H8	2/15/01	ALM053511	151.0 PPM	PROPANE

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
HPGC/5890/3115A34623	08/30/99	FID
HPGC/5890/3115A34623	08/30/99	FID

APPROVED BY: Devon Vonfeldt
DEVON VONFELDT

COMPLIANCE CLASS

Scott Specialty Gases

Dual-Analyzed Calibration Standard

500 WEAVER PARK RD,LONGMONT,CO 80501 Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: EPA Protocol Gas

Assay Laboratory

P.O. No.: P169978

SCOTT SPECIALTY GASES
Project No.: 08-61261-004
500 WEAVER PARK RD
LONGMONT,CO 80501

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

Certified to exceed the minimum specifications of EPA Prot ol 1 Procedure #G2.

Cylinder Number: AAL20141 **Certification Date:** 8/30/99 **Exp. Date:** 8/29/2002
Cylinder Pressure*:** 2000 PSIG

COMPONENT	CERTIFIED CONCENTRATION (Moles)		ANALYTICAL ACCURACY**	TRACEABILITY
METHANE	2,750	PPM	+/- 2%	GMIS
PROPANE	275	PPM	+/- 2%	GMIS
AIR		BALANCE		

*** Do not use when cylinder pressure is below 150 psig.

** Analytical accuracy is based on the requirements of EPA Protocal procedures , September 1997.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
CH4/AIR 50PP	2/18/01	ALM014418	50.20 PPM	METHANE
GMIS.01%C3H8	2/15/01	ALM053511	151.0 PPM	PROPANE

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
HPGC/5890/3115A34623	08/30/99	FID
HPGC/5890/3115A34623	08/30/99	FID

APPROVED BY: Devon VonFeldt

DEVON VONFELDT

COMPLIANCE CLASS

Dual-Analyzed Calibration Standard

Scott Specialty Gases

500 WEAVER PARK RD,LONGMONT,CO 80501 Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: EPA Protocol Gas

Assay Laboratory

P.O. No.: P169978

SCOTT SPECIALTY GASES
Project No.: 08-61261-004

500 WEAVER PARK RD
LONGMONT,CO 80501

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

Certified to exceed the minimum specifications of EPA Prot ol 1 Procedure #G2.

Cylinder Number: AAL20141 **Certification Date:** 8/30/99 **Exp. Date:** 8/29/2002

Cylinder Pressure*:** 2000 PSIG

COMPONENT	CERTIFIED CONCENTRATION (Moles)		ANALYTICAL ACCURACY**	TRACEABILITY
METHANE	2,750	PPM	+/- 2%	GMIS
PROPANE	275	PPM	+/- 2%	GMIS
AIR		BALANCE		

*** Do not use when cylinder pressure is below 150 psig.

** Analytical accuracy is based on the requirements of EPA Protocal procedures , September 1997.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
CH4/AIR 50PP	2/18/01	ALM014418	50.20 PPM	METHANE
GMIS.01%C3H8	2/15/01	ALM053511	151.0 PPM	PROPANE

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
HPGC/5890/3115A34623	08/30/99	FID
HPGC/5890/3115A34623	08/30/99	FID

APPROVED BY: Devon Von Feldt

DEVON VONFELDT

Scott Specialty Gases

Shipped From: 500 WEAVER PARK RD
LONGMONT CO 80501
Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ANALYSIS

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

PROJECT #: 08-58340-002
PO#: 404179
ITEM #: 0801809 A
DATE: 6/10/99

CYLINDER #: A017675
FILL PRESSURE: 2200 PSIG

PURE MATERIAL: NITROGEN CAS# 7727-37-9

GRADE: ULTRA-HI PURITY

PURITY: 99.9995%

IMPURITY	MAXIMUM CONCENTRATIONS	ACTUAL CONCENTRATIONS
THC	0.5 PPM	< 0.5 PPM
O2	0.5 PPM	< 0.5 PPM
CO	1 PPM	< 1 PPM
CO2	1 PPM	< 1 PPM
H2O	2 PPM	< 2 PPM

CGA 580 2200 PSIG

ANALYST: Wayne Johnson
WAYNE JOHNSON

Scott Specialty Gases

Shipped From: 500 WEAVER PARK RD
LONGMONT CO 80501
Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ANALYSIS

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

PROJECT #: 08-58340-002
PO#: 404179
ITEM #: 0801809 A
DATE: 6/10/99

CYLINDER #: 1A013986
FILL PRESSURE: 2200 PSIG

PURE MATERIAL: NITROGEN CAS# 7727-37-9

GRADE: ULTRA-HI PURITY

PURITY: 99.9995%

IMPURITY	MAXIMUM CONCENTRATIONS	ACTUAL CONCENTRATIONS
THC	0.5 PPM	< 0.5 PPM
O2	0.5 PPM	< 0.5 PPM
CO	1 PPM	< 1 PPM
CO2	1 PPM	< 1 PPM
H2O	2 PPM	< 2 PPM

CGA 580 2200 PSIG

ANALYST: Wayne Johnson
WAYNE JOHNSON

Scott Specialty Gases

Shipped From: 500 WEAVER PARK RD
LONGMONT CO 80501
Phone: 888-253-1635 Fax: 303-772-7673

C E R T I F I C A T E   O F   A N A L Y S I S

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

PROJECT #: 08-58340-003
PO#: 404179
ITEM #: 0801817 A
DATE: 6/10/99

CYLINDER #: XA1472
FILL PRESSURE: 2200 PSIG

PURE MATERIAL: NITROGEN CAS# 7727-37-9

GRADE: HIGH PURITY

PURITY: 99.99%

CGA 580 2200 PSIG

ANALYST: Wayne Johnson
WAYNE JOHNSON

Scott Specialty Gases

Shipped From: 500 WEAVER PARK RD
LONGMONT CO 80501
Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ANALYSIS

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

PROJECT #: 08-58340-003
PO#: 404179
ITEM #: 0801817 A
DATE: 6/10/99

CYLINDER #: XA1472
FILL PRESSURE: 2200 PSIG

PURE MATERIAL: NITROGEN

CAS# 7727-37-9

GRADE: HIGH PURITY

PURITY: 99.99%

CGA 580 2200 PSIG

ANALYST: Wayne Johnson
WAYNE JOHNSON

Scott Specialty Gases

1290 COMBERMERE STREET,TROY,MI 48083

Phone: 248-589-2950 Fax: 248-589-2134

COMPLIANCE CLASS

Dual-Analyzed Calibration Standard

CERTIFICATE OF ACCURACY: EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
1290 COMBERMERE STREET
TROY,MI 48083

P.O. No.: 814671
Project No.: 05-42293-002

Customer
COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure #G1; September, 1997.

Cylinder Number: ALM050151 Certification Date: 3/11/99 Exp. Date: 3/11/2001
Cylinder Pressure***: 1400 PSIG

COMPONENT	CERTIFIED CONCENTRATION		ACCURACY**	TRACEABILITY
NITRIC OXIDE	259.4	PPM	+/- 2%	NIST
NITROGEN DIOXIDE	181.3	PPM	+/- 2%	NIST
NITROGEN - OXYGEN FREE		BALANCE		
TOTAL OXIDES OF NITROGEN	440.7	BALANCE		Reference Value Only

*** Do not use when cylinder pressure is below 150 psig.
** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 2631	7/01/99	ALM058718	2817. PPM	NITRIC OXIDE
NTRM 2654	11/01/99	ALM049028	528.0 PPM	NITROGEN DIOXIDE

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
BECKMAN/951/0101177	03/11/99	CHEMILUMINESCENSE
BECKMAN/951/0101177	03/11/99	CHEMILUMINESCENSE

Special Notes:

APPROVED BY: [signature]

Scott Specialty Gases
500 WEAVER PARK RD,LONGMONT,CO 80501
Phone: 888-253-1635 Fax: 303-772-7673

COMPLIANCE CLASS

Dual-Analyzed Calibration Standard

CERTIFICATE OF ACCURACY: Interference Free™ Multi-Component EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: 814671
Project No.: 08-54617-001

Customer
COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

Certified to exceed the minimum specifications of EPA Protocol 1 Procedure #G2.

Cylinder Number: ALM068001 **Certification Date:** 3/16/99 **Exp. Date:** 3/16/2001
Cylinder Pressure*:** 1786 PSIG

COMPONENT	CERTIFIED CONCENTRATION		ACCURACY**	TRACEABILITY
CARBON DIOXIDE	6.80	%	+/- 2%	NIST
CARBON MONOXIDE	190	PPM	+/- 2%	NIST
METHANE	1,300	PPM	+/- 2%	GMIS
NITRIC OXIDE	262	PPM	+/- 2%	GMIS
NITROGEN - OXYGEN FREE		BALANCE		
TOTAL OXIDES OF NITROGEN	263.	PPM		Reference Value Only

*** Do not use when cylinder pressure is below 150 psig.
** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 5000	7/17/01	ALM049007	5.032 %	CO2/N2
NTRM 2636	2/01/03	ALM066877	248.7 PPM	CARBON MONOXIDE
CH4/AIR 50PP	2/18/01	ALM014418	50.20 PPM	METHANE
GMIS	1/06/01	ALM039666	497.0 PPM	NO/N2

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
CO2/AIA-220/570497012	03/12/99	NDIR
HPGC/5710A/2010A99310	03/09/99	FID
HPGC/5890/3115A34623	03/08/99	FID
FTIR System/8220/AAB9400251	03/05/99	Scott Enhanced FTIR

APPROVED BY: Devon VonFeldt
Devon VonFeldt

Scott Specialty Gases

Shipped From: 500 WEAVER PARK RD
LONGMONT CO 80501
Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ANALYSIS

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

PROJECT #: 08-54127-002
PO#: VERBAL PER GARY
ITEM #: 0802N0005201XL
DATE: 3/02/99

CYLINDER #: PGS9650
FILL PRESSURE: 232 PSIG

ANALYTICAL ACCURACY: +/-1%
PRODUCT EXPIRATION: 3/02/2000

BLEND TYPE : GRAVIMETRIC MASTER GAS

COMPONENT	REQUESTED GAS CONC MOLES	ANALYSIS (MOLES)
N-BUTANE	.2 %	0.200 %
CARBON DIOXIDE	2. %	2.00 %
ETHANE	4. %	4.00 %
N-HEXANE	.2 %	0.200 %
ISOBUTANE	.2 %	0.201 %
ISOPENTANE	.2 %	0.200 %
NITROGEN	2. %	1.98 %
N-PENTANE	.2 %	0.200 %
PROPANE	1. %	1.00 %
METHANE	BALANCE	BALANCE

CGA 510 232 PSIA GRAVIMETRICALLY PREPARED

EXPOSURE TO TEMPERATURE BELOW 32 DEG F MAY CAUSE COMPONENTS TO LIQUIFY. KEEP CYLINDER ABOVE 70 DEG F FOR 1-2 DAYS OR HEAT FOR 1-2 HOURS. ROLL CYLINDER FOR 15 MINUTES BEFORE USING.

****

DO NOT HEAT ABOVE 120 DEG F.
ALWAYS USE ADEQUATE TEMPERATURE CONTROL.

****

NIST TRACEABILITY: BY WEIGHTS

ANALYST: Virginia Chandler
VIRGINIA CHANDLER

Scott Specialty Gases

Shipped From: ~~6141 EASTON ROAD, BLDG 1~~ ~~PO BOX 310~~
PLUMSTEADVILLE PA 18949-0310
Phone: 215-766-8861 Fax: 215-766-2070

CERTIFICATE OF ANALYSIS

COLORADO STATE UNIVERSITY
PO # 814671
ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

PROJECT #: 01-14795-002
PO#: 814671
ITEM #: 0102F2002304AL
DATE: 3/17/99

CYLINDER #: ALM018968
FILL PRESSURE: 2015 PSIA

ANALYTICAL ACCURACY: +/-5%
PRODUCT EXPIRATION: 9/19/1999

BLEND TYPE : CERTIFIED MASTER GAS

COMPONENT	REQUESTED GAS CONC MOLES		ANALYSIS (MOLES)	
FORMALDEHYDE	10.	PPM	10.66	PPM
NITROGEN		BALANCE		BALANCE

ANALYST: CHRIS ABER

Scott Specialty Gases

COMPLIANCE CLASS

Dual-Analyzed Calibration Standard

1290 COMBERMERE STREET,TROY,MI 48083 Phone: 248-589-2950 Fax: 248-589-2134

CERTIFICATE OF ACCURACY: EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
1290 COMBERMERE STREET
TROY,MI 48083

P.O. No.: 814671
Project No.: 05-42293-002

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure #G1; September, 1997.

Cylinder Number: ALM050151 Certification Date: 3/11/99 Exp. Date: 3/11/2001
Cylinder Pressure***: 1400 PSIG

COMPONENT	CERTIFIED CONCENTRATION		ACCURACY**	TRACEABILITY
NITRIC OXIDE	259.4	PPM	+/- 2%	NIST
NITROGEN DIOXIDE	181.3	PPM	+/- 2%	NIST
NITROGEN - OXYGEN FREE		BALANCE		
TOTAL OXIDES OF NITROGEN	440.7	BALANCE		Reference Value Only

*** Do not use when cylinder pressure is below 150 psig.
** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 2631	7/01/99	ALM058718	2817. PPM	NITRIC OXIDE
NTRM 2654	11/01/99	ALM049028	528.0 PPM	NITROGEN DIOXIDE

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
BECKMAN/951/0101177	03/11/99	CHEMILUMINESCENSE
BECKMAN/951/0101177	03/11/99	CHEMILUMINESCENSE

Special Notes:

APPROVED BY: [signature]

Scott Specialty Gases

500 WEAVER PARK RD,LONGMONT,CO 80501 Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ANALYSIS: EPA PROTOCOL GAS

Customer
COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS,CO 80524

Assay Laboratory

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

Project No.: 08-52254-019
P.O. No.: P165299

ANALYTICAL INFORMATION

Certified to exceed the minimum specifications of EPA Protocol 1 Procedure #G2.

Cylinder Number: ALM047254 **Certification Date:** 12/28/98 **Exp. Date:** 12/28/2001
Cylinder Pressure***:** 1937 PSIG

COMPONENT	CERTIFIED CONCENTRATION		ANALYTICAL ACCURACY**
METHANE	4,510	PPM	+/- 2% NIST TRACEABLE
AIR		BALANCE	

*** Do not use when cylinder pressure is below 150 psig.
** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes.
Product certified as +/- 1% analytical accuracy is directly traceable to NIST standards.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
SRM 2750	5/06/03	CAL013993	49.30 PPM	METHANE

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	LAST DATE CALIBRATED	ANALYTICAL PRINCIPLE
HORIOBA/FIA-23A/OPE 435/850658079	12/28/98	FID

ANALYZER READINGS

(Z=Zero Gas R=Reference Gas T=Test Gas r=Correlation Coefficient)

First Triad Analysis | Second Triad Analysis | Calibration Curve

METHANE

First Triad Analysis		
Date: 12/28/98	Response Unit: PPM	
Z1=0.0000	R1=49.110	T1=4504.0
R2=49.410	Z2=0.0010	T2=4517.0
Z3=0.0000	T3=4512.0	R3=49.380
Avg. Concentration:	4510.	PPM

Calibration Curve:

Concentration=A+Bx+Cx2+Dx3+Ex4
r=0.999998
Constants: A=0.012491
B=32.829778 C=0.00000
D=0.00000 E=0.00000

Special Notes: CGA 590 1937 PSIG

ANALYST: Susan J. Brandon
SUSAN J. BRANDON

Scott Specialty Gases

Shipped From: 6141 EASTON ROAD, BLDG 1 PO BOX 310
PLUMSTEADVILLE PA 18949-0310
Phone: 215-766-8861 Fax: 215-766-2070

CERTIFICATE OF ANALYSIS

COLORADO STATE UNIVERSITY

DEPT MECH ENG ENERGY LAB
430 N. COLLEGE
FT COLLINS CO 80523

PROJECT #: 01-10819-001
PO#: P165299
ITEM #: 0102F2002304AL
DATE: 1/06/99

CYLINDER #: CC50760
FILL PRESSURE: 2015 PSIA

ANALYTICAL ACCURACY: +/-5%
PRODUCT EXPIRATION: 7/05/1999

BLEND TYPE : CERTIFIED MASTER GAS

COMPONENT	REQUESTED GAS CONC MOLES	ANALYSIS (MOLES)
FORMALDEHYDE	10. PPM	10.33 PPM
NITROGEN	BALANCE	BALANCE

ANALYST: Chris Aber
CHRIS ABER

RATA CLASS

Scott Specialty Gases

Dual-Analyzed Calibration Standard

500 WEAVER PARK RD,LONGMONT,CO 80501

Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: Interference Free™ EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: P165299
Project No.: 08-52254-027

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure #G1; September, 1997.

Cylinder Number: ALM025834 **Certification Date:** 1/15/99 **Exp. Date:** 1/15/2002

Cylinder Pressure*:** 2006 PSIG

COMPONENT	CERTIFIED CONCENTRATION	ANALYTICAL ACCURACY**	TRACEABILITY
CARBON MONOXIDE	450 PPM	+/- 1%	NIST
NITROGEN	BALANCE		

*** Do not use when cylinder pressure is below 150 psig.

** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes.
Product certified as +/- 1% analytical accuracy is directly traceable to NIST standards.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 1680	4/09/99	ALM066528	498.8 PPM	CO/N2

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
FTIR System/8220/AAB9400251	12/31/98	Scott Enhanced FTIR

ANALYZER READINGS

(Z=Zero Gas R=Reference Gas T=Test Gas r=Correlation Coefficient)

CARBON MONOXIDE

First Triad Analysis

Date: 01/08/99	Response Unit: PPM	
Z1=-0.192	R1=498.55	T1=450.05
R2=499.18	Z2=-0.014	T2=449.43
Z3=-0.105	T3=449.57	R3=498.67
Avg. Concentration:	449.7	PPM

Second Triad Analysis

Date: 01/15/99	Response Unit: PPM	
Z1=-0.304	R1=498.97	T1=450.17
R2=499.05	Z2=-0.218	T2=450.03
Z3=-0.226	T3=449.96	R3=498.37
Avg. Concentration:	450.1	PPM

Calibration Curve

Concentration=A+Bx+Cx2+Dx3+Ex4	
r=0.999990	
Constants:	A=0.000000
B=1.000000	C=0.000000
D=0.000000	E=0.000000

Special Notes:

APPROVED BY: Devon VonFeldt

Devon VonFeldt

RATA CLASS

Scott Specialty Gases

Dual-Analyzed Calibration Standard

500 WEAVER PARK RD,LONGMONT,CO 80501   Phone: 888-253-1635   Fax: 303-772-7673

CERTIFICATE OF ACCURACY: Interference Free™ EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: P165299
Project No.: 08-52254-027

Customer

COLORADO STATE UNIVERSITY

ENERGY LAB
430 NORTH COLLEGE
FORT COLLINS CO 80524

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure #G1; September, 1997.

Cylinder Number: ALM025834   Certification Date: 1/15/99   Exp. Date: 1/15/2002
Cylinder Pressure***: 2006 PSIG

COMPONENT	CERTIFIED CONCENTRATION		ANALYTICAL ACCURACY**	TRACEABILITY
CARBON MONOXIDE	450	PPM	+/- 1%	NIST
NITROGEN		BALANCE		

*** Do not use when cylinder pressure is below 150 psig.
** Analytical accuracy is inclusive of usual known error sources which at least include precision of the measurement processes.
Product certified as +/- 1% analytical accuracy is directly traceable to NIST standards.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 1680	4/09/99	ALM066528	498.8 PPM	CO/N2

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
FTIR System/8220/AAB9400251	12/31/98	Scott Enhanced FTIR

ANALYZER READINGS

(Z=Zero Gas R=Reference Gas T=Test Gas r=Correlation Coefficient)

CARBON MONOXIDE

First Triad Analysis

Date: 01/08/99	Response Unit: PPM	
Z1=-0.192	R1=498.55	T1=450.05
R2=499.18	Z2=-0.014	T2=449.43
Z3=-0.105	T3=449.57	R3=498.67
Avg. Concentration:	449.7	PPM

Second Triad Analysis

Date: 01/15/99	Response Unit: PPM	
Z1=-0.304	R1=498.97	T1=450.17
R2=499.05	Z2=-0.218	T2=450.03
Z3=-0.226	T3=449.96	R3=498.37
Avg. Concentration:	450.1	PPM

Calibration Curve

Concentration=A+Bx+Cx2+Dx3+Ex4	
r=0.999990	
Constants:	A=0.000000
B=1.000000	C=0.000000
D=0.000000	E=0.000000

Special Notes:

APPROVED BY: Devon VonFeldt
Devon VonFeldt

Scott Specialty Gases

Shipped From:	500 WEAVER PARK RD LONGMONT CO 80501 Phone: 888-253-1635	Fax: 303-772-7673

CERTIFICATE OF ANALYSIS

COLORADO STATE UNIVERSITY

DEPT MECH ENG ENERGY LAB
430 N. COLLEGE
FT COLLINS CO 80523

PROJECT #: 08-50854-002
PO#: P165299
ITEM #: 0802H2021764AL
DATE: 12/14/98

CYLINDER #: ALM047390
FILL PRESSURE: 2059 PSIG

ANALYTICAL ACCURACY: +/-2%
PRODUCT EXPIRATION: 12/10/1999

BLEND TYPE : CERTIFIED MASTER GAS

COMPONENT	REQUESTED GAS CONC MOLES		ANALYSIS (MOLES)	
HALOCARBON 22	40.	PPM	40.0	PPM
NITROGEN		BALANCE		BALANCE

CGA 580 2059 PSIG

ANALYST: [signature]
STEVE SHOCKITES

Scott Specialty Gases

Shipped From: 500 WEAVER PARK RD
LONGMONT CO 80501
Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ANALYSIS

COLORADO STATE UNIVERSITY

DEPT MECH ENG ENERGY LAB
430 N. COLLEGE
FT COLLINS CO 80523

PROJECT #: 08-50854-002
PO#: P165299
ITEM #: 0802H2021764AL
DATE: 12/14/98

CYLINDER #: ALM047390
FILL PRESSURE: 2059 PSIG

ANALYTICAL ACCURACY: +/-2%
PRODUCT EXPIRATION: 12/10/1999

BLEND TYPE : CERTIFIED MASTER GAS

COMPONENT	REQUESTED GAS CONC MOLES		ANALYSIS (MOLES)	
HALOCARBON 22	40.	PPM	40.0	PPM
NITROGEN		BALANCE		BALANCE

CGA 580 2059 PSIG

ANALYST:
STEVE SHOCKITES

APPENDIX I

BASELINE METHANE/NON-METHANE ANALYZER

1030H SOURCE METHANE/NON-METHANE

BASELINE FINAL TEST PROCEDURE

ORDER: CSU

SERIAL #: 1322

A VISUAL INSPECTION

1 Visual check per BLI Quality Assurance standards.
2 All cable connections secure and not damaged.
3 All solder connections clean, no cold solder joints.
4 Power cord and back panel plumbing fittings are provided.
5 All PC boards are serialized, with matching test slips in the unit file.
6 Verify plumbing according to attached application document.
7 Verify options according to attached engineering document.
8 Prior work order routings signed and completed.

B FUNCTIONAL CHECK

1 470 ohm resistors correct.
2 Air and H2 regulators turn and lock correctly, gauges reflect pressure change.
3 Range switches function correctly.
4 Signal selection switch set to two position and centered on panel.
5 Power, Pump, Zero, and H2 switches work correctly.
6 Span pots turn easily and are set correctly

C MOTHERBOARD

1 AC Power supply wired for correct source(110V/220V). 110V
2 -5V, +15VISO, and -15V regulator isolated from chassis ground.
3 Ignite button jumps cut.(For Auto Ignite Option)
4 Confirm orientation on all capacitors.

D ELECTRICAL CHECK

1 AC transformer voltages checked at J11.
2 DC regulator voltages checked at motherboard

a	+12VDC	11.97
b	-5 VDC=	-5.05
c	15 VDC=	14.9
d	-15 VDC=	-15.29
e	15V ISO=	15.25
f	+5 VDC=	5

3 Collector Voltage checked at E2

a	-150V supply =	-148
b	-15V supply =	-15
c	Custom supply =	100

E OPTIONS INSTALLED

OK	Custom Collector Voltage Board
OK	Jumper selectable Collector Voltage
OK	Secondary trim pot on Amp board at P1
OK	Dual 4-20mA Modules
OK	0-1V to 0-10V converters(on each 4-20mA module)

Auto Ignite	OK
Dual Range switch	OK

F INTERFACE BOARD INSTALLATION

1 Install interface board on an extender card in slot 4
2 Place unit in "manual" mode, enter the logic codes listed below.
3 Check the voltages at the pins indicated.

Pin #	REST	LOGIC	RESET	VOLTS
3	0 VDC	01	XX,00	5 VDC
4	0 VDC	11	XX,00	5 VDC
5	0 VDC	21	XX,00	5 VDC
6	0 VDC	31	XX,00	5 VDC
7	0 VDC	41	XX,00	5 VDC
8	0 VDC	51	XX,00	5 VDC
9	0 VDC	61	XX,00	5 VDC
10	5 VDC	X1	00	0 VDC
11	0 VDC	15 or 25 & X1	16,26,00	15 VDC (unloaded)
12	5 VDC	X1	00	0 VDC
13	0 VDC	33	XX,00	5 VDC
15	0 VDC	55	XX,00	5 VDC
16	0 VDC	13	14,00	15 VDC (unloaded)
17	0 VDC	23	24,00	15 VDC (unloaded)
18	0 VDC	45	46,00	5 VDC
20	0 VDC	25	26,00	5 VDC
22	0 VDC	15	16,00	5 VDC
L	5 VDC	X5	00	0 VDC
N	0 VDC	65	XX,00	5 VDC
P	0 VDC	35	XX,00	5 VDC
S	0 VDC	X1	00	15 VDC (unloaded)
U	0 VDC	03	04,00	5 VDC
V	0 VDC	05	06,00	5 VDC

4 Remove the extender card and replace the interface board in slot 4.

G AMPLIFIER BOARD INSTALLATION

1 Plug the amplifier board on the extender card in slot 7.
2 Clip a jumper between the bottom side of R4 and the upper right pin on the detector plug matrix.(DET 1)
3 In the MANUAL mode enter code 00(reset).
4 Set the RANGES to 2, the SPAN pots to 10, and the SIGNAL to Methane.
special Set the Dual Range (HIGH/LOW) switch to LOW.
5 Adjust the voltage at pin 10 of U2 to 0.0mVDC with P2.
special Adjust the voltage at pin 12 of U2 to 0.0mVDC with P1.
6 Enter code 01(enable detector 1 signal out).
7 Adjust the voltage at pin 12 of U4 to 0.0mVDC with P4.
8 Enter code 00(reset).
9 Adjust the voltage at pin 10 of U8 to 0.0mVDC with P12.
10 Adjust the voltage at pin 12 of U8 to 0.0mVDC with P13.
11 Enter code 01 and 05(SPAN).
12 Adjust the voltage at pin 10 of U8 to 1.00VDC with P3.
13 Remove the jumper and plug the ribbon cable into the electrometer.
14 Remove the extender card and replace the Amplifier board in slot 7.

H **AUTO IGNITE BOARD CHECK**

1 Make sure programmed PAL chip is in position U3 on the Auto Ignite board.
2 Adjust the voltage at test point 1 to 3.00V with P1.
3 Attach auto ignite test fixture to test points 1-12.
4 Adjust P2 until diode 10(occilation frequency) turns on every 10 seconds.
5 Turn unit off, then on to reset. Diodes 6-9 on the test fixture should step through a binary count sequence, with diode 4(coil on) lighting every other step.
6 Diode 5(H2 Shutoff) should remain lit until a binary count of 10. Afterwards, diode 5 should respond to the front panel H2 ON/OFF switch and diode 4(coil on) should respond to the Ignite button.
7 Short terminal 7 on the back panel to ground. The sequence should reset.

I **SAMPLE PUMP SETUP**

1 Turn on the pump with the front panel switch.
2 Check that the fittings and lines are not vibrating against the case as they pass through the oven wall.
3 Check that the internal lines are not vibrating against each other.
4 If vibration is a problem, adjust the pump shock mount spacing.

I **TEMPERATURE CONTROLLER SETUP**

1 Access the setup menu on the Watlow temperature controller by pressing the UP and DOWN keys simultaneously for three seconds.
2 Use the UP/DOWN keys to change variables within a selection and the M(mode) key to advance to the next selection.
3 The normal values used by MSA-Baseline are:

LOC	0	rL	-200	Ot 2	dEA	rtd	void
In	H	rH	1250	HSA	2	rP	OFF
dEC	0	Ot 1	ht	LAt	nLA	rt	void
C_F	C	HSC	2	SIL	OFF	PL	100

4 Access the operation menu by pressing the M(mode) key.
5 Use the UP/DOWN keys to change variables within a selection and the M(mode) key to advance to the next selection.
6 The normal values used by MSA-Baseline are:

Pb1	3	Ct1	5	rA2	void	ALH	25
rE1	0.15	Pb2	void	Ct2	void	CAL	-20
rA1	0.33	rE2	void	ALO	-25	AUt	0

7 Note: Most values in the operation menu will set themselves by setting the AUt selection to 2. See the Watlow Manual for more information.
8 Use the UP/DOWN keys to select a set point. Normally set at 200.
9 Monitor oven temperature with an external temperature probe. You will have to adjust the CAL value in the operation menu so that the Watlow controllers Temp. Read matches the external probe.
11 After athe temperature has stabilized, note the final value.

Watlow Display		Oven Chamber		CAL Value	
SET=	200	MAIN=	198.4	CAL=	-18
READ=	200	FID=	NA		

J **INTEGRATOR BOARD TEST**

special	Set integrator board dip switch to 4(may have to be adjusted w/custom ranges)	
1	Note dip switch setting	8
2	Set signal switch to Methane and the methane Range to 50.	
special	Set the Dual Range switch to LOW	
3	Enter code 00, 05, 01. Wait 50 seconds. Enter code 02.	Actual value found
4	Adjust the methane span pot until the display reads 50.0	50.0
	Change the range to 20, display should read 20.0	19.7
	Change the range to 10, display should read 10.0	09.6
	Change the range to 5, display should read 5.00	5.00
	Change the range to 2, display should read 2.00	1.97
	Note methane span pot setting	8.22
special	Note: When a multiplication factor is involved on an instrument, multiply both the range and the display by the same amount. For example, a range of 50ppm (x10) is 500ppm, and the display of 50.0 (x10) is also 500.	
5	Attach volt meter between pin 5(methane out) and pin 1(methane iso-ground).	
special	Output should be 20.0 mA(w/4-20mA module) or 1.000V.	1
7	Change the methane range back to 50.	
8	Enter code 00, 05, 01. Wait 25 seconds. Enter code 02.	
9	Value displayed should be 25.0	24.9
special	Output at pin 5 should be 12.0mA(w/4-20mA module) or 0.500V.	0.501
11	Set the signal switch to Non-Methane.	
12	Enter code 00, 05, 11. Wait 50 seconds. Enter code 12.	actual value found
13	Adjust the non-methane span pot until the display reads 50.0	50.0
	Change the range to 20, display should read 20.0	19.6
	Change the range to 10, display should read 10.0	09.6
	Change the range to 5, display should read 5.00	5.00
	Change the range to 2, display should read 2.00	1.96
14	Attach volt meter between pin 6(non-methane out) and pin 9(non-meth iso-ground).	
special	Output should be 20.0mA(w/4-20mA module) or1.000 VDC.	0.998
16	Change the non-methane range back to 50.	
17	Enter code 00, 05, 11. Wait 25 seconds. Enter code 12.	
18	Value displayed should be 25.0	24.9
special	Output at pin 5 should be 12mA(w/4-20mA module) or0.500 VDC.	0.5
19	Note non methane span pot setting.	8.01

K **4-20mA OUTPUT OPTION (Methane)**

Note: check all values below at the 4-20mA modules mounted on the instruments left side panel

1 Check for AC line voltage on dual 20V module.

2 Check U1 20V output	20.41
3 Check U2 20V output	20.3

4 Check 0-10V signal in at U on the mA module.
5 Check 4-20mA output between T (gnd) and I (signal) on the same side.
6 Indicate exaxt results using the span signal as the input.

input	output
00.0mV	4.05
10.11V	20.02

special Check that the x10V board is operating correctly(pin 4 = 0-1V in, pin 3 = 0-10V out)
(Non-Methane)

7 Check for AC line voltage on dual 20V module.

8 Check U1 20V output	20.2
9 Check U2 20V output	20.33

10 Check 0-10V signal in at UE on mA module.
11 Check 4-20mA output between terminal T (gnd) and I (signal) on the same side.
12 Indicate exaxt results using the span signal as the input.

input	output
00.0mV	3.99
10.11V	20.02

special Check that the x10V board is operating correctly(pin 4 = 0-1V in, pin 3 = 0-10V out)

L **FLOW CALIBRATION**

1 Attach H2 and HCF Air to their respective inlets on the back panel.
Bottle pressure should be 40PSI in both cases.
Note: It is common to "T" the Air line to provide pressure for both the combustion Air inlet and the SP (valve actuation) inlet.
2 Attach a flow meter to the outlet side of the built in H2 regulator.
Adjust the pressure until a flow of 40 cc/min is obtained.
3 Attach a flow meter to the outlet side of the Air regulator.
Adjust to pressure until a flow of 200cc/min is obtained.
4 Note exact results.

Air=	27	PSI at	200	cc/min.
H2=	21	PSI at	40	cc/min

5 Attach carrier gas to CARRIER IN port. (normally HCF Air or Zero N2)
6 Adjust carrier gas bottle pressure until a flow of 45cc/min is obtained.
Note: Flow must be measured at the FID inside the oven. H2 flow must be cut prior to measurement, and the temperature must have stabilized at the normal operational setting. Normally a bottle pressure of 25 PSI will produce the desired flow rate. Use a high temperature flow rate probe.
7 Note exact results for inject (03) and backflush (04) modes.

INJECT	22	cc/min	PSI AT BOTTLE	28
BACKFLUSH	22	cc/min		

8 Reopen H2 bottle.

M **IGNITE FID**

1 Install FID in the oven. Connect Fuel and Air lines. Make sure the extender and chimney locking collars are set tightly.
2 Attach the electrometer board to the extender as it emerges from the oven wall. After checking that the FID ignites, reattach the electrometer inside its shield with insulation.
3 Turn unit off, then on to reset the auto ignite sequence. Check for flame by looking for condensation on cold steel at the chimney vent.
4 Confirm that the ignite LED on the front panel lights when the flame does.
5 If the flame does not light:
  a Manually light the flame by holding open the H2 ON/OFF switch and pressing the ignite button.
  b Try increasing the H2 pressure slightly
  c Remove the FID chimney and check that the coil is glowing brightly when the ignite button is pressed.

M DISPLAY METER, RANGE, AND SIGNAL OUT TEST

special The Dual Range swith adds a multiplier to the amp board circuit prior to the span signal, and so it should have no impact on this test.

Step		CODE 01 Actual Values Found	CODE 11
1	Connect the multimeter to back panel terminals number 10(ground) and number 3(0 to 100mVDC signal out)		
2	Enter code 00(reset). Ranges set to 2. Signal set to Methane.		
3	Voltage at terminal 3 = 00.0 mVDC.	0	
5	Enter code 01(enable output)		
6	Voltage at terminal 3= 0.0 mVDC.	0	
7	Enter code 05(span).		
8	Voltage at terminal 3 =100.0 mVDC.	100	100
9	Range Set to 5. Voltage at terminal 3 = 40.0 mVDC.	39.8	37.8
11	Range Set to 10. Voltage at terminal 3 = 20.0 mVDC.	20	20
12	Range Set to 20. Voltage at terminal 3 = 10.0 mVDC.	10	9.9
14	Range Set to 50. Voltage at terminal 3 = 4.0 mVDC.	04.0	3.9
15	Enter code 00(reset)		
16	Voltage at terminal 2 = 0.000 VDC.	05.0	
17	Enter code 01(enable output) and 05(span)		
18	Voltage at terminal 2= 10.0 VDC.	10.07	

N BURN IN

1 Let unit run for 48 hours with the sample pump drawing from a zero nitrogen stream at a slight overpressure.

START BURN IN
Time = 8:00 AM Date = 12/28/98

STOP BURN IN
Time = 8:00 AM Date = 12/31/98

COMPLETED BY
AFN

12/31/98

1030H SOURCE METHANE / NON-METHANE

BASELINE APPLICATION DATA SHEET

ORDER:	CSU			SERIAL #:	1322
COLLECTOR VOLTAGE:		Low	-15.18	DETECTOR:	FID
		high	-99.8		

Ranges		DUAL (x100)200,500,1000,2000,5000(x1000)2K,5K,10K,20K,50K		
Columns		Part #	Material	tubing
	C1	SC001020	3S unibeads	6' x 1/8" SS
	C2	SC001021	1S unibeads	5' x 1/8" SS
		Arangement:	Port 7 on the valve to C2 to C1 to Port 6 on the valve	
Sample loop				
	S1	10.7" x .085 I.D. SS	aproximately 1 mL volume	

Program

Step	Time	Code		Description
00	~~00:00~~	03	0000	Inject valve one
01	~~00:15~~	15	0015	Enable detector one output
02	~~01:33~~	01	0119	Open peak one(methane) window
03	~~01:53~~	02	0137	Close peak one(methane) window
04	~~02:00~~	04	0140	Backflush valve one
05	~~03:36~~	11	0315	Open peak two(non-methane) window
06	~~04:30~~	12	0329	Close peak two(non-methane) window
07	~~04:45~~	00	0335	Reset logic
08	~~04:50~~	99	0345	Look to Recycle
99	~~00:05~~	00	0004	Recycle

LINEARITY TEST (LOW) Note: Dip switch on integrator card set to 8.

50(x100) range	Methane Peak		50(x100) range	Non Methane Peak	
peak	PPM	Display	peak	PPM	Display
1	5.00	04.9	2	5.00	04.8
3	50.0	49.9	4	50.0	48.9
Methane Span:		6.10	Non-Meth Span:		2.31
Curves Used:		2			

CURVE SHEETS ATTACHED

1 HIGH LINEARITY
2 LOW LINEARITY
3
4

Note: MEQ factors were not used since the Non-Methane peak can be independently scaled and ranged at the operators discretion.
SEE CURVE SHEETS FOR HIGH RANGE LINEARITY
After shipment, run clean carrier gas through columns for 24 hours for best results

FLOWS			ELECTROMETER		OVEN TEMPERATURES	
stream	psi	cc/min	1	MegOhm	Controller Type:	WATLOW
Air	27	200	1	uF	Temperature Set:	200
H2	21	40	1	T.C.	Temperature Read:	200
Sample	pump	2.2LPM	10k/100k	at R6	Main Oven:	198.4C
Carrier I	28	22	normal	Zero circuit		
CarrierB	28	22	Carrier Gas Used:	HCF Air		
		COMPLETED BY	AFN		DATE	12/31/98

CSU

UNIT: 1030H M/N

SERIAL # 1322

DATE 12/31/98 BY A.N.

Separation Test

1 5000 ppm Methane
2 5000 ppm Propane
3 1% Methane
4 1% Propane

BALANCE HCF Air

high range

FLOW SETTINGS

PSI	STREAM	RATE
27	AIR	200 cc/min
21	H2	40 cc/min
28	Carier Inj.	22 cc/min
28	Carrier Bk.	22 cc/min

TRIM POT SETTINGS

Methane	5.89
Non-Methane	2.26

ELECTROMETER

1 MEGOHM
1 MICROFARAD
1 SEC T.C.
10K/100K at R6
normal zero circuit

OVEN TEMPERATURES

TYPE: WATLOW
200 SET
200 READ
198.4°C MAIN OVEN
-18 CAL

DETECTOR

TYPE : FID

COLLECTOR VOLTS: -99.8

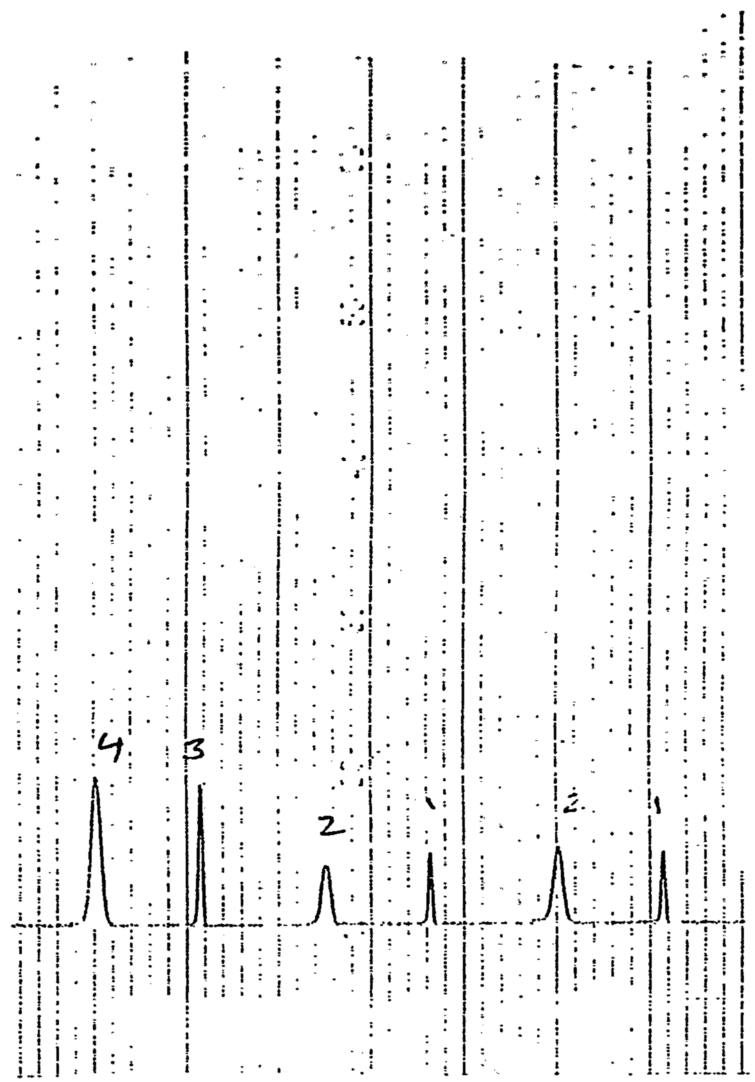
RANGE (x1000)

Methane	Non-Methane
50000 ppm	50000 ppm
50 POSITION	50 POSITION

CHART REC. SETTINGS

SPEED: 5 mm/min

FULL SCALE: 100mV



C30

UNIT:	1030H M/N
SERIAL #	1322
DATE 12/31/98	BY A.N.

Separation Test
1 500 ppm Methane
2 500 ppm Propane
3 5000ppm Methane
4 5000ppm Propane
BALANCE HCF Air
low range

FLOW SETTINGS

PSI	STREAM	RATE
27	AIR	200 cc/min
21	H2	40 cc/min
28	Carier Inj.	22 cc/min
28	Carrier Bk.	22 cc/min

TRIM POT SETTINGS
Methane 6.10
Non-Methane 2.31

ELECTROMETER
1 MEGOHM
1 MICROFARAD
1 SEC T.C.
10K/100K at R6
normal zero circuit

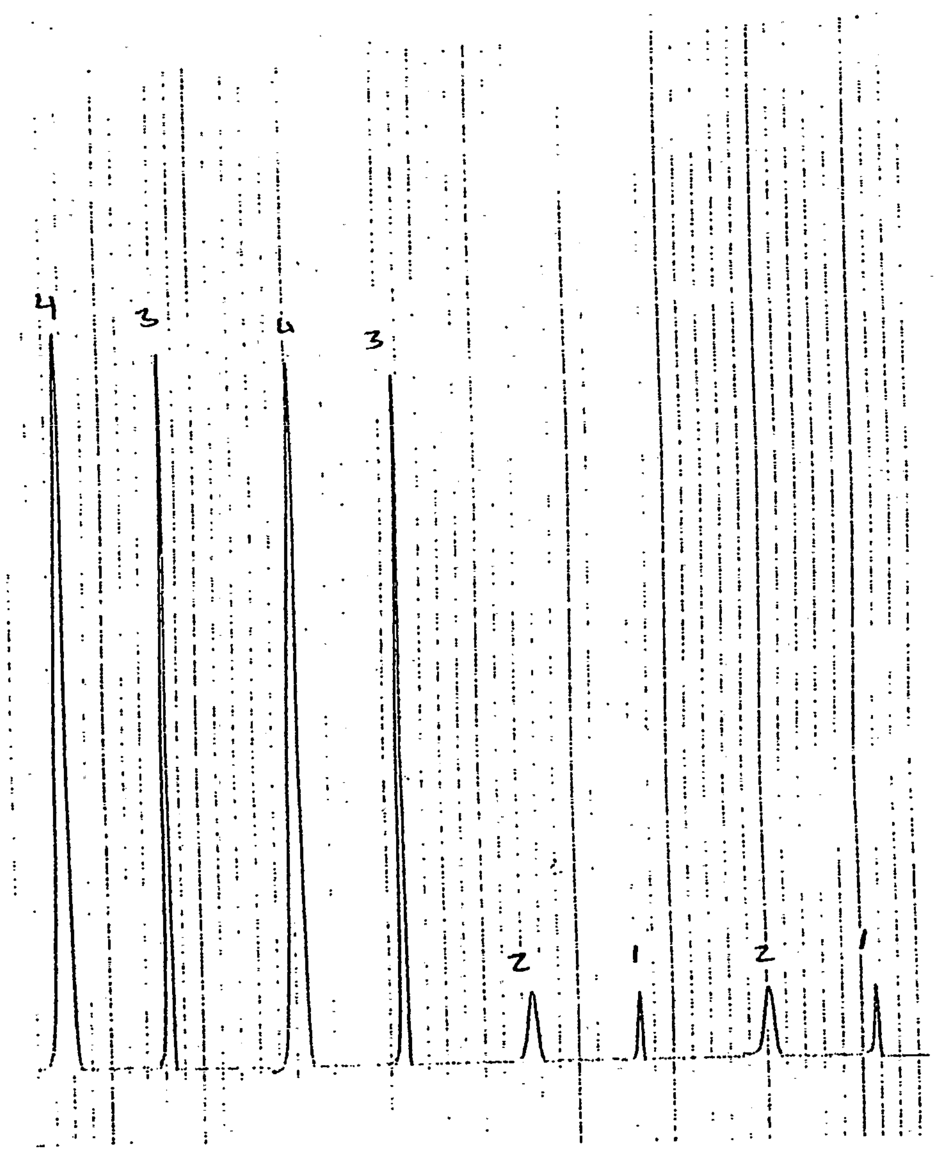
OVEN TEMPERATURES
TYPE: WATLOW
200 SET
200 READ
198.4°C MAIN OVEN
-18 CAL

DETECTOR
TYPE : FID
COLLECTOR VOLTS: -15

RANGE (x100)

Methane	Non-Methane
5000 ppm	5000 ppm
50 POSITION	50 POSITION

CHART REC. SETTINGS
SPEED: 5 mm/min
FULL SCALE: 100mV



1030H SOURCE METHANE/NON-METHANE

BASELINE FINAL TEST PROCEDURE

ORDER: CSU SERIAL #: 1321

A VISUAL INSPECTION

1 Visual check per BLI Quality Assurance standards.
2 All cable connections secure and not damaged.
3 All solder connections clean, no cold solder joints.
4 Power cord and back panel plumbing fittings are provided.
5 All PC boards are serialized, with matching test slips in the unit file.
6 Verify plumbing according to attached application document.
7 Verify options according to attached engineering document.
8 Prior work order routings signed and completed.

B FUNCTIONAL CHECK

1 470 ohm resistors correct.
2 Air and H2 regulators turn and lock correctly, gauges reflect pressure change.
3 Range switches function correctly.
4 Signal selection switch set to two position and centered on panel.
5 Power, Pump, Zero, and H2 switches work correctly.
6 Span pots turn easily and are set correctly

C MOTHERBOARD

1 AC Power supply wired for correct source(110V/220V). 110V
2 -5V, +15VISO, and -15V regulator isolated from chassis ground.
3 Ignite button jumps cut.(For Auto Ignite Option)
4 Confirm orientation on all capacitors.

D ELECTRICAL CHECK

1 AC transformer voltages checked at J11.
2 DC regulator voltages checked at motherboard

a	+12VDC	11.82
b	-5 VDC=	-5.02
c	15 VDC=	14.94
d	-15 VDC=	-15.17
e	15V ISO=	15.01
f	+5 VDC=	5

3 Collector Voltage checked at E2

a	-150V supply =	-146.8
b	-15V supply =	-15.18
c	Custom supply =	-98.7

E OPTIONS INSTALLED

OK	Custom Collector Voltage Board
OK	Jumper selectable Collector Voltage
OK	Secondary trim pot on Amp board at P1
OK	Dual 4-20mA Modules
OK	0-1V to 0-10V converters(on each 4-20mA module)

Auto Ignite	OK
Dual Range switch	OK

F INTERFACE BOARD INSTALLATION

1 Install interface board on an extender card in slot 4
2 Place unit in "manual" mode, enter the logic codes listed below.
3 Check the voltages at the pins indicated.

Pin #	REST	LOGIC	RESET	VOLTS
3	0 VDC	01	XX,00	5 VDC
4	0 VDC	11	XX,00	5 VDC
5	0 VDC	21	XX,00	5 VDC
6	0 VDC	31	XX,00	5 VDC
7	0 VDC	41	XX,00	5 VDC
8	0 VDC	51	XX,00	5 VDC
9	0 VDC	61	XX,00	5 VDC
10	5 VDC	X1	00	0 VDC
11	0 VDC	15 or 25 & X1	16,26,00	15 VDC (unloaded)
12	5 VDC	X1	00	0 VDC
13	0 VDC	33	XX,00	5 VDC
15	0 VDC	55	XX,00	5 VDC
16	0 VDC	13	14,00	15 VDC (unloaded)
17	0 VDC	23	24,00	15 VDC (unloaded)
18.	0 VDC	45	46,00	5 VDC
20	0 VDC	25	26,00	5 VDC
22	0 VDC	15	16,00	5 VDC
L	5 VDC	X5	00	0 VDC
N	0 VDC	65	XX,00	5 VDC
P	0 VDC	35	XX,00	5 VDC
S	0 VDC	X1	00	15 VDC (unloaded)
U	0 VDC	03	04,00	5 VDC
V	0 VDC	05	06,00	5 VDC

4 Remove the extender card and replace the interface board in slot 4.

G AMPLIFIER BOARD INSTALLATION

1 Plug the amplifier board on the extender card in slot 7.
2 Clip a jumper between the bottom side of R4 and the upper right pin on the detector plug matrix.(DET 1)
3 In the MANUAL mode enter code 00(reset).
4 Set the RANGES to 2, the SPAN pots to 10, and the SIGNAL to Methane.
special Set the Dual Range (HIGH/LOW) switch to LOW.
5 Adjust the voltage at pin 10 of U2 to 0.0mVDC with P2.
special Adjust the voltage at pin 12 of U2 to 0.0mVDC with P1.
6 Enter code 01(enable detector 1 signal out).
7 Adjust the voltage at pin 12 of U4 to 0.0mVDC with P4.
8 Enter code 00(reset).
9 Adjust the voltage at pin 10 of U8 to 0.0mVDC with P12.
10 Adjust the voltage at pin 12 of U8 to 0.0mVDC with P13.
11 Enter code 01 and 05(SPAN).
12 Adjust the voltage at pin 10 of U8 to 1.00VDC with P3.
13 Remove the jumper and plug the ribbon cable into the electrometer.
14 Remove the extender card and replace the Amplifier board in slot 7.

H **AUTO IGNITE BOARD CHECK**

1 Make sure programmed PAL chip is in position U3 on the Auto Ignite board.
2 Adjust the voltage at test point 1 to 3.00V with P1.
3 Attach auto ignite test fixture to test points 1-12.
4 Adjust P2 until diode 10(occilation frequency) turns on every 10 seconds.
5 Turn unit off, then on to reset. Diodes 6-9 on the test fixture should step through a binary count sequence, with diode 4(coil on) lighting every other step.
6 Diode 5(H2 Shutoff) should remain lit until a binary count of 10. Afterwards, diode 5 should respond to the front panel H2 ON/OFF switch and diode 4(coil on) should respond to the Ignite button.
7 Short terminal 7 on the back panel to ground. The sequence should reset.

I **SAMPLE PUMP SETUP**

1 Turn on the pump with the front panel switch.
2 Check that the fittings and lines are not vibrating against the case as they pass through the oven wall.
3 Check that the internal lines are not vibrating against each other.
4 If vibration is a problem, adjust the pump shock mount spacing.

I **TEMPERATURE CONTROLLER SETUP**

1 Access the setup menu on the Watlow temperature controller by pressing the UP and DOWN keys simultaneously for three seconds.
2 Use the UP/DOWN keys to change variables within a selection and the M(mode) key to advance to the next selection.
3 The normal values used by MSA-Baseline are:

LOC	0	rL	-200	Ot 2	dEA	rtd	void
In	H	rH	1250	HSA	2	rP	OFF
dEC	0	Ot 1	ht	LAt	nLA	rt	void
C_F	C	HSC	2	SIL	OFF	PL	100

4 Access the operation menu by pressing the M(mode) key.
5 Use the UP/DOWN keys to change variables within a selection and the M(mode) key to advance to the next selection.
6 The normal values used by MSA-Baseline are:

Pb1	3	Ct1	5	rA2	void	ALH	25
rE1	0.15	Pb2	void	Ct2	void	CAL	-20
rA1	0.33	rE2	void	ALO	-25	AUt	0

7 Note: Most values in the operation menu will set themselves by setting the AUt selection to 2. See the Watlow Manual for more information.
8 Use the UP/DOWN keys to select a set point. Normally set at 200.
9 Monitor oven temperature with an external temperature probe. You will have to adjust the CAL value in the operation menu so that the Watlow controllers Temp. Read matches the external probe.
11 After athe temperature has stabilized, note the final value.

Watlow Display		Oven Chamber		CAL Value	
SET=	200	MAIN=	198.8	CAL=	-11
READ=	200	FID=	NA		

J INTEGRATOR BOARD TEST

special Set integrator board dip switch to 4(may have to be adjusted w/custom ranges)

Step	Instruction	Actual value found
1	Note dip switch setting	8
2	Set signal switch to Methane and the methane Range to 50.	
special	Set the Dual Range switch to LOW	
3	Enter code 00, 05, 01. Wait 50 seconds. Enter code 02.	Actual value found
4	Adjust the methane span pot until the display reads 50.0	50.0
	Change the range to 20, display should read 20.0	19.7
	Change the range to 10, display should read 10.0	09.7
	Change the range to 5, display should read 5.00	5.00
	Change the range to 2, display should read 2.00	1.96
	Note methane span pot setting	7.99
special	Note: When a multiplication factor is involved on an instrument, multiply both the range and the display by the same amount. For example, a range of 50ppm (x10) is 500ppm, and the display of 50.0 (x10) is also 500.	
5	Attach volt meter between pin 5(methane out) and pin 1(methane iso-ground).	
special	Output should be 20.0 mA(w/4-20mA module) or 1.000V.	1
7	Change the methane range back to 50.	
8	Enter code 00, 05, 01. Wait 25 seconds. Enter code 02.	
9	Value displayed should be 25.0	24.3
special	Output at pin 5 should be 12.0mA(w/4-20mA module) or 0.500V.	0.488
11	Set the signal switch to Non-Methane.	
12	Enter code 00, 05, 11. Wait 50 seconds. Enter code 12.	actual value found
13	Adjust the non-methane span pot until the display reads 50.0	50.0
	Change the range to 20, display should read 20.0	19.8
	Change the range to 10, display should read 10.0	09.7
	Change the range to 5, display should read 5.00	5.00
	Change the range to 2, display should read 2.00	1.98
14	Attach volt meter between pin 6(non-methane out) and pin 9(non-meth iso-ground).	
special	Output should be 20.0mA(w/4-20mA module) or1.000 VDC.	0.999
16	Change the non-methane range back to 50.	
17	Enter code 00, 05, 11. Wait 25 seconds. Enter code 12.	
18	Value displayed should be 25.0	24.9
special	Output at pin 5 should be 12mA(w/4-20mA module) or0.500 VDC.	0.5
19	Note non methane span pot setting.	7.92

K 4-20mA OUTPUT OPTION (Methane)

Note: check all values below at the 4-20mA modules mounted on the instruments left side panel

1 Check for AC line voltage on dual 20V module.

2 Check U1 20V output	20.43
3 Check U2 20V output	20.23

4 Check 0-10V signal in at U on the mA module.
5 Check 4-20mA output between T (gnd) and I (signal) on the same side .
6 Indicate exaxt results using the span signal as the input.

input	output
00.0mV	3.98
10.11V	20.02

special Check that the x10V board is operating correctly(pin 4 = 0-1V in, pin 3 = 0-10V out)

(Non-Methane)

7 Check for AC line voltage on dual 20V module.

8 Check U1 20V output	19.9
9 Check U2 20V output	20.15

10 Check 0-10V signal in at UE on mA module.
11 Check 4-20mA output between terminal T (gnd) and I (signal) on the same side.
12 Indicate exaxt results using the span signal as the input.

input	output
00.0mV	3.97
10.11V	19.93

special Check that the x10V board is operating correctly(pin 4 = 0-1V in, pin 3 = 0-10V out)

L **FLOW CALIBRATION**

1 Attach H2 and HCF Air to their respective inlets on the back panel.
Bottle pressure should be 40PSI in both cases.
Note: It is common to "T" the Air line to provide pressure for both the combustion Air inlet and the SP (valve actuation) inlet.
2 Attach a flow meter to the outlet side of the built in H2 regulator.
Adjust the pressure until a flow of 40 cc/min is obtained.
3 Attach a flow meter to the outlet side of the Air regulator.
Adjust to pressure until a flow of 200cc/min is obtained.
4 Note exact results.

Air=	24	PSI at	200	cc/min.
H2=	22	PSI at	40	cc/min

5 Attach carrier gas to CARRIER IN port. (normally HCF Air or Zero N2)
6 Adjust carrier gas bottle pressure until a flow of 45cc/min is obtained.
Note: Flow must be measured at the FID inside the oven. H2 flow must be cut prior to measurement, and the temperature must have stabilized at the normal operational setting. Normally a bottle pressure of 25 PSI will produce the desired flow rate. Use a high temperature flow rate probe.
7 Note exact results for inject (03) and backflush (04) modes.

INJECT	18	cc/min	PSI AT BOTTLE	26
BACKFLUSH	18	cc/min		

8 Reopen H2 bottle.

M **IGNITE FID**

1 Install FID in the oven. Connect Fuel and Air lines. Make sure the extender and chimney locking collars are set tightly.
2 Attach the electrometer board to the extender as it emerges from the oven wall. After checking that the FID ignites, reattach the electrometer inside its shield with insulation.
3 Turn unit off, then on to reset the auto ignite sequence. Check for flame by looking for condensation on cold steel at the chimney vent.
4 Confirm that the ignite LED on the front panel lights when the flame does.
5 If the flame does not light:
  a Manually light the flame by holding open the H2 ON/OFF switch and pressing the ignite button.
  b Try increasing the H2 pressure slightly
  c Remove the FID chimney and check that the coil is glowing brightly when the ignite button is pressed.

M DISPLAY METER, RANGE, AND SIGNAL OUT TEST

special The Dual Range swith adds a multiplier to the amp board circuit prior to the span signal, and so it should have no impact on this test.

Step		CODE 01 Actual Values Found	CODE 11
1	Connect the multimeter to back panel terminals number 10(ground) and number 3(0 to 100mVDC signal out)		
2	Enter code 00(reset). Ranges set to 2. Signal set to Methane.		
3	Voltage at terminal 3 = 00.0 mVDC.	0	
5	Enter code 01(enable output)		
6	Voltage at terminal 3= 0.0 mVDC.	0	
7	Enter code 05(span).		
8	Voltage at terminal 3 =100.0 mVDC.	100	101.8
9	Range Set to 5. Voltage at terminal 3 = 40.0 mVDC.	39.1	40.6
11	Range Set to 10. Voltage at terminal 3 = 20.0 mVDC.	19.5	20.5
12	Range Set to 20. Voltage at terminal 3 = 10.0 mVDC.	9.7	10.2
14	Range Set to 50. Voltage at terminal 3 = 4.0 mVDC.	03.8	4.1
15	Enter code 00(reset)		
16	Voltage at terminal 2 = 0.000 VDC.	00.0	
17	Enter code 01(enable output) and 05(span)		
18	Voltage at terminal 2= 10.0 VDC.	10.04	

N BURN IN

1 Let unit run for 48 hours with the sample pump drawing from a zero nitrogen stream at a slight overpressure.

START BURN IN
Time = 8:00 AM Date = 12/28/98
STOP BURN IN
Time = 8:00 AM Date = 12/31/98

COMPLETED BY
AFN

12/31/98

1030H SOURCE METHANE / NON-METHANE

BASELINE APPLICATION DATA SHEET

ORDER:	CSU		SERIAL #:	1321
COLLECTOR VOLTAGE:	Low	-15.18	DETECTOR:	FID
	high	-15.18		

Ranges: DUAL (x10)20,50,100,200,500(x100)200,500,1000,2000,5000

Columns	Part #	Material	tubing
C1	SCO01020	3S unibeads	6' x 1/8" SS
C2	SCO01021	1S unibeads	5' x 1/8" SS

Arangement: Port 7 on the valve to C2 to C1 to Port 6 on the valve

Sample loop

S1	10.7" x ,085 I.D. SS	aproximately 1 mL volume

Program

Step	Time	Code	Description
00	~~00:00~~	03 0000	Inject valve one
01	~~00:15~~	15 0015	Enable detector one output
02	~~01:25~~	01 0135	Open peak one(methane) window
03	~~01:50~~	02 0154	Close peak one(methane) window
04	~~02:00~~	04 0200	Backflush valve one
05	~~03:15~~	11 0335	Open peak two(non-methane) window
06	~~04:30~~	12 0418	Close peak two(non-methane) window
07	~~04:45~~	00 0430	Reset logic
08	~~04:50~~	99 0445	Look to Recycle
99	~~00:05~~	00 0005	Recycle

LINEARITY TEST (LOW) — Note: Dip switch on integrator card set to 8.

50(x100) range	Methane Peak		50(x100) range	Non Methane Peak	
peak	PPM	Display	peak	PPM	Display
1	5.00	05.1	2	5.00	05.0
3	50.0	49.9	4	50.0	50.2
Methane Span:	5.38 ~~4.08~~		Non-Meth Span:	1,75 ~~1.48~~	
Curves Used:	2				

Note: MEQ factors were not used since the Non-Methane peak can be independently scaled and ranged at the operators discretion.

SEE CURVE SHEETS FOR HIGH RANGE LINEARITY

After shipment, run clean carrier gas through columns for 24 hours for best results

CURVE SHEETS ATTACHED

1 HIGH LINEARITY
2 LOW LINEARITY
3
4

FLOWS stream	psi	cc/min	ELECTROMETER		OVEN TEMPERATURES	
Air	26	200	10	MegOhm	Controller Type:	WATLOW
H2	20	40	0.1	uF	Temperature Set:	200
Sample	pump	2.2LPM	1	T.C.	Temperature Read:	200
Carrier I	26	18	10k/100k	at R6	Main Oven:	198.8C
CarrierB	26	18	normal	Zero circuit		
			Carrier Gas Used:	HCF Air		

COMPLETED BY: AFN — DATE: 12/31/98

UNIT: 1030H M/N
SERIAL # 1321
DATE 12/31/98 BY A.N.

Separation Test
1 50 ppm Methane
2 50 ppm Propane
3 500ppm Methane
4 500ppm Propane
BALANCE HCF Air
low range

FLOW SETTINGS

PSI	STREAM	RATE
24	AIR	200 cc/min
22	H2	46 ~~30~~ cc/min
26	Carier Inj.	18 cc/min
26	Carrier Bk.	18 cc/min

TRIM POT SETTINGS
Methane 4.08
Non-Methane 1.48

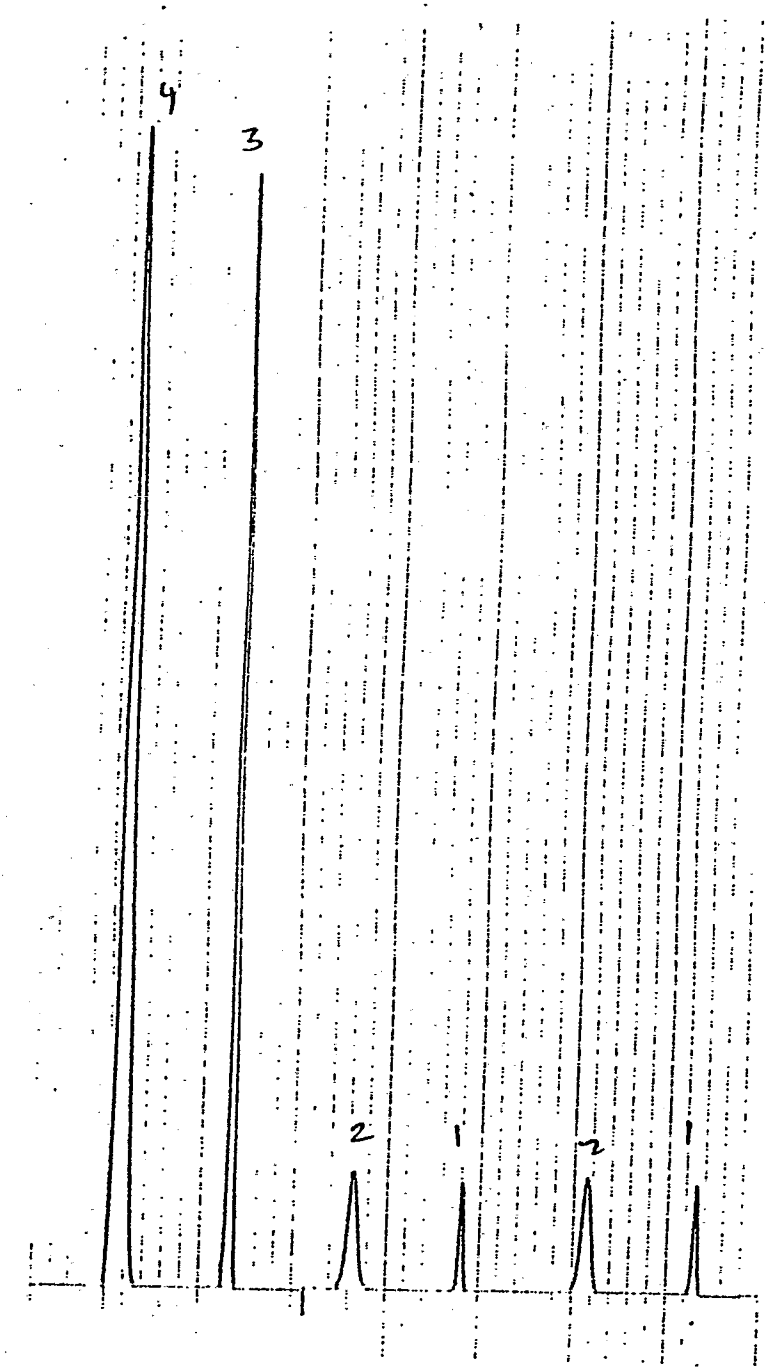
ELECTROMETER
10 MEGOHM
0.1 MICROFARAD
1 SEC T.C.
10K/100K at R6
normal zero circuit

OVEN TEMPERATURES
TYPE: WATLOW
200 SET
200 READ
198.8°C MAIN OVEN
-11 CAL

DETECTOR
TYPE : FID
COLLECTOR VOLTS: -15.18

RANGE (x10)
Methane Non-Methane
500 ppm 500 ppm
50 POSITION 50 POSITION

CHART REC. SETTINGS
SPEED: 5 mm/min
FULL SCALE: 100mV



CSU

UNIT: 1030H M/N

SERIAL # 1321

DATE 12/31/98 BY A.N.

Separation Test

1 500 ppm Methane
2 500 ppm Propane
3 5000ppm Methane
4 5000ppm Propane

BALANCE HCF Air

high range

FLOW SETTINGS

PSI	STREAM	RATE
24	AIR	200 cc/min
22	H2	40 ~~30~~ cc/min
26	Carier Inj.	18 cc/min
26	Carrier Bk.	18 cc/min

TRIM POT SETTINGS

Methane 4.08

Non-Methane 1.48

ELECTROMETER

10 MEGOHM

0.1 MICROFARAD

1 SEC T.C.

10K/100K at R6

normal zero circuit

OVEN TEMPERATURES

TYPE: WATLOW

200 SET

200 READ

198.8°C MAIN OVEN -11 CAL

DETECTOR

TYPE : FID

COLLECTOR VOLTS: -15.18

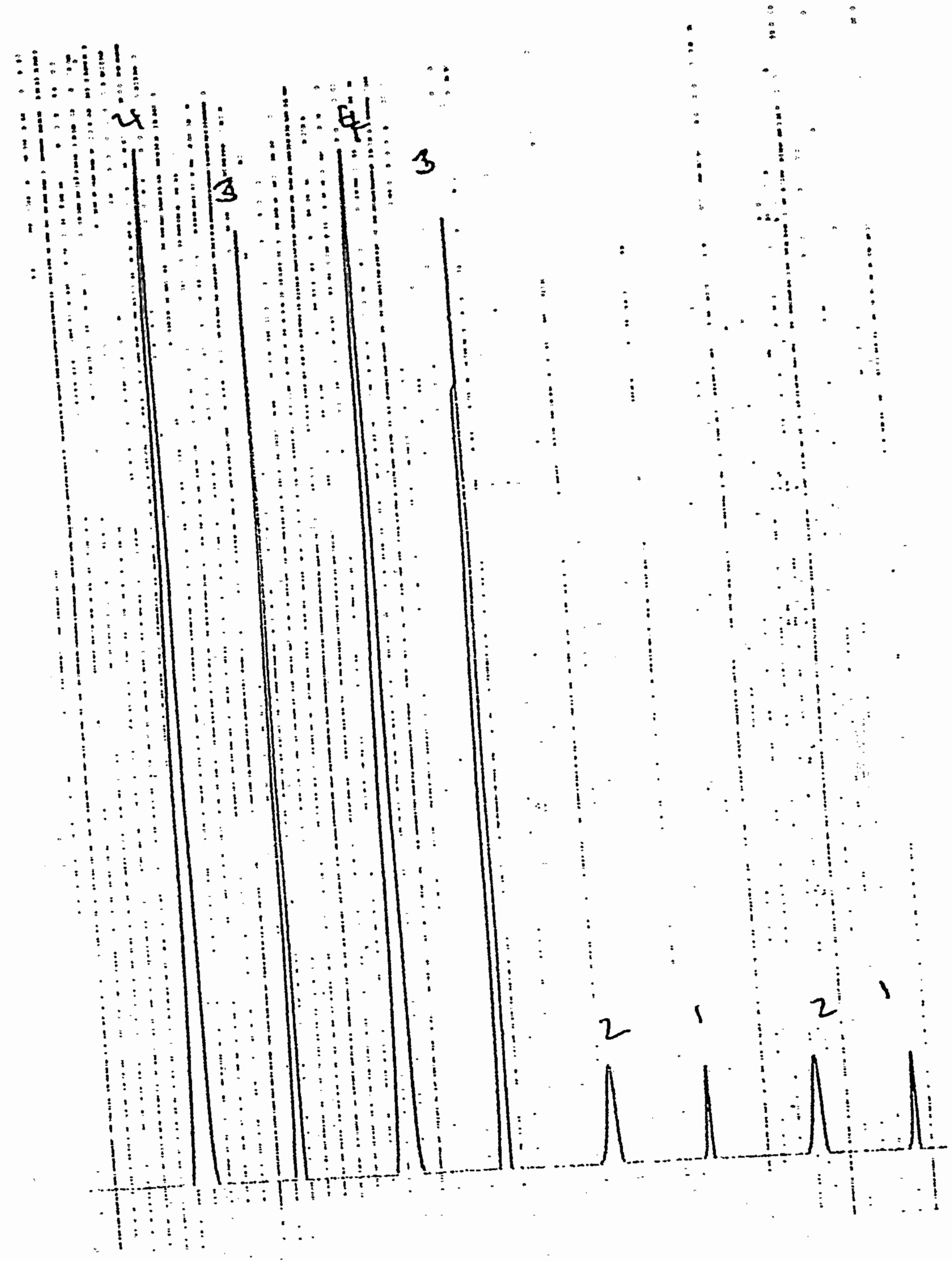
RANGE (x100)

Methane	Non-Methane
5000 ppm	5000 ppm
50 POSITION	50 POSITION

CHART REC. SETTINGS

SPEED: 5 mm/min

FULL SCALE: 100mV



APPENDIX J

PRESSURE AND TEMPERATURE CALIBRATIONS

Waukesha Engine Testbed Calibrations

Date: 3-2-99
Test: EPA

PRESSURES

Location	Range	Zero	Span	Setpoint	Reading
Intercooler Water	0-30psi	0	29	20	20.1
Fuel/Air Manifold and Air Manifold Diff.	0-250"H2O	0	250.4	125	125.2
Fuel Supply and Air Manifold Diff	0-15"H2O	0.1	15	7	7.1
Fuel Supply	0-50psi	0.2	50.5	30	30
Intercooler Water Diff	0-150"H2O	-1	148	75	74
Intercooler Air Diff	0-15"H2O	0	15	7	7
Airbox	0-100"H2O	0	99.9	50	49.9
Intercooler Air	0-130psi	0	130.1	70	70.8
Exhaust	0-100"H2O	0	98	50	49
Catalyst Diff	0-80"H2O	0.2	79.3	40	39.7
Orifice Diff	0-100"H2O	0	99.8	55	55.1
Orifice Static	0-70psi	0	69.8	69.7	69.64
Engine Oil	0-300psi	0.1	299.4	200	199.7
Turbo Oil	0-300psi	0	299.7	200	199.8
Pre Turbo Exhaust	0-30psi	0	30.1	20	19.9

Waukesha Engine Testbed Calibrations

Date: 8/2/99

Test: EPA

TEMPERATURES

Location	Range	Zero	Span	Setpoint	Reading
Dyno Water In	0-200°F	3	203	80	83
Dyno Water Out	0-200°F	3	203	130	133
Intercooler Water In	0-200°F	3	203	120	123
Intercooler Water Out	0-200°F	3	203	180	183
Intercooler Air In	0-300°F	4	303	290	293
Intercooler Air Out	0-300°F	6	304	130	135
Intake Manifold	0-200°F	3	203	130	133
Engine Jacket Water In	0-200°F	4	204	180	184
Engine Jacket Water Out	0-200°F	3	203	180	183
Air/Fuel Intake Manifold	0-200°F	3	203	150	153
Air Manifold In	0-200°F	4	204	130	134
Lube Oil Cooling Water In	0-200°F	3	203	160	163
Lube Oil Cooling Water Out	0-200°F	3	203	160	164
Oil Header	0-200°F	2	203	160	163
Engine Lube Oil In	0-200°F	2	203	160	163
Engine Lube Oil Out	0-200°F	4	204	180	184
Engine Fuel Gas	0-200°F	3	203	150	153
Exhaust Cylinder #1	0-~~850~~°F 1000	2	1002	950	952
Exhaust Cylinder #2	0-~~850~~°F	3	1003	950	953
Exhaust Cylinder #3	0-~~850~~°F	3	1003	950	953
Exhaust Cylinder #4	0-~~850~~°F	4	1004	950	954
Exhaust Cylinder #5	0-~~850~~°F	3	1003	950	953
Exhaust Cylinder #6	0-~~850~~°F	4	1004	950	954
Pre Turbo Exhaust	0-1000°F	4	1004	950	954
Post Turbo Exhaust	0-1000°F	3	1003	700	703
Pre Catalyst	0-850°F	2	853	650	653
Post Catalyst	0-850°F	3	853	650	653
Exhaust Header	0-850°F	3	854	650	654

APPENDIX K

EQUIPMENT CERTIFICATION SHEETS

El Paso Energy
Tennessee Gas Pipeline Measurement Services
Metrology Center Laboratory Report

Important Document

These documents certify that the instrument indicated has been inspected in accordance with accepted measurement practices and quality control procedures established for this laboratory and demonstrates reliable performance made by direct comparison to standards maintained by the Metrology Center. The Metrology Center standards are serviced and re-certified on a periodic basis with an unbroken chain of measurements traceable to the U.S. National metrology standards retained by the National Institute of Standards and Technology(NIST).

Duplicate copies of these documents are maintained on file for five years. The statistical information from our prior certifications provides the basis for assignment of certification period validity and preventative maintenance procedures.

The Metrology Center is a controlled environment facility located 30 06 15 North and 95 50 14 West at an elevation of 253ft above sea level. For additional information, duplicates of this document, or a complete file copy, please write to P.O. box 280, Hockley TX 77447 or call (713) 757-6685, and talk to Tim Hannan the Lead Metrology Specialist.

Report # **99031903**

El Paso Energy
Tennessee Gas Pipeline Measurement Services
Metrology Center Laboratory Report # 99031903
Receiving Report

Date Received in Lab:	3/17/99
Serial Numbers	11514
Model Numbers	Beta 0-5, 0-100

Inspections:

1. Received with or without freight damage decribed as follows: None
2. Received missing parts listed as follows: None
3. Received with physical damage described as follows: None
4. Received without case? No
5. Received with damaged case? No
6. Received with calibration tag removed? No
7. Received partially or completely assembled? No
8. Received with apparent fluid or particle contamination? No
9. Received with quick connects or valves? No

(quick connects and valves will be removed for testing.)

Maintenance & Repair Report

The information below is in reference to any preventative or repair measures provided during the certification procedures.

1. Inspected connectors & cables for electrical integrity as applicable. OK
2. Tested battery and charger as applicable

Parts used:	qty	Description/Reason for usage
1		
2		
3		
4		
5		
6		

Recommendations: None

Comments:

El Paso Energy
Tennessee Gas Pipeline Measurement Services
Metrology Center Laboratory Report # 99031903
Standards of Comparison

The primary and secondary standards below are the comparison basis for the equipment under test. These instruments are periodically tested by approved authorities and may be traced to the National Institute of Standards and Technology.

Equipment	Range Accuracy	Certification Date Re-certification Due
1. DH Hydraulic piston & cyl. No. 3342	200 psi/kg 0.01 % of reading	04/30/98 04/30/00
2. DH 1502 Divider No. 4087	0-20 psid 0.01 % of reading	04/22/98 04/22/00
3. DH 10KG Mass Set No. 2590	0-10 kg 0.002% of reading	07/17/97 07/17/99
4. DH Pneumatic piston & cyl. No. 3674A	250 psig/kg 0.01 % of reading	07/24/97 07/23/99
5. Ametek PK Ball & Nozzle No. 82579	654 In. H2O 0.015 % of reading	07/31/98 07/31/99
6. Ametek PK Mass Set No. 82579	4&10"wtc+654"WC Included	07/31/98 07/31/99
7. Paroscientific Mdl 760-15G No. 67204	0-15 psig .01% FS	08/10/98 08/10/99
8. Hart Scientific Mdl 9105 No.82563	-13 to +284 degrees F .1 degrees F	02/13/98 02/13/99
9. Ametek / M & G RK-200 SS No. 72793	0-200 psig 0.025% of reading	08/14/98 08/14/99

Report # 99031903 DATE: 3/19/99

Certificate of Accuracy

DIVISION / OWNER:	Gary Hutcherson
INSTRUMENT TYPE:	Beta 320 , 0-5
INSTRUMENT MFG.:	Hathaway
GRAVITY:	N/A
SERIAL #:	11514
TEST STANDARD:	AMETEK - PK TESTER (.015 % OF READING)

COMMENTS: Tested with Paroscientific Standard. The following results are based on 73 degree data.. Prior to testing the unit was powered up for 30 minutes. Cycled unit from zero to span several times before testing.

* Unit left within manufacturers specifications.

AMETEK PK STANDARD (IN. H2O) CORRECTED FOR SITE GRAVITY + A.G.A. TEMP.			AS RECEIVED INST. READING	AS RECEIVED % READ ERROR	AS RECEIVED % F.S. ERROR	AFTER CALIBRATION INST. READING	AFTER CALIBRATION % READ ERROR	AFTER CALIBRATION % F.S. ERROR
0.00	=	0.00	0.000	0.000	0.000	0.000	0.000	0.000
30.00	=	30.00	30.140	0.467	0.009	29.990	0.033	0.001
60.00	=	60.00	60.210	0.350	0.014	59.990	0.017	0.001
90.00	=	90.00	90.190	0.211	0.013	89.990	0.011	0.001
120.00	=	120.00	120.030	0.025	0.002	120.020	0.017	0.001
140.00	=	140.00	139.820	0.129	0.012	140.000	0.000	0.000
120.00	=	120.00	120.050	0.042	0.003	120.020	0.017	0.001
90.00	=	90.00	90.240	0.267	0.016	90.010	0.011	0.001
60.00	=	60.00	60.260	0.433	0.017	60.010	0.017	0.001
30.00	=	30.00	30.190	0.633	0.013	30.000	0.000	0.000
0.00	=	0.00	0.000	0.000	0.000	0.000	0.000	0.000

Calibration Date : 3/19/99

Calibration Due Date : 9/16/99

BY: Rene Elizalde

signature:

230UPDN.WK3

6-97

PCM 1997

eport # 98072101 DATE: 3/19/99

Certificate of Accuracy

DIVISION / OWNER: Gary Hutcherson
INSTRUMENT TYPE: Beta 320 , 0-100
INSTRUMENT MFG.: Hathaway
GRAVITY: N/A
SERIAL #: 11514
TEST STANDARD: Ametek HL-200-SS D.W. (.05 % OF READING)

OMMENTS: Tested with Paroscientific Standard. The following results are based on 73 degree data.. Prior to testing the unit was powered up for 30 minutes. Cycled unit from zero to span several times before testing.

Unit left within manufacturers specifications.

Ametek STANDARD (PSIG) CORRECTED FOR SITE GRAVITY * 979.308(lab)/980.665(standard)			AS RECEIVED			AFTER CALIBRATION		
			INST. READING	% READ ERROR	% F.S. ERROR	INST. READING	% READ ERROR	% F.S. ERROR
0.00	=	0.00	0.000	0.000	0.000	0.000	0.000	0.000
25.00	=	24.965	24.96	0.022	0.000	24.95	0.062	0.001
50.00	=	49.931	49.94	0.018	0.001	49.93	0.002	0.000
75.00	=	74.896	74.94	0.058	0.003	74.89	0.008	0.000
100.00	=	99.862	99.90	0.038	0.003	99.85	0.012	0.001
75.00	=	74.896	74.95	0.072	0.004	74.88	0.022	0.001
50.00	=	49.931	49.94	0.018	0.001	49.93	0.002	0.000
25.00	=	24.965	24.97	0.018	0.000	24.95	0.062	0.001
0.00	=	0.00	0.000	0.000	0.000	0.000	0.000	0.000

Calibration Date : 3/19/99
Calibration Due Date : 9/16/99 BY: Tim Hannan

signature:

230UPDN.WK3
6-97

PCM 1997

AMETEK
MANSFIELD & GREEN DIVISION
8600 SOMERSET DRIVE, LARGO, FLORIDA 34643 TELEPHONE: (813) 536-7831

CERTIFICATION OF ACCURACY FROM M & G STANDARDS LABORATORY

M & G Model PK2-254WC-SS   Purchase Order No. P77840   Serial No. 84809

Certification Date: 12/13/95   Recommended Recertification Date: 12/13/96

ACCURACY: THE INSTRUMENT IS CERTIFIED TO BE ACCURATE WITHIN A MAXIMUM ERROR OF .025% OF INDICATED READING.

CERTIFICATION PROCEDURE

This Certification was made by direct comparison with Ametek/Mansfield & Green Division Laboratory master standards, which are periodically referred to one or more of the primary standards traceable to NIST or other national physical measures recognized as equivalent by NIST. This calibration procedure meets the requirements of MIL-STD-45662A, ANSI/ASME N45.2, and 10CFR50 Appendix B. The above standards are traceable to the National Institute of Standards and Technology on Report Numbers:

PISTON & CYLINDER/BALL & NOZZLE AREA REFERENCED TO 23 DEG. C

MODEL	SQ. IN.	NIST AREA REPORT NUMBERS (CAL DATE)
RK.		P-8436 (12/21/92)
RK.		P-8476 (5/17/94)
PK.		P-8436 (12/21/92)
HK.		P-8365 (10/22/90)
10,T,R,WG,HL. .	.01 -	P-8469 (01/10/94)
	.02 -	P-8469 (01/10/94)
	.05 -	P-8390 (10/04/91), P-8469 (01/10/94)
	.10 -	P-8390 (10/04/91)

MASS @ 35% RELATIVE HUMIDITY

NIST MASS REPORT NUMBERS:
822/MET56, (09/17/92); 822/MET55, (4/23/93)
822/MET57, (10/01/93); 822/253849, (07/21/94)
731/243669, (03/03/93)

PRESSURE READINGS ARE REFERENCED TO A GRAVITY OF 980.6650 GALS.

CERTIFIED CORRECT

THE SERVICE WAS PROCESSED IN ACCORDANCE WITH QA MANUAL REV. 25 DATED 12/1/94.

Registered Firm ... Certificate ...   REGISTRAR ACCREDITATION BOARD   DUTCH COUNCIL FOR CERTIFICATION

AMETEK
MANSFIELD & GREEN DIVISION

by H. Ray Heitner
QUALITY ASSURANCE MANAGER

FORM 71 - 7 REV. 10 OCT 1994

RONAN

CERTIFICATE OF CALIBRATION

CUSTOMER NAME:
COLORADO STATE UNIVERSITY
CENTRAL RECEIVING
FORT COLLINS, CO 80523-6011

MODEL NO.: X88
DESCRIPTION: CALIBRATOR

SERIAL NO.: 00447

DATE CALIB.: 02/10/99

REPORT NO.: 92-3998TR

PURCHASE ORDER NO.: DPO767588

PROCEDURE: QCTX88FINAL

TEMPERATURE: 78 DEGREES F.

ITEM CONDITION
AS RECEIVED: IN TOLERANCE
AS LEFT: IN TOLERANCE

CALIB. DUE : 02/10/2000

Ronan Engineering Company does hereby certify the above listed instrument meets or exceeds all published specifications and has been calibrated using standards whose accuracies are traceable to the National Institute of Standards and Technology. Our "Calibration System Requirements" satisfy MIL-STD-45662A.

STANDARDS EMPLOYED

I/D NO.	MANUFACTURER	MOD. NO.	DUE DATE	NIST
CC24311	DATA PRECISION	8200	10/23/99	6599
CC88401	FLUKE	8840A	11/03/99	15803
CC86TE35	RONAN	X86	09/28/99	254980
NB-101A	JULIE RESEARCH	10 OHM	06/11/99	PRO-106LT
NB-102A	JULIE RESEARCH	100 OHM	06/11/99	PRO-106LT
NB-103	JULIE RESEARCH	1K OHM	06/11/99	PRO-106LT

Anthony Fesca
QUALITY ASSURANCE

2/11/99
DATE

RONAN ENGINEERING COMPANY
P.O. Box 1275 • Woodland Hills, California 91365
21200 Oxnard Street • Woodland Hills, California 91367 • (818) 883-5211
FAX (818) 992-6435

MODEL X88 CALIBRATOR
TEST DATA SHEET

RMA# 92-3998

SERIAL NUMBER 00447
BY 40
DATE 2-10-99

	INPUT			OUTPUT		
	CALIBRATOR INPUT	DISPLAY	CALIBRATOR LIMIT	DISPLAY	MEASURED	CALIBRATION LIMIT
150 mV	00.00 mV	00.00	±.01	00.00 mV	00.002	** ±.01
	100.00 mV	100.00	±.02	100.00 mV	100.001	±.02
	149.90 mV	149.91	±.03	50.00 mV	50.003	
1.5 V	.0000V	.0000	±.0001			
	1.0000 V	1.0000	±.0002			
	1.4990 V	1.4991	±.0003			
15V INPUT 10V OUTPUT	0.000 V	0.000	±.001	0.000 V	0.0001	* ±.001
	10.000 V	10.000	±.002	9.999 V	9.9990	±.001
	14.990 V	14.991	±.003	10.000 V	10.0000	±.001
150 V	10.00 V	10.00	±.01			
	100.00 V	100.00	±.02			
	149.90 V	149.91	±.03			
100 mA	20 mA	20.00	±.01	1.00 mA	1.004	** ±.01
	100 mA	100.00	±.02	20.00 mA	20.002	±.01
	4 mA	04.00				
	10 mA	10.00		60.00 mA	60.001	±.02
150 ohms	00.00 ohms	00.00	±.01	☑ COARSE ADJ.	OK	
	10.00 ohms	10.00	±.01	☑ FINE ADJ.	OK	
	100.00 ohms	100.00	±.02	Battery voltage = 7.04V		
1.5 kohms	100.0 ohms	100.0	±.1	☑ AUTO SEQUENCE	OK	
	1000.0 ohms	1000.0	±.2	☑ 2-WIRE TRANSMITTER SUPPLY	OK	

* Record data to .XXXX (4 places).
** Record data to .XXX (3 places).

As Left Factory:
Unit meets the specifications.

cc: 24311
cc: 88401
cc: 66502
cc: 03792
cc: X86TE35

cc: X86TE36
NB101A S/N 200
NB102A S/N 1153
NB103 S/N 1260
cc: 03556

VAISALA

ISO 9002 CERTIFIED

Calibration Laboratory
REPORT OF RELATIVE HUMIDITY CALIBRATION

Report #: 99-1-0122-L11 S.O. #: N/A Calibration Date: 1/22/99
Instrument Model: HMP233 Serial Number: T4310021
Instrument Range: 0 to 100% RH Calibration Procedure: 3-19-20c.doc
Accuracy: Relative Humidity; ±1% RH (0 to 90% RH), ±2% RH (90 to 100% RH)
Temperature; ± 0.2° C @ 20° C Due Date: 1 year from above date
Customer: COLORADO STATE UNIVERSITY
City, State: FT. COLLINS, CO

Calibration Information

This unit was calibrated by comparing its readings at 0.0 and 75.5% RH to a reference humidity instrument: Vaisala model HMP 233, S/N: R1630017. Additional instrument verification checkpoints were made at 11.3% and 97.6% RH, respectively. Calibration and instrument verification sequences utilize dry nitrogen and a set of Controlled Aqueous Salt Solutions, Vaisala S/N: P3940000. Interval: 6 months. Laboratory ambient conditions are maintained at a temperature of 22 ±1°C with a relative humidity level of 50% ±5% RH. Sensor stabilization time is > 30 minutes prior to adjustment. Calibration uncertainty is ±0.6% RH @ 22°C. The temperature is checked at ambient temperature against NIST standard traceable through a F250 (SN# 1297-030-597), PRT ASL T25/02 (SN# S257).

Calibration Data

Temperature	Unit as Calibrated	Tolerance
Standard	22.8	
Unit Under Test	22.9	±0.2° C

Humidity Solution	Nominal Value	(UUT)	(REF)	Acceptance Limits (Low)	Acceptance Limits (High)	Tolerance
Dry Nitrogen	0.1% RH	0.1%	0.1%	-0.9%	1.1%	±1.0%RH
NaCl	75.5% RH	74.9%	74.9%	73.9%	75.9%	±1.0%RH
LiCl	11.3% RH	10.8%		10.3%	12.3%	±1.0%RH
K_2SO_4	97.6% RH	96.6%		95.6%	99.6%	±2.0%RH

Service Technician

Service Department Supervisor

This calibration report is traceable to the National Institute of Standards and Technology through NIST Test Report Number TN 261093 dated 10 December, 1998. Due date: 12/10/1999. Vaisala's calibration system complies with the requirements ANSI/NCSL Z540-1-1994. This certificate can not be reproduced except in full, without the expressed written consent of Vaisala.

Mailing address:
Vaisala Inc.
100 Commerce Way
Woburn, MA 01801-1068
Tel. (781) 933-4500
Fax (781) 933-8029
http://www.vaisala.com

APPENDIX L

DYNAMOMETER CALIBRATION

Dynamometer Calibration

Colorado State University
Engines & Energy Conversion Laboratory

Test Sponsor: EPA

Date: 8-2-99

Actual Torque	Calculated Torque	% Actual Torque
0		
833	838 830	100.1
1524	1540 1522	100.46
2217	2241 2215	100.5
2909	2943 2908	100.5
3600	3644 3600	100.61
4292	4347 4292	100.64
4984	5048 4983	100.63

% Actual Torque = Calculated Torque/Actual Torque

Dynamometer Calibration

Colorado State University
Engines & Energy Conversion Laboratory

Test Sponsor: EPA

Date: 8-3-99

Actual Torque	Calculated Torque	% Actual Torque
0		
833	829 830	99.58%
1524	1521 1523	99.87%
2217	2214 2215	99.89%
2909	2906 2908	99.93%
3600	3599 3601	100.00%
4292	4292 4293	100.01%
4984	4984	100% Goodness!!!

% Actual Torque = Calculated Torque/Actual Torque

Dynamometer Calibration

Colorado State University
Engines & Energy Conversion Laboratory

Test Sponsor: EPA

Date: 8-5-99

Actual Torque	Calculated Torque	% Actual Torque
0		
833	830 831	100.3
1524	1522 1524	100.06
2217	2215 2217	100.04
2909	2908 2909	100.03
3600	3600 3602	100.02
4292	4293 4294	100.03
4984	4985 4985	100.02

% Actual Torque = Calculated Torque/Actual Torque

APPENDIX M

DYNAMOMETER CALIBRATION PROCEDURE

Midwest Eddie Current Dynamometer

Calibration

Check zero with no weights or calibration arm. If it is a couple units or more off, set toggles to zero, press, and hold Auto Zero button on DynLoc controller for one second.

Record reading.

Put on calibration arm and first weight. Let it settle and record reading.

Repeat for next five weights.

Put on last weight (there will be one weight not used) and let it settle. If it is a couple units or more off, set toggle switches to 4984, press, and hold Auto Span button on DynLoc controller for one second.

Record reading.

Remove weight; let it settle, and record reading.

Repeat for next six weights.

Remove calibration arm.

Average loading and unloading calculated torque. Calculate % actual torque as per calibration sheet.

All should be within one % of actual torque. If not, recalibrate.

APPENDIX N

GAS ANALYSIS

Gas Analysis

alculation Results from CO St U Stream 1 Tue Aug 03 06:05:12 1999

	MolPct	BTUGross	RelDens
-HEXANE	0.0125	0.66	0.0004
PANE	1.9428	49.00	0.0296
i-BUTANE	0.1273	4.15	0.0026
-BUTANE	0.1870	6.11	0.0038
EOPENTANE	0.0000	0.00	0.0000
i-PENTANE	0.0241	0.97	0.0006
-PENTANE	0.0172	0.69	0.0004
ITROGEN	0.4001	0.00	0.0039
METHANE	78.3579	793.22	0.4340
ARBON DIOXIDE	2.9035	0.00	0.0441
THANE	16.0275	284.28	0.1664
TOTAL	100.0000	1139.08	0.6857

ompressibility Factor	=	1.0030
eating Value Gross BTU Dry	=	1142.51
Heating Value Gross BTU Sat.	=	1122.63
eating Value Gross BTU Act.	=	1142.51
eating Value Net BTU Act.	=	1034.07
Relative Density Gas Corr.	=	0.6875
otal Unnormalized Conc.	=	106.823
s Density lbm/1000 ft3	=	52.595

Analysis

Calculation Results from CO St U Stream 1 Wed Aug 04 12:18:09 1999

	MolPct	BTUGross	RelDens
n-HEXANE	0.0265	1.40	0.0009
PROPANE	1.7286	43.59	0.0263
i-BUTANE	0.0875	2.85	0.0018
n-BUTANE	0.1380	4.51	0.0028
NEOPENTANE	0.0000	0.00	0.0000
i-PENTANE	0.0211	0.85	0.0005
n-PENTANE	0.0234	0.94	0.0006
NITROGEN	0.4370	0.00	0.0042
METHANE	78.9644	799.36	0.4374
CARBON DIOXIDE	2.8890	0.00	0.0439
ETHANE	15.6846	278.20	0.1628
TOTAL	100.0000	1131.70	0.6812

Compressibility Factor	=	1.0030
Heating Value Gross BTU Dry	=	1135.06
Heating Value Gross BTU Sat.	=	1115.31
Heating Value Gross BTU Act.	=	1135.06
Heating Value Net BTU Act.	=	1027.12
Relative Density Gas Corr.	=	0.6829
Total Unnormalized Conc.	=	106.464
Gas Density lbm/1000 ft3	=	52.242

alculation Results from CO St U Stream 1 Wed Aug 04 05:32:44 1999

Analysis

	MolPct	BTUGross	RelDens
HEXANE	0.0118	0.62	0.0004
)PANE	1.7758	44.78	0.0270
BUTANE	0.0811	2.64	0.0016
BUTANE	0.1361	4.45	0.0027
EOPENTANE	0.0000	0.00	0.0000
-PENTANE	0.0145	0.58	0.0004
PENTANE	0.0134	0.54	0.0003
TROGEN	0.4425	0.00	0.0043
ETHANE	77.4268	783.79	0.4289
RBON DIOXIDE	2.9507	0.00	0.0448
HANE	17.1474	304.14	0.1780
OTAL	100.0000	1141.55	0.6885

mpressibility Factor	=	1.0030
eating Value Gross BTU Dry	=	1145.03
Heating Value Gross BTU Sat.	=	1125.11
ating Value Gross BTU Act.	=	1145.03
ating Value Net BTU Act.	=	1036.45
Relative Density Gas Corr.	=	0.6903
tal Unnormalized Conc.	=	107.839
s Density lbm/1000 ft3	=	52.807

Calculation Results from CO St U Stream 1 Thu Aug 05 05:36:07 1999

Analysis

	MolPct	BTUGross	RelDens
n-HEXANE	19.0 PPM	0.10	0.0001
PROPANE	1.8505	46.67	0.0282
i-BUTANE	0.0788	2.57	0.0016
n-BUTANE	0.1200	3.92	0.0024
NEOPENTANE	0.0000	0.00	0.0000
i-PENTANE	84.3 PPM	0.34	0.0002
n-PENTANE	58.3 PPM	0.23	0.0001
NITROGEN	0.4137	0.00	0.0040
METHANE	76.9053	778.51	0.4260
CARBON DIOXIDE	2.7897	0.00	0.0424
ETHANE	17.8258	316.18	0.1851
TOTAL	100.0000	1148.52	0.6900

Compressibility Factor	=	1.0031
Heating Value Gross BTU Dry	=	1152.06
Heating Value Gross BTU Sat.	=	1132.01
Heating Value Gross BTU Act.	=	1152.06
Heating Value Net BTU Act.	=	1042.95
Relative Density Gas Corr.	=	0.6919
Total Unnormalized Conc.	=	109.891
Gas Density lbm/1000 ft3	=	52.926

lculation Results from CO St U Stream 1 Fri Aug 06 05:22:13 1999

Gas Analy.

	MolPct	BTUGross	RelDens
HEXANE	57.3 PPM	0.30	0.0002
OPANE	1.4401	36.32	0.0219
BUTANE	0.1019	3.32	0.0020
BUTANE	0.1371	4.48	0.0028
OPENTANE	0.0000	0.00	0.0000
i-PENTANE	0.0182	0.73	0.0005
PENTANE	0.0117	0.47	0.0003
TROGEN	0.5355	0.00	0.0052
METHANE	83.5854	846.13	0.4630
RBON DIOXIDE	2.8971	0.00	0.0440
HANE	11.2673	199.85	0.1170
TOTAL	100.0000	1091.61	0.6568

mpressibility Factor	=	1.0027
ating Value Gross BTU Dry	=	1094.56
Heating Value Gross BTU Sat.	=	1075.51
ating Value Gross BTU Act.	=	1094.56
ating Value Net BTU Act.	=	989.36
Relative Density Gas Corr.	=	0.6583
tal Unnormalized Conc.	=	103.889
s Density lbm/1000 ft3	=	50.360

APPENDIX O

GAS ANALYSIS CALIBRATIONS

Calculation Results from CO St U Stream 1 Tue Aug 03 05:39:19 1999

	MolPct	BTUGross	RelDens
n-HEXANE	0.1941	10.26	0.0064
PROPANE	1.0006	25.23	0.0152
i-BUTANE	0.2002	6.52	0.0040
n-BUTANE	0.1990	6.51	0.0040
NEOPENTANE	0.0000	0.00	0.0000
i-PENTANE	0.1973	7.91	0.0049
n-PENTANE	0.1964	7.89	0.0049
NITROGEN	2.0095	0.00	0.0194
METHANE	90.0624	911.70	0.4989
CARBON DIOXIDE	1.9861	0.00	0.0302
ETHANE	3.9545	70.14	0.0411
TOTAL	100.0000	1046.17	0.6290

Compressibility Factor	=	1.0024
Heating Value Gross BTU Dry	=	1048.63
Heating Value Gross BTU Sat.	=	1030.39
Heating Value Gross BTU Act.	=	1048.63
Heating Value Net BTU Act.	=	946.66
Relative Density Gas Corr.	=	0.6302
Total Unnormalized Conc.	=	100.239
Gas Density lbm/1000 ft3	=	48.211

Calculation Results from CO St U Stream 1 Wed Aug 04 05:49:59 1999

Cal check

	MolPct	BTUGross	RelDens
n-HEXANE	0.1987	10.51	0.0066
PROPANE	0.9994	25.20	0.0152
i-BUTANE	0.2005	6.54	0.0040
n-BUTANE	0.1994	6.52	0.0040
NEOPENTANE	0.0000	0.00	0.0000
i-PENTANE	0.1984	7.96	0.0049
n-PENTANE	0.1979	7.95	0.0049
NITROGEN	1.9831	0.00	0.0192
METHANE	89.9826	910.89	0.4984
CARBON DIOXIDE	2.0025	0.00	0.0304
ETHANE	4.0374	71.61	0.0419
TOTAL	100.0000	1047.19	0.6296

Compressibility Factor	=	1.0024
Heating Value Gross BTU Dry	=	1049.65
Heating Value Gross BTU Sat.	=	1031.39
Heating Value Gross BTU Act.	=	1049.65
Heating Value Net BTU Act.	=	947.61
Relative Density Gas Corr.	=	0.6309
Total Unnormalized Conc.	=	100.007
Gas Density lbm/1000 ft3	=	48.260

lculation Results from CO St U Stream 1 Thu Aug 05 06:10:37 1999

cal check

	MolPct	BTUGross	RelDens
HEXANE	0.1999	10.57	0.0066
PANE	1.0009	25.24	0.0152
i-BUTANE	0.2013	6.56	0.0040
BUTANE	0.2002	6.55	0.0040
OPENTANE	0.0000	0.00	0.0000
i-PENTANE	0.1998	8.01	0.0050
PENTANE	0.1986	7.98	0.0049
TROGEN	1.9843	0.00	0.0192
ETHANE	90.1251	912.34	0.4992
CARBON DIOXIDE	1.9771	0.00	0.0300
HANE	3.9129	69.40	0.0406
TAL	100.0000	1046.65	0.6289

mpressibility Factor	=	1.0024
ating Value Gross BTU Dry	=	1049.11
Heating Value Gross BTU Sat.	=	1030.86
Heating Value Gross BTU Act.	=	1049.11
ating Value Net BTU Act.	=	947.10
lative Density Gas Corr.	=	0.6301
Total Unnormalized Conc.	=	101.049
s Density lbm/1000 ft3	=	48.203

Calculation Results from CO St U Stream 1 Fri Aug 06 05:56:44 1999

Cal Check

	MolPct	BTUGross	RelDens
n-HEXANE	0.2007	10.61	0.0066
PROPANE	1.0032	25.30	0.0153
i-BUTANE	0.2016	6.57	0.0040
n-BUTANE	0.2005	6.56	0.0040
NEOPENTANE	0.0000	0.00	0.0000
i-PENTANE	0.1993	7.99	0.0050
n-PENTANE	0.1972	7.92	0.0049
NITROGEN	1.9956	0.00	0.0193
METHANE	90.4182	915.30	0.5008
CARBON DIOXIDE	1.9252	0.00	0.0293
ETHANE	3.6586	64.89	0.0380
TOTAL	100.0000	1045.15	0.6272

Compressibility Factor	=	1.0023
Heating Value Gross BTU Dry	=	1047.60
Heating Value Gross BTU Sat.	=	1029.37
Heating Value Gross BTU Act.	=	1047.60
Heating Value Net BTU Act.	=	945.66
Relative Density Gas Corr.	=	0.6284
Total Unnormalized Conc.	=	100.026
Gas Density lbm/1000 ft3	=	48.075

APPENDIX P

GAS ANALYSIS CALCULATIONS

GAS ANALYSIS CALCULATIONS

Gas Analysis Date	3-Aug-99	4-Aug-99	5-Aug-99	6-Aug-99
Constituent	Mol. Fraction	Mol. Fraction	Mol. Fraction	Mol. Fraction
NITROGEN	0.4001	0.4370	0.4137	0.5355
CARBON DIOX.	2.9035	2.8890	2.7897	2.8971
METHANE	78.3579	78.9644	76.9053	83.5355
ETHANE	16.0275	15.6846	17.8258	11.2673
PROPANE	1.9428	1.7286	1.8505	1.4401
I-BUTANE	0.1273	0.0875	0.0788	0.1019
N-BUTANE	0.1870	0.1380	0.1200	0.1371
I-PENTANE	0.0241	0.0211	0.0084	0.0182
N-PENTANE	0.0172	0.0234	0.0058	0.0117
HEXANE +	0.0125	0.0265	0.0019	0.0057

Heating Values				
Lower Dry	1030.7	1023.9	1039.6	1039.6
Upper Dry	1142.5	1135.1	1152.1	1094.6

Properties				
Specific Gravity	0.6850	0.6810	0.6890	0.6890
Density	0.0524	0.0521	0.0527	0.0527

Constituent	Mass Fraction	Mass Fraction	Mass Fraction	Mass Fraction
NITROGEN	0.1121	0.1224	0.1159	0.1500
CARBON DIOX.	1.2778	1.2714	1.2277	1.2750
METHANE	12.5711	12.6684	12.3380	13.4017
ETHANE	4.8195	4.7164	5.3603	3.3881
PROPANE	0.8567	0.7623	0.8160	0.6350
I-BUTANE	0.0740	0.0509	0.0458	0.0592
N-BUTANE	0.1087	0.0802	0.0697	0.0797
I-PENTANE	0.0174	0.0152	0.0061	0.0131
N-PENTANE	0.0124	0.0169	0.0042	0.0084
HEXANE +	0.0120	0.0254	0.0018	0.0055

Fuel MW Total	19.8617	19.7295	19.9856	19.0159
Fuel MW HC	18.4718	18.3357	18.6420	17.5909

Constituent	Density	Density	Density	Density
NITROGEN	0.0296	0.0323	0.0306	0.0396
CARBON DIOX.	0.3375	0.3358	0.3243	0.3368
METHANE	3.3200	3.3457	3.2585	3.5394
ETHANE	1.2729	1.2457	1.4157	0.8948
PROPANE	0.2263	0.2013	0.2155	0.1677
I-BUTANE	0.0195	0.0134	0.0121	0.0156
N-BUTANE	0.0287	0.0212	0.0184	0.0210
I-PENTANE	0.0046	0.0040	0.0016	0.0035
N-PENTANE	0.0033	0.0045	0.0011	0.0022
HEXANE +	0.0040	0.0085	0.0006	0.0018

Calculated Density	0.0525	0.0521	0.0528	0.0502

Carbon In Fuel	120.6835	119.6919	121.7760	114.4274
Pct. Carbon In Fuel	0.0608	0.0607	0.0609	0.0602
Comb. Carbon In HC	117.7800	116.8029	118.9863	111.5303
Comb. Hydrogen In HC	428.9526	426.9540	431.5657	416.0956

H/C Ratio-Total Fuel	3.5544	3.5671	3.5439	3.6363
H/C Ratio-HC Only	3.6420	3.6553	3.6270	3.7308
H/C Ratio-Non CH4	2.9304	2.9361	2.9454	2.9275

GAS ANALYSIS CALCULATIONS

Fuel Calculations				
Total HC In Fuel(Hh)	96.6963	96.6741	96.7966	96.5175
HC1/Hh	0.8104	0.8168	0.7945	0.8655
HC2/Hh	0.1658	0.1622	0.1842	0.1167
HC3/Hh	0.0201	0.0179	0.0191	0.0149
HC4/Hh	0.0033	0.0023	0.0021	0.0025
HC5/Hh	0.0004	0.0005	0.0001	0.0003
HC6/Hh	0.0001	0.0003	0.0000	0.0001

MW of HC In Fuel	19.1029	18.9665	19.2589	18.2256

Non CH4 Fuel Calc.				
Total HC - Non CH4	18.3384	17.7097	19.8913	12.9820
NmC2/Nmh	0.8740	0.8857	0.8962	0.8679
NmC3/Nmh	0.1059	0.0976	0.0930	0.1109
NmC4/Nmh	0.0171	0.0127	0.0100	0.0184
NmC5/Nmh	0.0023	0.0025	0.0007	0.0023
NmC6/Nmh	0.0007	0.0015	0.0001	0.0004

MW of Non CH4 HC	32.1769	32.0010	31.6921	32.2688

Constituent	Mol. Fraction	Mol. Fraction	Mol. Fraction	Mol. Fraction
NITROGEN	0.4001	0.4370	0.4137	0.5355
CARBON DIOX.	2.9035	2.8890	2.7897	2.8971
METHANE	78.3579	78.9644	76.9053	83.5355
ETHANE	16.0275	15.6846	17.8258	11.2673
PROPANE	1.9428	1.7286	1.8505	1.4401
I-BUTANE	0.1273	0.0875	0.0788	0.1019
N-BUTANE	0.1870	0.1380	0.1200	0.1371
I-PENTANE	0.0241	0.0211	0.0084	0.0182
N-PENTANE	0.0172	0.0234	0.0058	0.0117
HEXANE +	0.0125	0.0265	0.0019	0.0057

F-Factor Calculation				
Constituent	Mol. Fraction	Mol. Fraction	Mol. Fraction	Mol. Fraction
NITROGEN	0.004001	0.004370	0.004137	0.005355
CARBON DIOX.	0.029035	0.028890	0.027897	0.028971
METHANE	0.783579	0.789644	0.769053	0.835355
ETHANE	0.160275	0.156846	0.178258	0.112673
PROPANE	0.019428	0.017286	0.018505	0.014401
I-BUTANE	0.001273	0.000875	0.000788	0.001019
N-BUTANE	0.001870	0.001380	0.001200	0.001371
I-PENTANE	0.000241	0.000211	0.000084	0.000182
N-PENTANE	0.000172	0.000234	0.000058	0.000117
HEXANE +	0.000125	0.000265	0.000019	0.000057

GAS ANALYSIS CALCULATIONS

Fuel MW Total	19.8617	19.7295	19.9856	19.0159

Upper Dry Heating Value	1030.70	1023.90	1152.06	1094.56
Fuel Density	0.05239	0.05209	0.05270	0.05270

EPA F-Factor (dscf/MMBtu)	9599.9	9607.2	8656.6	9087.7

Carbon Content				
Constituent				
NITROGEN	0.000000	0.000000	0.000000	0.000000
CARBON DIOX.	0.029035	0.028890	0.027897	0.028971
METHANE	0.783579	0.789644	0.769053	0.835355
ETHANE	0.320550	0.313692	0.356516	0.225346
PROPANE	0.058284	0.051858	0.055515	0.043203
I-BUTANE	0.005092	0.003500	0.003152	0.004076
N-BUTANE	0.007480	0.005520	0.004800	0.005484
I-PENTANE	0.001205	0.001055	0.000422	0.000910
N-PENTANE	0.000860	0.001170	0.000292	0.000585
HEXANE +	0.000837	0.001775	0.000127	0.000384
Carbon Wt. %:	**0.729894**	**0.728807**	**0.731890**	**0.722812**

Hydrogen Content				
Constituent				
NITROGEN	0.000000	0.000000	0.000000	0.000000
CARBON DIOX.	0.000000	0.000000	0.000000	0.000000
METHANE	3.134316	3.158576	3.076212	3.341420
ETHANE	0.961650	0.941076	1.069548	0.676038
PROPANE	0.155424	0.138288	0.148040	0.115208
I-BUTANE	0.012730	0.008750	0.007880	0.010190
N-BUTANE	0.018700	0.013800	0.012000	0.013710
I-PENTANE	0.002892	0.002532	0.001012	0.002184
N-PENTANE	0.002064	0.002808	0.000700	0.001404
HEXANE +	0.001924	0.004079	0.000292	0.000882
Hydrogen Wt. %:	**0.217706**	**0.218154**	**0.217667**	**0.220569**

Oxygen Content				
Constituent				
NITROGEN	0.000000	0.000000	0.000000	0.000000
CARBON DIOX.	0.058070	0.057780	0.055794	0.057942
METHANE	0.000000	0.000000	0.000000	0.000000
ETHANE	0.000000	0.000000	0.000000	0.000000
PROPANE	0.000000	0.000000	0.000000	0.000000
I-BUTANE	0.000000	0.000000	0.000000	0.000000
N-BUTANE	0.000000	0.000000	0.000000	0.000000
I-PENTANE	0.000000	0.000000	0.000000	0.000000
N-PENTANE	0.000000	0.000000	0.000000	0.000000
HEXANE +	0.000000	0.000000	0.000000	0.000000
Oxygen Wt. %:	**0.046778**	**0.046856**	**0.044666**	**0.048751**

Nitrogen Content				
Constituent				
NITROGEN	0.008002	0.008740	0.008274	0.010710
CARBON DIOX.	0.000000	0.000000	0.000000	0.000000
METHANE	0.000000	0.000000	0.000000	0.000000
ETHANE	0.000000	0.000000	0.000000	0.000000
PROPANE	0.000000	0.000000	0.000000	0.000000
I-BUTANE	0.000000	0.000000	0.000000	0.000000
N-BUTANE	0.000000	0.000000	0.000000	0.000000
I-PENTANE	0.000000	0.000000	0.000000	0.000000
N-PENTANE	0.000000	0.000000	0.000000	0.000000
HEXANE +	0.000000	0.000000	0.000000	0.000000
Nitrogen Wt. %:	**0.005643**	**0.006205**	**0.005799**	**0.007889**

Stoichiometric Air/Fuel Ratio Calculation

Combustion Stoichiometry
Analysis Date: 8/3/99

Fuel								
Constit.	%	Mole Fraction	MW	MW* Mole Frac.	C content	H content	O content	N content
CH4	78.3579	0.783579	16.0426	12.57064	0.783579	3.134316	0	0
C2H6	16.0275	0.160275	30.0694	4.819373	0.32055	0.96165	0	0
C3H8	1.9428	0.01943	44.0962	0.856701	0.058284	0.155424	0	0
C4H10	0.3143	0.00314	58.123	0.182681	0.012572	0.03143	0	0
C6H14	0.0125	0.00013	86.1766	0.010772	0.00075	0.00175	0	0
C10H22	0.0413	0.00041	142.2838	0.058763	0.00413	0.009086	0	0
N2	0.4001	0.004001	28.0134	0.112082	0	0	0	0.008002
02	0.0001	0.000001	31.9988	3.2E-05	0	0	0.000002	0
CO2	2.9035	0.029035	44.0098	1.277825	0.029035	0	0.05807	0
Sums-->	100	1	480.8136	19.88887	1.2089	4.293656	0.058072	0.008002

MWave =	19.88887

Air					
Constit.	%	Mole Fraction	MW	MW* Mole Frac.	02 normal
N2	77.16266	0.771627	28.0134	21.61588	3.773725
02	20.44734	0.204473	31.9988	6.542904	1
H2O	2.39	0.0239	18.0152	0.430563	0.116886
Sums		1			

MWave =	28.58935

MW of Elements	
C	12.011
H	1.0079
N	14.0067
O	15.9994

Urban and Sharp, 1994	
y =	3.551705
z =	0.048037
f =	0.006619
A =	1.863908
A/Fs =	15.6655

A/Fstoic =	15.6655

Stoichiometric Air/Fuel Ratio Calculation

Combustion Stoichiometry
Analysis Date: 8/4/99

Fuel								
Constit.	%	Mole Fraction	MW	MW* Mole Frac.	C content	H content	O content	N content
CH4	78.9644	0.789644	16.0426	12.66794	0.789644	3.158576	0	0
C2H6	15.6846	0.156846	30.0694	4.716265	0.313692	0.941076	0	0
C3H8	1.7286	0.01729	44.0962	0.762247	0.051858	0.138288	0	0
C4H10	0.2255	0.00226	58.123	0.131067	0.00902	0.02255	0	0
C6H14	0.0265	0.00027	86.1766	0.022837	0.00159	0.00371	0	0
C10H22	0.0445	0.00045	142.2838	0.063316	0.00445	0.00979	0	0
N2	0.437	0.00437	28.0134	0.122419	0	0	0	0.00874
O2	0.0001	0.000001	31.9988	3.2E-05	0	0	0.000002	0
CO2	2.889	0.02889	44.0098	1.271443	0.02889	0	0.05778	0
Sums-->	100.0002	1.000002	480.8136	19.75757	1.199144	4.27399	0.057782	0.00874

MWave =	19.75757

Air					
Constit.	%	Mole Fraction	MW	MW* Mole Frac.	02 normal
N2	77.16266	0.771627	28.0134	21.61588	3.773725
O2	20.44734	0.204473	31.9988	6.542904	1
H2O	2.39	0.0239	18.0152	0.430563	0.116886
Sums		1			

MWave =	28.58935

MW of Elements	
C	12.011
H	1.0079
N	14.0067
O	15.9994

Urban and Sharp, 1994	
y =	3.564201
z =	0.048186
f =	0.007289
A =	1.866957
A/Fs =	15.66795

A/Fstoic =	15.66795

Stoichiometric Air/Fuel Ratio Calculation

Combustion Stoichiometry
Analysis Date: 8/5/99

Fuel								
Constit.	%	Mole Fraction	MW	MW* Mole Frac.	C content	H content	O content	N content
CH4	76.9053	0.769053	16.0426	12.33761	0.769053	3.076212	0	0
C2H6	17.8258	0.178258	30.0694	5.360111	0.356516	1.069548	0	0
C3H8	1.8505	0.01851	44.0962	0.816	0.055515	0.14804	0	0
C4H10	0.1988	0.00199	58.123	0.115549	0.007952	0.01988	0	0
C6H14	0.0019	0.00002	86.1766	0.001637	0.000114	0.000266	0	0
C10H22	0.0142	0.00014	142.2838	0.020204	0.00142	0.003124	0	0
N2	0.4137	0.00437	28.0134	0.115891	0	0	0	0.008274
O2	0.0001	0.000001	31.9988	3.2E-05	0	0	0.000002	0
CO2	2.7897	0.027897	44.0098	1.227741	0.027897	0	0.055794	0
Sums-->	100	1	480.8136	19.99478	1.218467	4.31707	0.055796	0.008274

MWave =	19.99478

Air					
Constit.	%	Mole Fraction	MW	MW* Mole Frac.	O2 normal
N2	77.16266	0.771627	28.0134	21.61588	3.773725
O2	20.44734	0.204473	31.9988	6.542904	1
H2O	2.39	0.0239	18.0152	0.430563	0.116886
Sums		1			

MWave =	28.58935

MW of Elements	
C	12.011
H	1.0079
N	14.0067
O	15.9994

Urban and Sharp, 1994	
y =	3.543034
z =	0.045792
f =	0.00679
A =	1.862863
A/Fs =	15.69705

A/Fstoic =	15.69705

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COMPUTING AIR/FUEL RATIO FROM EXHAUST COMPOSITION

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ABSTRACT

Alternative fuels, catalytic converters, and high scavenging ratios necessitate refined approaches toward calculating air/fuel ratio from measured exhaust composition. Computation methods were developed for most of the situations encountered, including a method based on oxidation potential for use in catalyst applications. The methods developed, along with the technical basis and derivations, are provided in this paper.

INTRODUCTION

This is the third in a series of technical papers involving emissions related computations for alternative fuels. The two previous papers by Urban et al (1992 and 1993) involved hydrogen and natural gas engines. The subject of this paper is the computation of air/fuel ratio, from exhaust composition, for combustion of any carbon-containing fuel. Computations provided in this paper were developed as a result of specific needs within the laboratory of the authors. It is hoped that providing these computations will save others from having to go through the mathematical derivation exercise, when the need arises in their activities.

Over the past almost 100 years, there have been several periods of development of air/fuel ratio calculations. The most recent extensive development was in the 1960's, which is considered exemplified by the "landmark" technical paper by Spindt (1965). With the wide-spread use of alternative fuels and personal computers, further development of AFR calculational methods has again become both essential and practical. Any who are interested in the history of the development of air/fuel ratio calculations are referred to a technical paper of a few years ago by Uyehara(1991), which contains numerous pertinent references.

DERIVATION APPROACH

After a brief review of previous efforts toward developing air/fuel ratio (AFR) calculations for alternate fuels, the decision was made to begin with the basic combustion equation and to include as many of the potential fuel and exhaust constituents as practical in developing standard AFR computations. Another approach involved determination of an "oxidation potential" for use when the AFR is very near stoichiometric. It was also decided that no laboratory effort would be conducted in this endeavor, and that the literature would be relied on to provide a suitable water-gas equilibrium constant.

In this paper, multiplication will be designated by an asterisk (*) and division will be designated by an oblique line (/). Rather than have a list of definitions to which the reader must continually refer, an attempt has been made to minimize the number of terms and identifiers requiring definition, and to provide necessary definitions at the point where needed.

Water-Gas Equilibrium Constant

At the present time, water and hydrogen are not measured in the exhaust. The hydrogen (H_2) concentration is related to the concentrations of carbon monoxide (CO), carbon dioxide (CO_2), and water (H_2O) as follows:

$$CO_2 + H_2 \rightleftharpoons CO + H_2O$$

Extent of reaction is defined by the water-gas equilibrium constant (k) defined as follows:

$$k = CO \cdot H_2O / CO2 \cdot H_2$$

An initial question is whether k is really a constant. The answer appears to be that k is not an actual constant, and an absolute value for k is not known and For practical purposes, however, the value of k is adequately known and sufficiently constant to enable acceptable computation of AFR.

Reported values for k have ranged from a low of 3 to a high of 4, but the predominant accepted value appears to be 3.5.[4] First, let us look at the effect of variation in the value of k on computed AFR. The error in calculated AFR with variation in k is approximately as follows:

% Error in AFR = 0.0025*[(% Variation in k)*(Exh %CO)*HCR]

Where: HCR = Fuel Hydrogen to Carbon Ratio
(Atoms of H per atom of C)

Even taking a worst case of ten percent variation in k, ten percent CO in the exhaust, and a fuel HCR of 4, the error in computed AFR would only be a relatively insignificant one percent. Therefore, the predominantly-used value for k of 3.5 will be used in developing the computations in this paper.

It should be pointed out that the value of k could change when a catalyst is being used, because the activity of the catalyst on CO and H_2 can differ, and the resulting concentrations may not equilibrate. Error in calculated AFR would generally be insignificant, however, because with a catalyst in the exhaust stream, concentrations of CO and H_2 will generally be low.

Combustion Equation

Based on review of numerous equations over the years, the usefulness of meaningful variable names has been well established. In this paper, fuel components will be expressed as atoms and exhaust constituents will be expressed as molecules. The generally used x, y, and z for the fuel components of carbon (C), hydrogen (H), and oxygen (O) will be retained, and an "f" will be used for all other components of the fuel. Variable names for exhaust constituents, other than oxygen (O_2), will be the first letter of the last word in their names (e.g., d for CO_2, n for oxides of nitrogen (NO_x), w for water (H_2O), etc.). A "t", rather than an "o", is used for exhaust O_2, to eliminate possible confusion between the letter "o" and zero, and an "A" is used for air (rather than an "a").

Therefore, to follow the equations in this paper, it will only be necessary to memorize the variables designated by "f" and "t" and to remember the process used in naming the other variables. Also, in an attempt to make the equations less confusing, from this point forward, subscripts will not be used (e.g., CO_2 = CO2, H_2O = H2O, etc).

The combustion equation is as follows:

$$\text{FUEL} + \text{AIR} \rightarrow \text{EXHAUST} \qquad (1)$$

$$\text{FUEL} = xC + yH + zO + fN$$

$$\text{AIR} = AO2 + [3.7742*A]N2$$

$$\text{EXHAUST} = cHC + mCO + hH2 + dCO2 + nNOX + wH20 + tO2 + [3.7742*A - 0.5n]N2 + fN$$

The fuel components are to include all of each component, regardless of the source (e.g., the C and the O for gaseous fuels include that from the CO2), and the N is to include all components that are not C, H, or O. Initially, let x equal 1; then y becomes the hydrogen- to-carbon ratio (HCR), and z becomes the oxygen-to-carbon ratio of the fuel (on a per atom basis). Note that the N2 in the "AIR" includes all of the constituents of air, other than oxygen, as given on Page F-155 of the CRC Handbook (1988). Also, the oxides of nitrogen (NOX) are considered to be nitric oxide (NO), because the ratio of NO to NO2 is generally unknown, and the majority of the NOX is generally NO in raw exhaust.

COMPUTING STOICHIOMETRIC AFR

For stoichiometric combustion (c, m, h, and t = 0, w = 0.5 y, and n set = 0), the AFR can be determined as follows:

$$\text{SAFR} = [A*(MW_{O2} + 3.7742*MW_{N2})] \,/\, [AW_C + y*AW_H + z*AW_O + f*AW_N]$$

Where: $A = 1 + 0.25y - 0.5z$

Note: MW is molecular weight and AW is atomic weight

Using the preceding value for A and inserting the molecular and atomic weights, the SAFR is as follows:

$$\text{SAFR} = \frac{(1 + 0.25y - 0.5z)*(31.999 + 3.7742*28.159)}{12.011 + 1.008y + 15.999z + 14.007f}$$

Notes:
- The MW of 28.159 given for N2 is the average MW for all of the components in air, other than oxygen.
- If some additional fuel constituent other than the N is present in significant quantity, use a corrected AW in place of the 14.007 .

$$\text{SAFR} = \frac{138.28*(1.0 + 0.25y - 0.5z)}{12.011 + 1.008y + 15.999z + 14.007f} \qquad (2)$$

COMPUTING COMBUSTION AFR

This section of the paper describes the approach taken and provides the basic criteria applied toward computation of the combustion air/fuel ratio (AFR). The derivations of the equations for computing the AFR are given in the attachment to this paper. In essence, the computation requires deriving the value of variable "A" from the exhaust constituents. This would involve a rather simple exercise if the concentrations of all exhaust constituents were known. Such is not the case, however, because the amounts of hydrogen and water from combustion are not generally measured, and at times oxygen is not measured. The AFR calculated is for dry air (does not include humidity). To compare the results to an AFR calculated from measured fuel and air, the water vapor in the intake air must be mathematically subtracted from the AFR derived from measured fuel and air or added to result derived from measured exhaust constituents.

Initial Conversion of Input Data

Initially all fuel and exhaust composition data must be converted into consistent units. Assuming fuel components are input as mass fractions of the total fuel (i.e., Total Fuel = 1), the conversions to number of atoms of a fuel constituent per atom of carbon (or moles per mole) are as follows:

FUEL FACTORS: (3)

$x = (FFC/FFC) * (12.011/12.011)$ for carbon
$y = (FFH/FFC) * (12.011/1.008)$ for hydrogen
$z = (FFO/FFC) * (12.011/15.999)$ for oxygen
$f = (FFX/FFC) * (12.011/AAWX)$ for all other

FF = Fuel Fraction
AAW = Average Atomic Weight *(Use 14.007 if N or unknown)*
Use total C, H, and O - including that in CO2, H20, etc.

For the exhaust constituents, all measured concentrations must be expressed in percent on a dry basis. Additionally, the CO2 concentration must be corrected for background (BG), and the HC concentration must be corrected for FID response. Equations for performing the necessary conversions are as follows:

CONVERSION EQUATIONS: *(Exhaust Constituents)* (4)

Measured Dry (dew point less than −30°C):
Dry %XX = Measured %XX

Measured Ice-Trap Dry (dew point 0°C to 2°C):
Dry %XX = (Measured %XX)*1.0068

Note: Following equations include constants derived empirically by primary author.

Measured Wet (no water removed from sample):
Dry%XX ≈ Wet%XX*[(100 +H2OFAC +HUMFAC)/100]
H2OFAC ≈ 0.005*y*%CO2 + 0.005*y*%CO − 0.01*y*SAFR*[%CO +0.0121*(%CO)$^{2.6}$]
HUMFAC ≈ 0.168*HUM
(HUM = Intake humidity in grams/kg of dry air).

CO2 Corrected for Background CO2:
%CO2 ≈ Measured %CO2 − 1.1*BG%CO2
≈ Measured %CO2 − 0.04 (if BG%CO2 not measured)

HC Corrected for FID Response:
%HC = Measured %HC / FID Response Factor
If unknown: FIDRF ≈ [0.87 +0.07*y −0.33*z]

Balance Equations and Water-Gas Ratio

Three balance equations can be generated from the combustion equation. The equations (for carbon, oxygen, and hydrogen) are:

BALANCE EQUATIONS: (5)

Carbon Balance:
$1 = c + m + d$ *(When x = 1)*

Oxygen Balance:
$0.5z + A = 0.5zc + 0.5m + d + 0.5n + t + 0.5w$

Hydrogen Balance:
$0.5y = 0.5yc + h + w \qquad w = 0.5y - 0.5yc - h$

The water-gas ratio for determining exhaust H2 from measured exhaust constituents is as follows:

$k = 3.5 = [CO*H2O] / [H2*CO2] = [m*w] / [h*d]$

Substituting for "w" and solving for "h" provides:

$h = [0.5m(y - c)] / [3.5d + m]$ (6)

Relating Variables To Concentrations

The next requirement is to define the variables in the combustion equation in terms of the measured values for the exhaust constituents. This can be done in the form of ratios, as follows:

c/c = %HC/%HC   m/c = %CO/%HC   d/c = %CO2/%HC

Then substituting into the carbon balance equation:

1 = c + m + d
1 = c(%HC/%HC) + c(%CO/%HC) + c(%CO2/%HC)
c = %HC / (%HC + %CO + %CO2)

Solving all of the other variables in terms of the measured exhaust constituents, in like manner, provides the following:

VARIABLES IN TERMS OF CONCENTRATIONS: (7)

c = %HC / (%HC + %CO + %CO2)
m = %CO / (%HC + %CO + %CO2)
d = %CO2 / (%HC + %CO + %CO2)
n = %NOX / (%HC + %CO + %CO2)
t = %O2 / (%HC + %CO + %CO2)

Solution of AFR Equation

At this point, all of the necessary conversions have been defined and all of the necessary equations have been developed to enable deriving the equations for computation of AFR. It only remains to carry the resolution to a final solution.

Initially, an attempt was made to use the computer to effect the solution, but no available program was capable of solving the numerous simultaneous equations. Therefore, the solution was derived manually. The solution is included in Appendix A to the extent practical.

If H_2O is measured,
$H_2 = (CO)(H_2O) / 3.5 (CO_2)$ wet emissions

EQUATIONS FOR CALCULATING AFR AND LAMBDA

Computations of AFR and Lambda (λ) have been developed for cases in which:

- All exhaust constituents are measured;
- All exhaust constituents, except oxygen, are measured;
- Oxygen is the only exhaust constituent measured.

Lambda is the combustion AFR divided by the stoichiometric AFR. In the definition of lambda, the O in the exhaust NO is effectively taken as being available oxygen. With three-way catalyst systems, the NO is the source for the oxygen involved in oxidizing the CO .

Basic equations for calculation of AFR and λ are as follows:

$$AFR = \frac{138.28*A}{12.011 + 1.008*y + 15.999*z + 28.016*f} \qquad (8)$$

$$\lambda = AFR / SAFR \qquad (9)$$

Derivations for most, and the computations for all, of the variables (except "A") are provided in the text of this paper. Derivations for "A" are more involved and are provided only in the attachment. In these applications, exhaust H2 concentration is computed (identified as H2FAC) as follows:

$$H2FAC = \frac{0.5*\%CO*[y*(\%HC+\%CO+\%CO2) - \%HC]}{3.5*\%CO2 + \%CO} \qquad (10)$$

All Exhaust Constituents Available

For the situations in which all exhaust constituents are measured, and it can be assumed that CO2 and O2 are both measured with equal accuracy (accuracy as a percent of the measured value), the measured values of both are included in the computation. In situations where the O2 measurements are significantly less accurate than the CO2 measurements, use the computation in the next section, in which an O2 value is effectively derived from the measured CO2. The equation for computation of "A" when the measured CO2 and O2 are considered to be equally valid is as follows:

$$\begin{aligned} A = {} & [(0.5*z - 0.25*y)*\%HC + 0.5*\%CO + \%CO2 \\ & + 0.5*NOX + \%O2 - 0.5*H2FAC] \\ & / [\%HC+\%CO+\%CO2] + 0.25*y - 0.5*z \end{aligned} \qquad (11)$$

Oxygen Balance Computation

An oxygen balance computation (O2BAL) has been developed to indicate accuracy of the measured exhaust CO2 and O2, when both are measured. In this process, an O2 value is calculated from the other exhaust constituents, and that calculated O2 value is compared to the measured O2 value. Derivation of the balance computation is as follows:

$$\begin{aligned} O2BAL = {} & [(\%O2 - CALO2)*100.] \\ & / [(A + 0.5*z)*(\%HC+\%CO+\%CO2)] \end{aligned}$$

$$CALO2 = [\text{Calculated } t] * [\%HC+\%CO+\%CO2]$$

$$O2BAL = \frac{\%O2/(\%HC+\%CO+\%CO2) - \text{Calc. } t*100.]}{A + 0.5*z} \qquad (12)$$

$$\begin{aligned} \text{Calc. } t = {} & [20.946/(\%HC+\%CO+\%CO2)] \\ & - [(0.2095 - 0.1976y + 0.393z)c - 0.6047m \\ & + 0.1858h - d - 0.5n - 0.1976y + 0.3953z - 0.2095f] \end{aligned}$$

The result in percent is defined as the difference between the measured O2 and the value O2 should be, assuming measured values of other exhaust constituents (primarily CO2) were exactly correct. In general, when the O2BAL value is significant (the primary author usually uses a limit of two percent), either the O2 or the CO2 measurement is incorrect.

Exhaust O2 Concentration Not Available

When all exhaust constituents, other than O2, are available, the computation process computes a concentration for O2. This calculated concentration is that which would be present, assuming the measured concentrations for all the other exhaust constituents were exact. When a valid exhaust O2 concentration is not available, the equation for computation of "A" is as follows:

$$\begin{aligned} A = {} & [20.946 - (0.2095 + 0.0524*y - 0.1047*z)*\%HC \\ & - 0.1047*\%CO - 0.3142*H2FAC] / [\%HC+\%CO+\%CO2] \\ & + 0.0524*y - 0.1047*z - 0.2095*f \end{aligned} \qquad (13)$$

Only Exhaust CO2 or O2 Available

When only the exhaust CO2 concentration or the O2 concentration is available, and the concentrations of other exhaust constituents are known to be negligible, it is possible to compute a reasonable estimate of AFR. When only the exhaust CO2 or O2 is known, and the other constituents are either unknown or negligible, the equations for "A" reduce to the following:

CO2 Known:

$$A = 20.946/\%CO2 + 0.0524*y - 0.1047*z - 0.2095*f \qquad (14)$$

O2 Known:

$$\begin{aligned} A = {} & [\%O2*(4.7742 + 0.9435*y - 1.8871*z + f)] \\ & / [100. - 4.7742*\%O2] + 1.0 + 0.25*y - 0.5*z \end{aligned} \qquad (15)$$

AFR COMPUTATION PROCESS

Computation of AFR is outlined as follows:

1. Compute fuel factors using Equations 3.
2. Convert emissions using Equations 4.
3. Compute A using Equation 11, 13, 14 or 15.
4. When Equation 10 is used, compute **O2BAL**.
5. Compute **SAFR** and **AFR** using Equations 2 and 8.
6. If λ is desired, compute using Equation 9.

OXIDATION POTENTIAL PROCESS

When the AFR is very close to stoichiometric (such as with three-way catalyst systems), the standard AFR computation can result in significant error, relative to the magnitude of the AFR. Under such conditions, a better approach is to utilize an "oxidation potential" process (OXIPOT). This process is related to the REDOX computation developed by Gandhi et al (1976), and utilizes the exhaust constituents that are present in relatively small quantities near stoichiometric AFR (OXIPOT process does not use CO_2, H_2O, and N_2). The exhaust AFR is stoichiometric, relative to oxidation potential, when:

$$t + 0.5n = (1+0.25y-0.5z)c + 0.5m + 0.5h$$

The components having oxidizing potential are to the left of the equal sign, and those having reducing potential are on the right of the equal sign. OXIPOT is defined as the oxidizing potential divided by the reducing potential:

$$OXIPOT = [t + 0.5n] / [(1+0.25y-0.5z)c + 0.5m + 0.5h]$$

Solving OXIPOT in terms of the concentrations of the exhaust constituents results in (H2FAC from Equation 10):

$$OXIPOT = \frac{[2.*\%O2 + \%NOX]}{[(2.+0.5*y-z)*\%HC + \%CO + H2FAC]} \qquad (16)$$

It is also possible to calculate lambda (λ = AFR/SAFR) using the oxidation potential. The AFR is stoichiometric when the total oxygen from the intake air is (2. + 0.5*y - z), and the computation for OXIPOTλ is as follows:

$$OXIPOT\ \lambda = \frac{[(2. + 0.5*y - z) + O2FAC]}{[2. + 0.5*y - z]} \qquad (17)$$

$$O2FAC = [2.*\%O2 + \%NOX - (2.+0.5*y-z)*\%HC - \%CO - H2FAC] / [\%HC + \%CO + \%CO2]$$

The values for OXIPOT and OXIPOTλ can be used in determining whether the exhaust composition is oxidizing (has excess O_2) or reducing (deficient in O_2) as follows:

OXIPOT or OXIPOT$\lambda \geq 1$ Exhaust is Oxidizing (18)

OXIPOT or OXIPOT$\lambda \leq 1$ Exhaust is Reducing (19)

OTHER CONSIDERATIONS

There are several other considerations, such as wet air-to-fuel ratio (WAFR), fuel-to-air ratio (FAR and WFAR), and air-to-combustible fuel ratio (ACFR and WACFR), that can be computed:

Wet Air-to-Fuel Ratio

Calculated dry AFR can be converted to a wet air-to-fuel ratio (WAFR) as follow:

$$WAFR = AFR*(1 + H/1000) \qquad (20)$$

H = Absolute humidity *(grams of water per kg of dry air)*

Fuel-to-Air Ratio

Fuel-to-air ratio (FAR) is total fuel divided by dry air (FAR is the inverse of the AFR):

$$FAR = FUEL/AIR$$

$$FAR = 1/AFR \qquad (21)$$

FAR divided by the stoichiometric FAR (SFAR) is identified as ϕ:

$$\phi = FAR/SFAR$$

$$\phi = SAFR/AFR \qquad (22)$$

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APPENDIX A. DERIVATIONS

All of the equations derived in this appendix originate from the basic combustion equation given in the text, as (1), and repeated below:

$$\text{FUEL} + \text{AIR} \rightarrow \text{EXHAUST} \qquad [A]$$

$$\text{FUEL} = xC + yH + zO + fN$$

$$\text{AIR} = AO2 + [3.7742*A]N2$$

$$\text{EXHAUST} = cHC + mCO + hH2 + dCO2 + nNOX + wH20 + tO2 + [3.7742*A - 0.5n]N2 + fN$$

In all cases, the derivation revolves around solving for the amount of air "A" in the combustion equation. Fuel components are known, but some of the some exhaust constituents are not known. Derivations presented cover two cases: when oxygen in the exhaust is measured, in addition to HC, CO, CO_2, and NO_x; and when oxygen is not measured.

OXYGEN MEASURED

When oxygen is measured, the value of t is known, and the solution is reasonably straightforward.

Begin with the equations:

$$A = 0.5zc + 0.5m + d + 0.5n + t + 0.5w - 0.5z \qquad \textit{(from the oxygen balance)} \qquad [B]$$

$$w = 0.5y - 0.5yc - h \qquad \textit{(from the hydrogen balance)} \qquad [C]$$

Substituting [C] into [B] and simplifying yields:

$$A = (0.5z - 0.2y)c + 0.m + d + 0.5n + t - 0.5h + 0.25y - 0.5z \qquad [D]$$

"A" can be expressed in terms of measured emission concentrations by substituting the following equations, taken from (6) and (7) in the text for c, m, d, n, t, and h.

VARIABLES IN TERMS OF CONCENTRATIONS: [E]

$$c = \%HC \;/\; (\%HC + \%CO + \%CO2)$$

$$m = \%CO \;/\; (\%HC + \%CO + \%CO2)$$

$$d = \%CO2 \;/\; (\%HC + \%CO + \%CO2)$$

$$n = \%NOX \;/\; (\%HC + \%CO + \%CO2)$$

$$t = \%O2 \;/\; (\%HC + \%CO + \%CO2)$$

$$h = [0.5m(y - c)] \;/\; [3.5d + m] \qquad \textit{(from hydrogen balance and water-gas ratio)}$$

Combining (D) and (E) and simplifying the result yields:

$$A = \frac{(0.5z-0.25y)\%HC + 0.5\%CO + \%CO2 + 0.5\%NOX + \%O2 - 0.5\,H2FAC}{\%HC + \%CO + \%CO2} + 0.25y - 0.5z \qquad [F]$$

Where: $H2FAC = 0.5*\%CO * [y*(\%HC+\%CO+\%CO2) - \%HC] / [3.5*\%CO2 + \%CO]$

OXYGEN NOT MEASURED

This solution is more complex because the value of t must be expressed in terms of other exhaust constituents, and thus eliminated, before expressing "A" in terms of measured emission concentrations. The solution is from the basic combustion equation as follows:

Begin with the following from [B], [C], and [E] on the previous page:

$$A = 0.5zc + 0.5m + d + 0.5n + t + 0.5w + 0.5z \qquad [G]$$

$$w = 0.5y - 0.5yc - h \qquad [H]$$

$$\%O2 = t*(\%HC + \%CO + \%CO2) \qquad \textit{from } t = \%O2/(\%HC + \%CO + \%CO2) \qquad [I]$$

From the basic combustion equation, the percentage of free oxygen in the total <u>dry</u> exhaust is:

$$\%O2 = \frac{t*100}{c + m + h + d + n + t + 3.7792A - 0.5n + f} \qquad [J]$$

Setting [I] equal to [J] yields:

$$\frac{100}{\%HC + \%CO + \%CO2} = c + m + h + d + 0.5n + t + 3.7742A + f \qquad [K]$$

Substituting [H] into [G] and then substituting revised [G] into [K] yields:

$$100 / [\%HC + \%CO + \%CO2] =$$
$$c + m + h + d + 0.5n + t + 1.8871zc + 1.8871m + 3.7742d + 1.8871n + 3.7742t + 0.9436y - 0.9436yc - 1.8871h \qquad [L]$$

Simplifying [L] and solving for t gives:

$$t = \frac{20.946}{\%HC+\%CO+\%CO2} - 0.2095c - 0.6047m + 0.1858h - d - 0.5n - 0.3953zc - 0.1976y + 0.1976yc + 0.3953z - 0.2095f \qquad [M]$$

Now that t is known, "A" may be solved for in terms of exhaust emission concentrations.

Substituting [M] into [G], for t, and simplifying yields:

$$A = 0.1047zc - 0.1047m + \frac{20.946}{\%HC+\%CO+\%CO2} - 0.2095c - 0.3142h + 0.00524y - 0.0524yc - 0.1047z + 0.2095f \qquad [N]$$

Now the equations for c, m, and h from [E] are substituted into [N] to express "A" in terms of measured emission concentrations.

Simplifying the resulting equation yields the final solution:

$$A = \frac{20.946 - (0.2095 + 0.0524y - 0.1047z)*\%HC - 0.1047*\%CO - 0.3142*H2FAC}{\%HC + \%CO + \%CO2]} + 0.0524y - 0.1047z - 0.2095f \qquad [O]$$

Where: $H2FAC = 0.5*\%CO * [y*(\%HC + \%CO + \%CO2) - \%HC]/[3.5*\%CO2 + \%CO]$

APPENDIX S

AN INVESTIGATION OF INLET AIR HUMIDITY EFECTS ON A LARGE-BORE, TWO STROKE NATURAL GAS FIRED ENGINE

AN INVESTIGATION OF INLET AIR HUMIDITY EFFECTS ON A LARGE-BORE, TWO STROKE NATURAL GAS FIRED ENGINE

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ABSTRACT

The natural gas transmission industry has in service over 8000 large-bore, natural gas engines of various makes and vintages for compressing natural gas. Many of these engines are operated in high relative humidity conditions of the gulf and East Coast regions of the United States. Significant changes in emissions are often observed with changing ambient conditions and can be related to a combination of inlet air temperature as well as humidity effects. In an effort to investigate the humidity parameter, a project was sponsored by the American Gas Association to study humidity effects at the Colorado State University Large Bore Engine Test Bed. In this project, an inlet air humidification system was constructed to deliver a known amount of entrained water vapor to a Cooper-Bessemer GMV engine. A combination of steam injection and atomizing water nozzles were used to inject the desired quantity of water into the inlet air of the GMV test engine. Feedback control was accomplished through humidity sensors located in the inlet air duct. Due to the extensive level of instrumentation and control on this engine, it was possible to isolate the effects of humidity on engine performance and emissions.

In this paper, the direct effects of changing the humidity of the inlet air on engine performance and emissions are presented. Test data and theory are used to demonstrate the effects of varying inlet air humidity on the emission of oxides of nitrogen, unburned hydrocarbons, carbon monoxide, and air toxics (formaldehyde) from the engine.

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This paper is based on work funded under various contracts with PRC International (PCRI) and the Gas Research Institute (GRI). The data presented is considered to be work in progress and therefore it has not been approved by the sponsors. The opinions, findings, and conclusions expressed are those of the author and not necessarily those of the American Gas Association (A.G.A.), or PRCI or GRI. Mention of company or product name is not to be considered an endorsement by A.G.A., PRCI or GRI. Neither A.G.A., members of A.G.A., PRCI, or members of PRCI, GRI, or members of GRI, or any person acting on behalf of them; makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this paper, or that the use of any information, apparatus, method, or process disclosed in this paper may not infringe privately-owned rights. Finally, neither A.G.A. and its members, PRCI and its members, or GRI and its members, or any person acting on their behalf of all three organizations, assumes any liability with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this paper.

INTRODUCTION

The automotive industry has conducted research regarding the effects of humidity on emissions in four stroke gasoline and diesel engines (1,2,3). This body of work has identified the general trends of emissions with increasing humidity levels and investigated the relationships between humidity and air fuel ratio and in-cylinder heat capacity change (4, 5). As is usually the case, there is little data examining the humidity effects on large-bore engines. Additionally, the majority of the automotive research was conducted before there was any interest in air toxic emissions and only considered criteria pollutants.

The American Gas Association (AGA) sponsored a project in the fall of 1996 to investigate the effects of varying humidity levels on emissions from a large-bore engine. The project was conducted at the Colorado State University Large-Bore Engine Test-bed (LBET) and included criteria and air toxic emission data. The project equipment was specified, installed and the testing completed by September 1997.

PROJECT OBJECTIVE

The goal was to provide a system capable of simulating a 100% relative humidity day at sea level and 90°F in the LBET for the range of ambient conditions typically encountered in Fort Collins, Colorado. Additionally, the capability to control and vary the humidity level from the minimum possible (Fort Collins ambient conditions) to 100% RH on a 90°F day at sea level was required. Once the system was in place, the testing program consisted of various humidity maps in which the humidity was the only independent parameter.

TEST SETUP

The humidity control system was designed and specified by the EECL personnel and consisted of a variety of commercially available items. The Woodward Governor Company provided assistance with the controls and integrated them into the existing engine controller. The major components of the humidity control system included the LBET, water supply system, steam humidification delivery system, the atomizing nozzle system, and humidity sensors.

Large-Bore Engine Test-bed

The LBET was commissioned by the gas pipeline industry in 1992 to provide an independent research facility to assist in the development of emission reduction technologies for large-bore engines. Due to the generous support of the industry, the LBET has evolved into a state-of-the-art facility conducting some of the most advanced research ever attempted on large-bore engines. The centerpiece of the test-bed is a highly instrumented four cylinder, 14 inch bore, 14 inch stroke, two-cycle natural gas fired Cooper-Bessemer GMV-4TFS engine. The engine has a sea-level rating of 440 bhp at 300 rpm. There are 102 engine parameters continuously monitored, including in-cylinder pressures for real-time combustion analysis. Load control is accomplished with a water brake dynomometer and the engine is outfitted with a turbocharger simulation package which allows operation at a range of air manifold pressures to mimic piston scavenged and clean burn GMV configurations. The engine is equipped with a Woodward Governor Autobalancer system to provide precise cylinder peak pressure balance during testing. The test-bed uses protocol analyzers as well as a Fourier Transform Infrared Spectrometer (FTIR) to examine criteria and air toxic emissions. The addition of the humidity system compliments the existing systems that allow control of air manifold temperature and pressure, fuel manifold temperature and pressure, and jacket water temperature.

Water Supply System

A reverse osmosis water supply system was selected to provide the pure water for humidification of the engine inlet air (Figure 3). A 1500 gallon storage tank was added to reduce the duty cycle of the reverse osmosis machine.

Steam Humidification Delivery System

A high pressure, natural gas fired boiler was used to generate steam and deliver it through a control valve to injection rails placed inside the inlet air duct of the engine (Figures 1, 2 ,6). The injection was carried out downstream of the supercharger (turbocharger simulator) and required the addition of a mixing section of duct to ensure entrainment of the water vapor in the air stream (Figure 2). The steam injection was the primary method of injecting water vapor. In order to maintain a constant air manifold temperature in the summer months, an atomizing nozzle water injection system was also installed in the mixing section of the duct (Figure 4).

Water Injection System

Atomizing nozzles using pressurized water and compressed air were installed to deliver water vapor and to cool the inlet air stream if needed to maintain a constant air manifold temperature in the summer months (Figure 4). The intercooler (Figure 2) at the LBET operates near 100% of its capacity during the hottest summer months of operation. Steam injection during the summer has the potential to exceed the cooling capacity of the intercooler which required installation of the atomizing nozzles to ensure year round operation of the humidity system. Both the steam and atomizing nozzles can be operated at the same time and in this manner provide the capability to control both humidity and air manifold temperature.

Humidity Sensors

Vailsiala humidity sensors were placed in the inlet air duct both upstream and downstream of the supercharger. The downstream humidity sensor was used to provide feedback control of the humidity delivery system and provided setpoint control for the delivery systems. To verify the accuracy of the humidity sensors, the engine intake air was sampled periodically with the FTIR to determine the percent water in the intake air. Percent water is easily correlated to the required relative humidity level and provided an easy check of the measurement system.

HUMIDITY UNITS

The amount of water vapor contained in atmospheric air can be described either by the humidity ratio or the relative humidity. The humidity ratio is defined as the ratio of water mass to the mass of dry air in a moist air sample and is usually given the symbol W. The units are pounds of water per pounds of air.

W= lbs water/lbs dry air

For an air-water mixture:

$W = 0.61298 * (P_w/(P_{tot}-P_w)$, where:

P_w = partial pressure of water vapor
P_{tot} = total pressure of mixture

Relative humidity is the ratio of the partial pressure of the water vapor to the saturation pressure at the temperature of the air. For every temperature, there is a unique saturation pressure.

$RH = P_v / P_{sat}$

If the partial pressure of the water vapor is equal to the saturation pressure, the air is saturated (i.e., 100 % relative humidity).

These two terms are easily correlated to each other by using ideal gas equations and the liquid-vapor saturation curve for water. The humidity ratio is a more meaningful parameter for the purpose of this research. This is because the relative humidity is exponentially dependent on ambient temperature, which can confuse the results if ambient temperature is not held constant. Humidity ratio represents the mass fraction of water in the intake charge, which affects the combustion process directly.

TESTING PROCEDURE

Test points were determined by first calculating the humidity ratio of 90 °F, 14.696 psig air at a desired relative humidity. This humidity ratio was then back calculated to a test point relative humidity at the operating air manifold temperature and pressure of the engine. The test point relative humidity was then used as the control set point for the system.

The primary humidity map was conducted at 7.5 inches Hg boost and 110 °F air manifold temperature. This map consists of 8 points varying in humidity ratio from 0.007 to 0.25 lb/lb dry air. To verify the trends observed in the first humidity map points, additional maps were conducted at 10 and 12.5 inches Hg boost pressure and 90 and 140 °F air manifold temperature. Finally, to investigate the effects of humidity at a constant air/ fuel ratio, additional data was taken to permit analysis at matched trapped air/ fuel ratio points. A summary of the data points used in the maps and matched air fuel ratio points is contained in Tables I through IX.

Protocol analyzers were used to measure the concentrations of NOx, CO, THC, O2, and CO2 during the testing. A FTIR was used to measure Formaldehyde concentrations.

ENGINE CONFIGURATION

Testing was performed on the GMV-4TF engine with Woodward Governor Electronic Gas Admission Valves (EGAV). Speed control was accomplished by governing on duration through the Autobalancer 5000 system. Duration governing works by using a proportional / integral / derivative (PID) speed loop to increase or decrease fuel delivered to the engine to maintain the speed at the desired setpoint.

The engine balance was precisely maintained by using the Autobalancer feature, and the Altronic CPU 2000 ignition system was used in all the testing.

Table I: Test Matrix 1
440 BHP, 7.5" AMP, 110 °F AMT

Test Points	Relative Humidity 90 °F & 29.92 in Hg	Grains/lb
H1.4-6	24.29	68.32
H1.7-9	41.63	87.93
H1.10-12	52.97	112.51
H1.13-15	63.5	135.58
H1.20-22	68.33	146.24
H1.26-28	74.81	160.60
H1.29-31	79.27	170.56
H1.32-34	83.40	179.84

Table II: Test Matrix 2
440 BHP, 10" AMP, 110 °F AMT

Test Points	Relative Humidity 90 °F & 29.92 in Hg	Grains/lb
H2.2-4	29.56	62.09
H2.8-9	53.62	113.93
H2.10-11	64.55	137.90
H2.12-13	73.38	157.44
H2.14-15	98.83	214.72

Table III: Test Matrix 3
440 BHP, 12.5" AMP, 110 °F AMT

Test Points	Relative Humidity 90 °F & 29.92 in Hg	Grains/lb
H2.5-7	24.74	51.83
H2.22-23	39.74	83.87
H2.18-19	66.17	141.47
H2.20-21	77.17	165.87

Table IV: Test Matrix 4
440 BHP, 7.5" AMP, 90 °F AMT

Test Points	Relative Humidity 90 °F & 29.92 in Hg	Grains/lb
H3.5-7	36.63	77.20
H3.8-10	51.30	108.89
H3.11-13	72.50	155.48
H3.14-16	75.31	161.74

Table V: Test Matrix 5
440 BHP, 7.5" AMP, 140 °F AMT

Test Points	Relative Humidity 90 °F & 29.92 in Hg	Grains/lb
H3.2-4	30.97	65.09
H3.31-32?	45.00	95.21
H3.29-30	58.90	125.42
H3.21-22	84.74	182.83
H3.27-28	86.00	185.67

Table VI: Test Matrix 6
A/F MATCH, 440 BHP, 7.5" AMP, 110 °F AMT

Test Points	Relative Humidity 90 °F & 29.92 in Hg	Grains/lb
H1.1-3	32.49	68.32
H1.10-12	52.97	112.51
H1.26-28	74.81	160.60
H4.3-4	81.44	175.42

Table VII: Test Matrix 7
A/F MATCH, 440 BHP, 10" AMP, 110 °F AMT

Test Points	Relative Humidity 90 °F & 29.92 in Hg	Grains/lb
H2.2-4	29.56	62.09
H2.8-9	53.62	113.93
H2.12-13	73.38	157.44
H4.5-6	77.61	166.86

Table VIII: Test Matrix 8
A/F MATCH, 440 BHP, 12.5" AMP, 110 °F AMT

Test Points	Relative Humidity 90 °F & 29.92 in Hg	Grains/lb
H2.5-7	24.74	51.83
H2.18-19	66.17	165.87
H2.20-21	77.17	165.87
H4.7-8	79.86	171.89

Table IX: Test Matrix 9
A/F MATCH, 440 BHP, 12.5" AMP, 140 °F AMT

Test Points	Relative Humidity 90 °F & 29.92 in Hg	Grains/lb
H3.2-4	30.97	65.09
H3.31-32	45.00	95.21
H4.1-2	73.45	157.59
H3.21-22	84.74	182.83

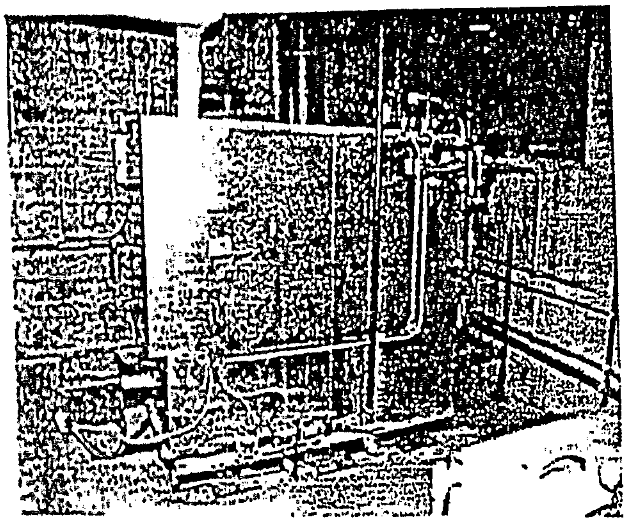


Figure 1: Boiler

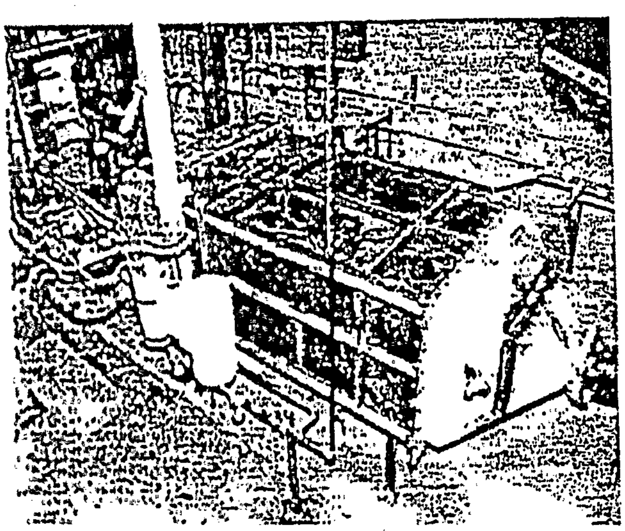


Figure 2: Mixing Duct, Air Manifold Intercooler

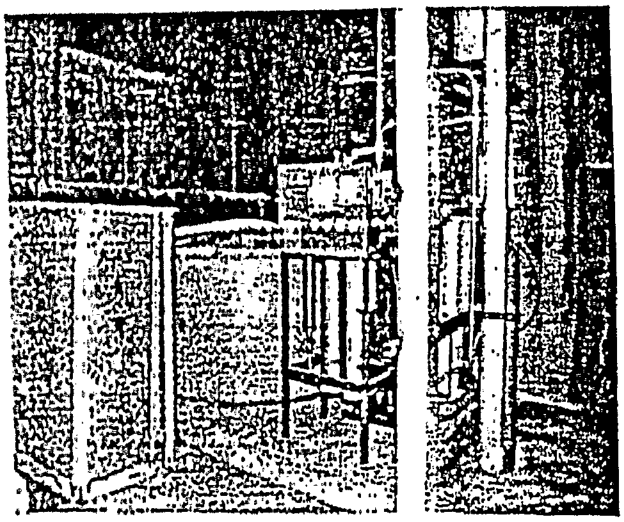


Figure 3: Reverse Osmosis Water Supply and Storage Tank

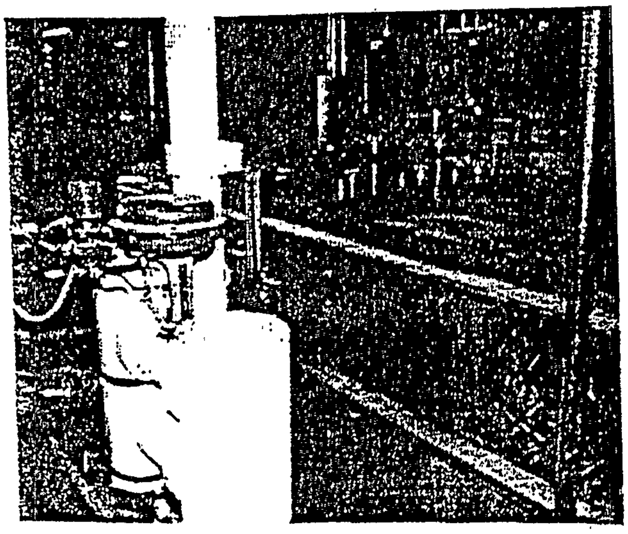


Figure 4: Steam Control Valve and Atomizing Nozzle Tubing

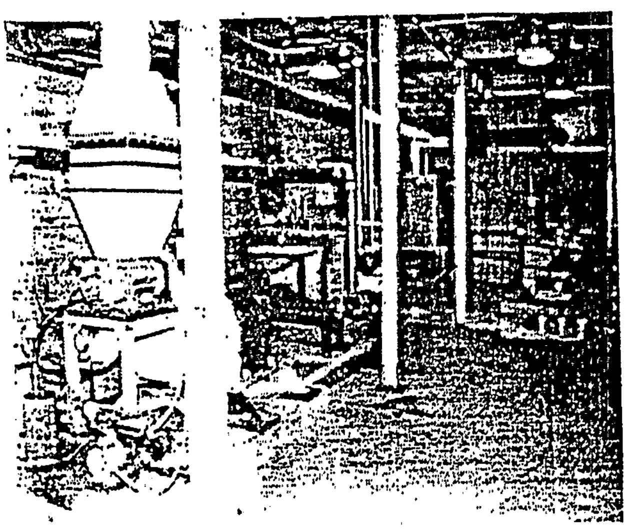


Figure 5: Supercharger, Mixing Duct, and Boiler

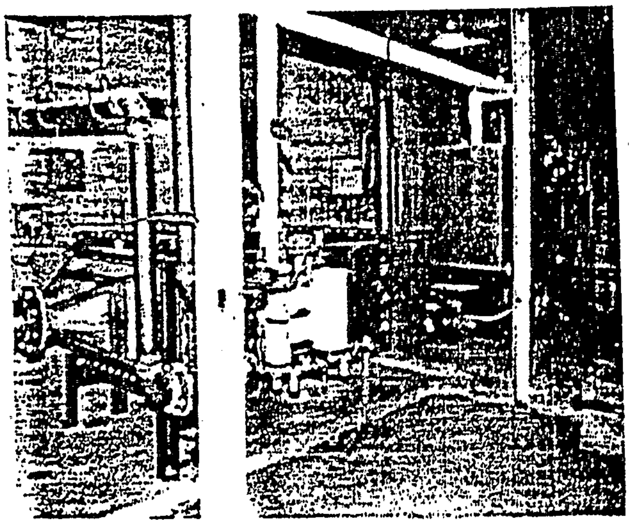


Figure 6: Mixing Duct and Boiler

RESULTS AND DISCUSSION

The results presented here are a summary of findings of the AGA sponsored testing. Colorado State University will issue the official AGA project test report.

Previous researchers have shown that inlet air humidity has an affect on engine emissions and performance. Two prominent mechanisms have been offered to explain the effects of humidity on engine performance and emissions. The first is the decrease in cylinder temperatures caused by the increase in the total heat capacity of the cylinder charge. The second, the decrease in the air fuel ratio as water vapor displaces oxygen in the inlet air. The decrease in oxygen supplied to the engine causes a richer mixture. The lower air fuel ratio translates to a higher in cylinder temperature. Although opposite in effect, both mechanisms have an affect on in-cylinder temperature. The decrease in the oxygen concentration in the in cylinder charge, appears to have more of an affect on engines operating at or near stoichiometric conditions (rich burn four-stroke engines (1)).

The majority of research has focused on the most prominent affect of these changes, NO_x production. Additionally, research papers reviewed in conjunction with this program, indicate that to date, no work has been conducted on either two-stroke, or large-bore industrial class engines in the relation to the effects of humidity on engine performance and emissions. Results presented within this document will provide information on variations in inlet air humidity in relation to engine emissions, and engine combustion parameters. In order to completely understand the ensuing discussion, a definition of the terminology used to explain the effects of humidity on engine emissions and performance is required.

Trapped Air Fuel Ratio

The trapped air / fuel ratio refers to the mixture captured in the cylinder that participates in the combustion event. On a two-stroke engine, determining the trapped air / fuel ratio is complicated by the presence of scavenging air. To determine a trapped air / fuel ratio, an assumption of engine trapping efficiency is made and is applied to the overall air / fuel ratio of the engine. The overall air / fuel ratio is determined by measuring the air and fuel mass flow rates, or an analysis of the exhaust gas constituents.

Previous work by Olsen et al. (5) at the EECL has used a tracer gas method to measure the trapping efficiency of the test engine. A tracer gas was used that was destroyed at in cylinder combustion temperatures but would pass through the engine if used in a scavenging process. Before and after engine concentrations of the tracer gas were measured with a FTIR spectrometer and the concentrations are a direct indication of trapping efficiency.

Figure 8 show the calculated trapped air fuel ratio decreasing with increasing humidity levels for all boost levels. For each of the three boost levels, the air / fuel ratio decreased approximately one air / fuel ratio unit. The data was taken at a fixed air manifold pressure, therefore as intake humidity was increased the air was displaced with the water vapor the air / fuel ratio decreased. This is characteristic of fixed air supply engines.

Figures 11-14 show the humidity effect at a constant trapped air / fuel ratio. This means the humidity effect is due to more than just a changing air / fuel ratio and for these plots directly indicate the effects of increasing heat capacity.

Specific Heat Capacitiy

The specific heat capacity, or specific heat is a thermodynamic property which is defined as the amount of heat required per unit mass to raise the temperature by one degree. To evaluate the specific heat changes associated with increasing humidity, calculations were performed to evaluate the specific heat capacity of the trapped cylinder charge. A fuel gas analysis, measured intake air moisture content, and calculated trapped air / fuel ratio were used to calculate a constant volume adiabatic flame temperature. The products of combustion were assumed to be H2O, CO2, O2 and N2. The specific heat of the combustion products was then evaluated at the flame temperature. Figures 15 - 18 are a plot of emissions versus specific heat at the flame temperature for the humidity maps at the different boost levels tested. The calculated flame temperatures are presented in Figure 21 for different boost levels.

To account for the mass changes of different air / fuel ratios, the mixture specific heat was multiplied by the trapped mass to give an absolute measure of the cylinder heat capacity which is termed total heat capacity. The total heat capacity of a gas mixture can be augmented three ways, (1) by adding a constituent with a significantly different specific heat capacity such as H2O, (2) by adding more mass, and (3) by increasing the temperature provided that the mixture does not consist entirely of monatomic gases. The absolute heat capacity data for the different boost levels tested are plotted in Figure 19 and compared to a constant humidity boost map.

In Cylinder Bulk Temperature

In cylinder temperature is a calculated average temperature and is based on peak pressure, location of peak pressure, engine geometry, mass of charge and speed. Bulk temperature data are plotted in Figure 10. The bulk in cylinder temperatures were insensitive to changes in humidity ratio but did decrease with increasing boost levels. The lack of change of bulk temperatures is most likely due to the offsetting effects of the decreasing air / fuel ratio and increasing mixture total heat capacity. This behavior was also seen with the calculated flame temperatures.

Stack Temperature

Figure 9 show the exhaust stack temperature increasing slightly with increasing humidity. This is partly due to a decrease in trapped air / fuel ratio with increasing humidity. Also, the location of peak pressures occur later as the humidity increases, which generally results in an increase in stack temperature. When cylinder pressure peaks later in the cycle, less of the chemical energy from the fuel is converted to shaft power, resulting in higher exhaust temperatures. The stack temperature, which is tied strongly to location of peak pressure, does not necessarily correlate with peak bulk in-cylinder temperature, calculated directly from peak pressure amplitude. The stack temperature also does not correlate to calculated flame temperatures. This insensitivity of the bulk and flame temperatures to the humidity ratio most likely results from competing effects of decreasing air / fuel ratio and increased charge heat capacity.

Combustion Parameters

Figures 23-26 display the results of increasing humidity levels on the combustion parameters. The only combustion parameters affected by the humidity were the cylinder peak pressures and location of peak pressures. Cylinder peak pressures are decreasing slightly with increasing humidity and do not correspond to an expected decrease in cylinder bulk temperature. This is due to the increased heat capacity in the cylinder from the increased moisture content. The location of peak pressure is increasing as the humidity increases and the mixture becomes richer.

Standard deviations of the combustion parameters generally describe the combustion stability, or the cycle to cycle variability of the combustion event. Increasing humidity levels did not adversely affect the combustion. No significant levels of misfires were observed during the testing.

BSFC Results

Figure 7 shows a trend of increasing fuel consumption as humidity levels are increased. This trend has been previously documented in a paper by Quader (1), which shows specific fuel consumption increasing with percent by volume of water in the intake charge. Although the previous author provided no explanation for this trend, it is most likely related to the high value and strong temperature dependence of the specific heat of water.

NOx Results

As previously mentioned, variations in inlet air humidity appear to have the most prominent effect on NO_x production.. This trend is uniform over all air manifold pressures and temperatures tested. The data indicates that increases in humidity ratio bring about a resulting decrease in NO_x production. The reduction in NOx appears to be not as pronounced at leaner air / fuel ratios. By looking at the data in terms of trapped air/fuel ratio and heat capacity of the trapped charged, it can be seen that the NO_x emissions are being reduced at higher humidity levels even though the air fuel ratio is becoming richer. This can be seen in Figure (X). Bulk cylinder temperatures and calculated flame temperatures were previously shown to be relatively constant through the humidity map. Therefore, the decreasing NOx emissions are likely due to the effects of increasing heat capacity from increased moisture in the air / fuel mixture.

The current school of thought is that the increased heat capacity brings about a reduction in the overall combustion temperatures by lowering combustion pressures and slowing the combustion flame propagation. Test programs which derived these results maintained a constant air / fuel ratio while changing humidity ratio. The current test program increased the humidity ratio at a constant air manifold pressure. The air / fuel ratio changed by one air / fuel unit over the range of humidity ratios tested at each boost condition. The increase in humidity ratio has an offsetting effect to the changes in air / fuel ratio which resulted in a constant adiabatic flame temperature. Additional data was collected in which air / fuel ratio was held constant over varying humidity ratios. This was conducted at all three test boost pressures. The results from this data are displayed in Figures 11 to 14 which show the trend of decreasing NOx with increasing humidity. The data from these various mapping processes support the current school of thought and offer a second plausible explanation for the reduction in NOx with increasing humidity ratio.

The data which displays the constant air / fuel ratio points for varying humidity ratios shows a decrease in NOx as humidity increases. The combustion pressures decrease and locations of peak pressure occur later (figures 23-26). These changes do occur but are not of a great magnitude. The data which represents the varying humidity ratios at a constant boost pressure indicate minimal change in the combustion parameters, with adiabatic flame temperature remaining constant. These minimal changes in peak pressures and adiabatic flame temperatures indicate that the combustion is occurring in essentially the same manner. With the assumption that the combustion processes for all humidity ratios is starting at a similar adiabatic flame temperature (as indicated by test data), what happens as the composition cools during the expansion stroke becomes important. During the expansion stroke, the NO formed in the flame front is decomposing to an equilibrium state as the temperatures decline. As the expansion stroke continues and the temperature drops, the NO equilibrium reaction is frozen prior to reaching the final equilibrium state (N2 and O2). With increased heat capacity (due to increased water vapor) of the post combustion composition, the change in temperature in relation to the change in time (dT/dt) is less. This translates to the post combustion composition remaining at a higher temperature for a longer period of time. The effect of this mechanism on the NOx production would be a decrease in NOx emissions.

Test data collected tend to support this mechanism. Calculated adiabatic flame temperatures and bulk in cylinder peak temperature calculations show constant temperatures for varying humidity ratios. Measured exhaust gas temperatures show an increase in temperature, which would be expected with higher post combustion temperatures during the expansion stroke. This data correlates well with the slight changes in the measured combustion parameters, which appear to have minimal changes in relation to the reduction in NOx. Additionally, the slight decreases in peak pressures are at richer air / fuel ratios where one would expect elevated temperatures and pressures.

Total Hydrocarbons and Carbon Monoxide

The effects of humidity ratio and specific heat on total hydrocarbon (THC) and carbon monoxide (CO) emissions are given in Figures (12,13,16,17). THC emissions display a gradual increasing trend with increasing humidity ratio with the exception of the 7.5 in. Hg boost data, which does not change significantly for the range of humidity ratio tested. The increasing trend seen at higher boost levels has been observed by other researchers (4, 5). One possible explanation for the increasing trend in our data is the decrease in air/fuel ratio as humidity ratio increases. For richer mixtures, higher concentrations of hydrocarbons exist in regions which are not processed by the flame, such as crevice volumes. As humidity ratio increases, CO emissions are reduced initially then increase. Thus, there is a optimum level of humidity that minimizes CO. However, the changes in CO are small, between the range of 3 to 14% with the largest effect occurring at the lowest boost. This is in contrast to THC emissions, where the smallest effect was seen at the lowest boost level. A hydrocarbon trend is not evident during the humidity map at 7.5 inches of boost. It is likely that any additional hydrocarbon emissions resulting from the decrease in air / fuel ratio are oxidized at the relatively high bulk gas temperature at this boost level.

Figure 19

B.S. NOx vs Total Heat Capacity @ Flame Temperature

at 440Bhp, 300Rpm, and 110AMT

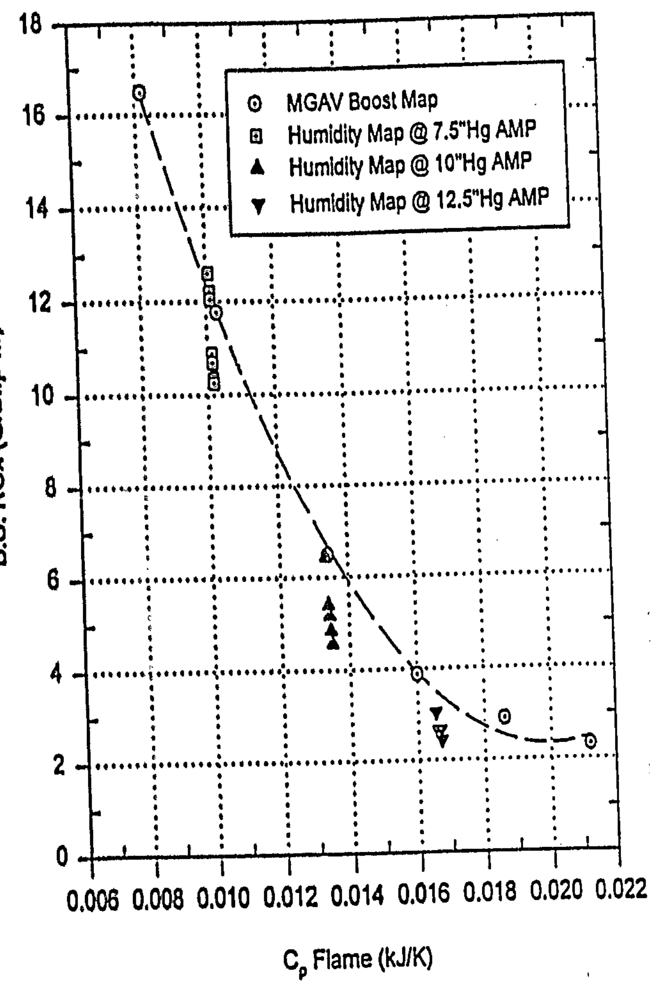


Figure 20

B.S. NOx vs T_{ad} - Flame

at 440Bhp, 300Rpm, and 110AMT

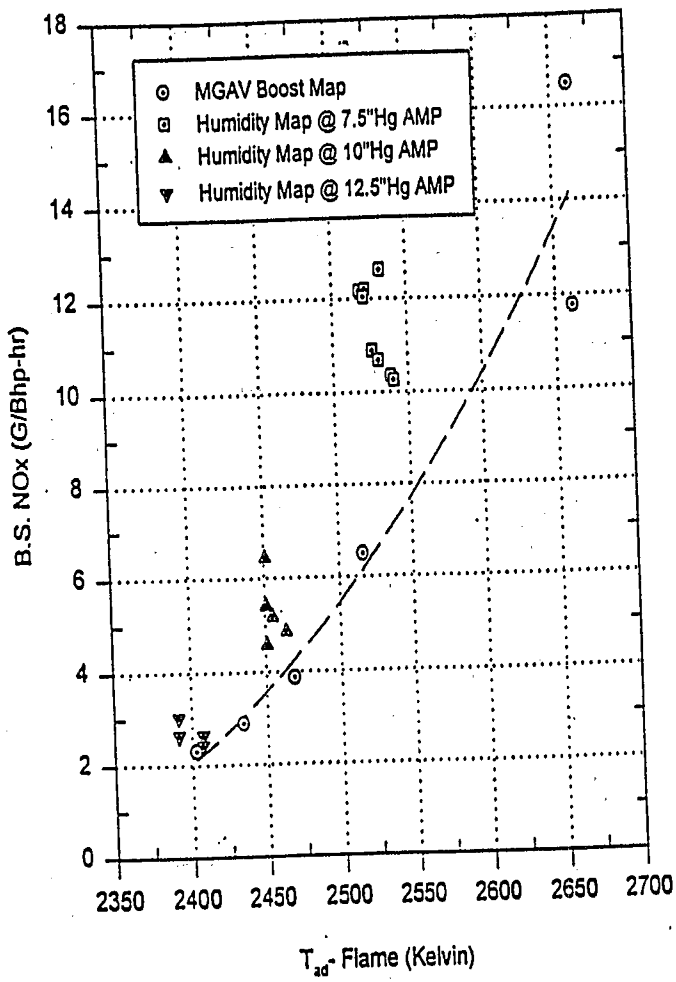


Figure 21

T_{ad} - Flame vs Humidity Ratio

st 440 Bhp,300 Rpm, and 110 AMT

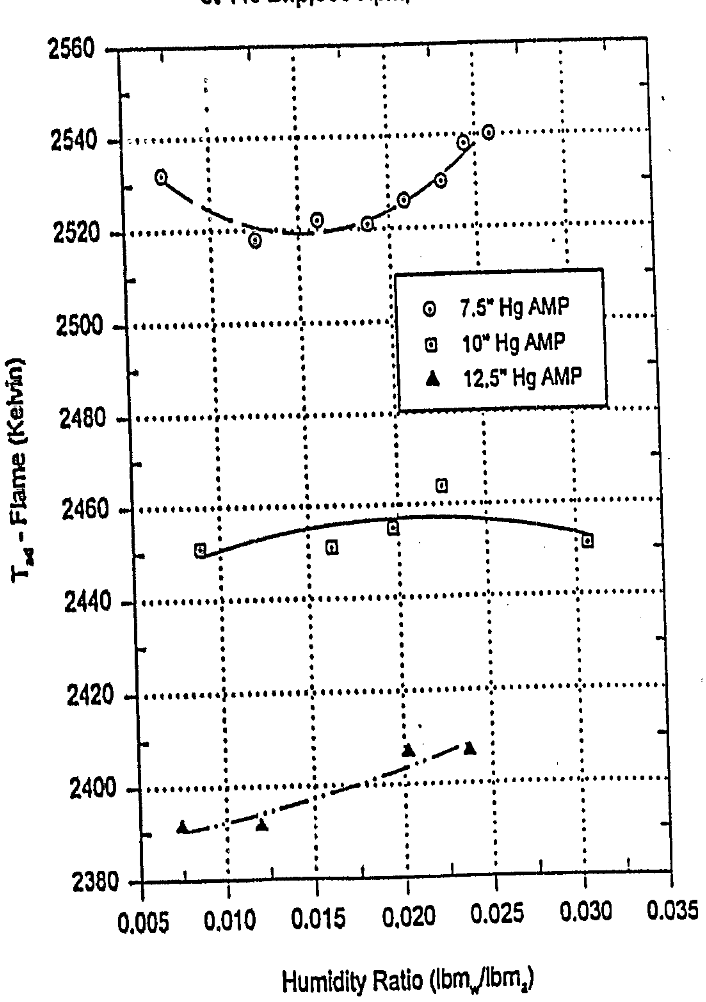


Figure 22

T_{ad} - Flame vs Trapped Air/Fuel Ratio

st 440 Bhp,300 Rpm, and 110 AMT

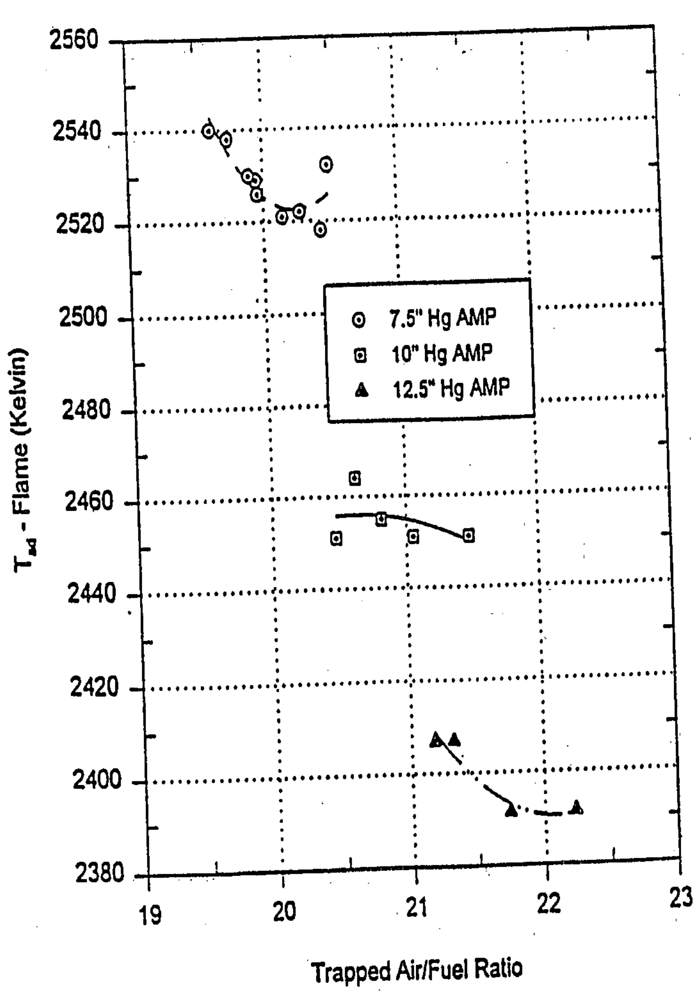


Figure 23

Peak Pressure vs Humidity Ratio

at 440Bhp, 300Rpm, and 110AMT

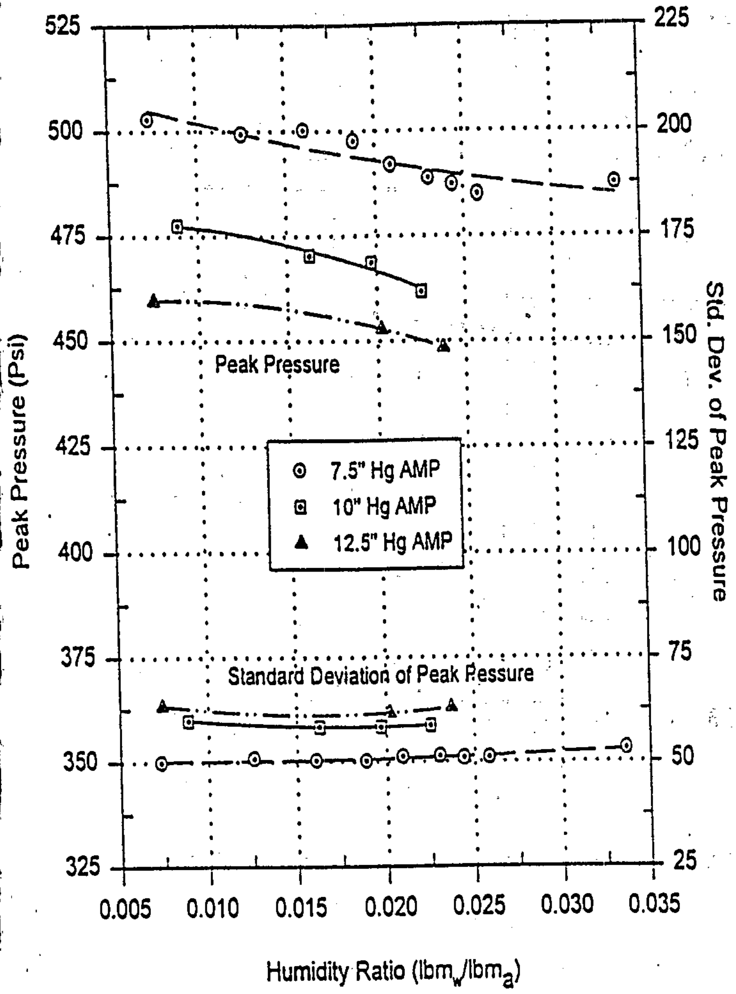


Figure 24

Location of Peak Pressure vs Humidity Ratio

at 440Bhp, 300Rpm, and 110AMT

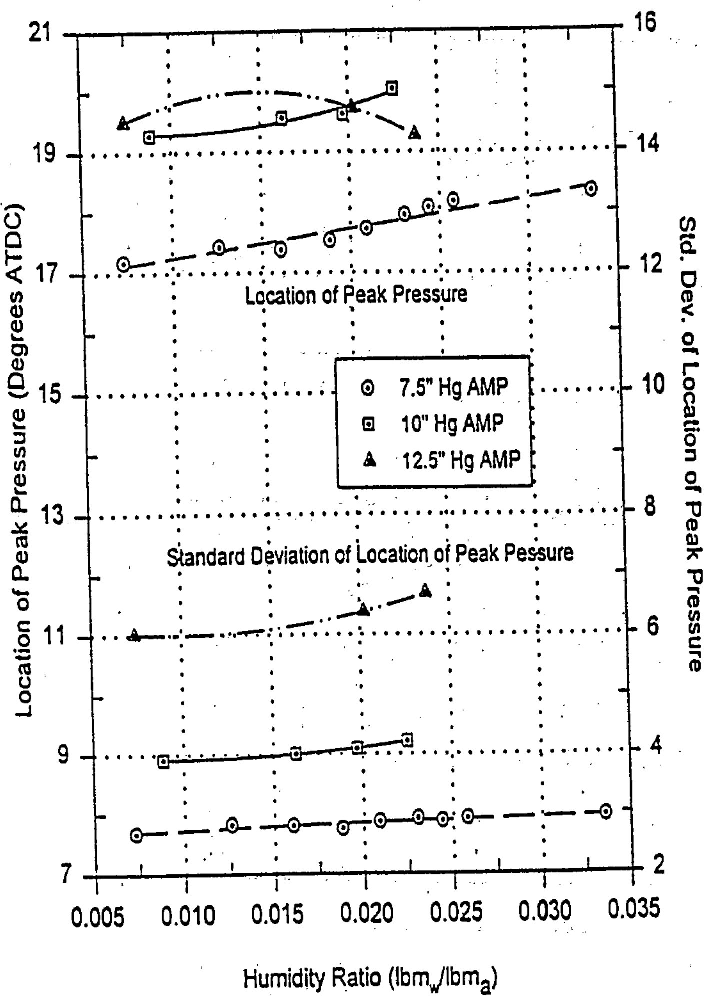


Figure 25

0-10% Burn Duration vs Humidity Ratio

at 440Bhp, 300Rpm, and 110AMT

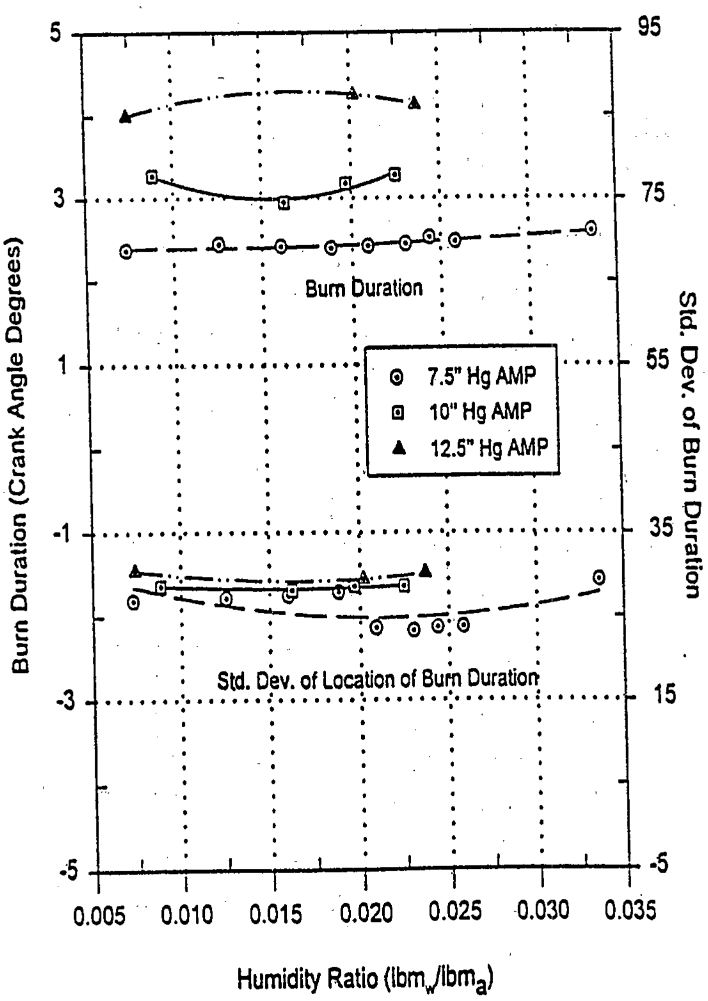
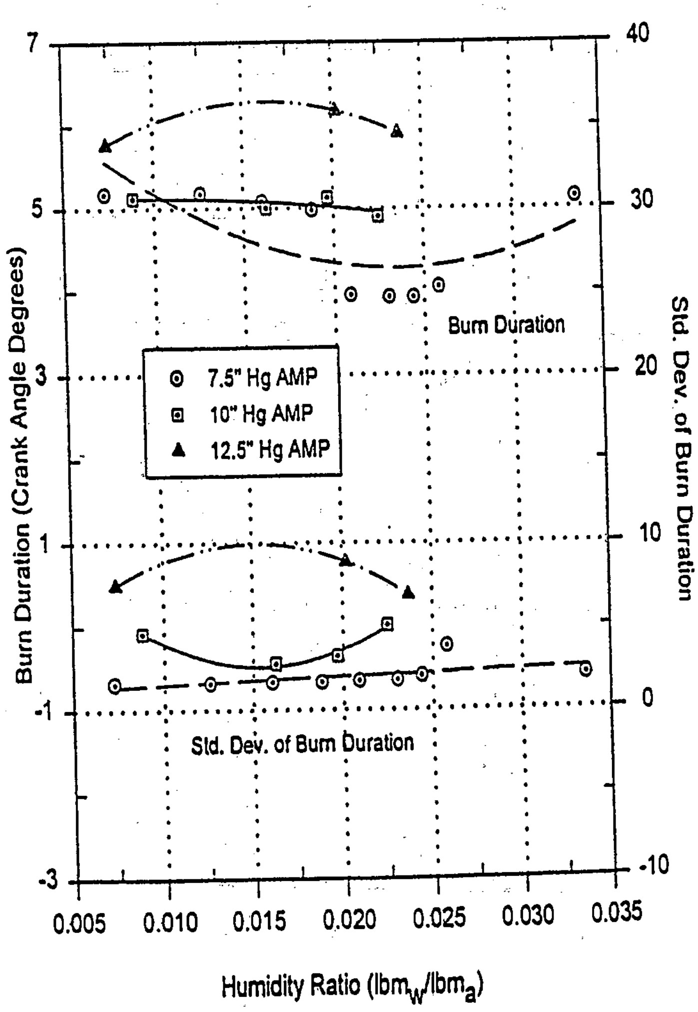


Figure 26

10-90% Burn Duration vs Humidity Ratio

at 440Bhp, 300Rpm, and 110AMT



$$\text{Mass/hr} = \frac{\text{Mass of Emission}}{\text{Mole of Exhaust Gas}} \times \frac{\text{Moles of Exhaust Gas}}{\text{hr}} \qquad (2)$$

However, the moles of exhaust gas/hr produced by the combustion source is not known. It is this quantity that can be derived from the fact that the fuel and exhaust gas contain the same amount of carbon, as shown in the next section.

B. Derivation of an Expression for Moles/Hr of Exhaust Gas

An expression for the Moles of Exhaust/Hr can be derived from fuel composition and molecular weight and the measured values of fuel flow and volumetric concentrations of CO, CO_2, and hydrocarbons in the exhaust. The expression is:

$$\frac{\text{Moles of Exhaust}}{\text{hr}} = \frac{\left(\dfrac{\text{Mass of Carbon in Fuel}}{\text{hr}}\right)}{\left(\dfrac{\text{Mass of Carbon in Exhaust}}{\text{Mole of Exhaust}}\right)} \qquad (3)$$

Since the total mass of carbon/hr put into the system by the fuel must be equal to the total mass of carbon/hr leaving the system in the exhaust gas.

Sections 1 and 2 below will derive the expressions for mass of carbon from fuel/hr and mass of carbon from exhaust/mole of exhaust, respectively.

1. Derivation of Expression for Mass of Carbon from Fuel/Hr

The problem is to determine the Mass of Carbon/Hr put into the system from the fuel using either an assumed or actual fuel composition and the measured fuel flow.

If the mass (or mass rate) of a gas mixture is known, the mass (or mass rate) of each constituent can be found as follows:

$$\text{Mass of Constituent} = \text{Mass of Mixture} \times \text{Mass \%} \qquad (4)$$

where:

$$\text{Mass \%} = \frac{\text{Mass of Constituent/Mole of Mixture}}{\text{Molecular Weight of Mixture}} \qquad (5)$$

and the mass of constituent/mole of mixture is found from measured volumetric concentrations using equation (1).

Now, the mass of carbon in any carbon compound can be calculated knowing the mass of compound, the compound molecular weight, and the number of carbon atoms per molecule, thusly:

$$\frac{\text{Mass of Carbon}}{\text{Compound}} = \text{Mass of Compound} \times \frac{\text{Molecular Weight of Carbon}}{\text{Molecular Weight of Compound}} \times \frac{\text{Number of Carbon Atoms}}{\text{Molecule of Compound}} \qquad (6)$$

Substituting equations (1), (4), and (5) in equation (6) gives the following equation for the mass of carbon from one compound:

$$\frac{\text{Mass of Carbon}}{\text{Compound}} = \text{Mass of Mixture} \times \frac{\text{Vol. \% of Comp.} \times \text{Molecular Wt. of Carbon}}{\text{Molecular Weight of Mixture}} \times \frac{\text{Molecular Weight of Carbon}}{\text{Molecular Weight of Compound}} \times \frac{\text{Number of Carbon Atoms}}{\text{Molecule of Compound}}$$

Simplifying:

$$= \text{Mass of Mixture} \times \frac{\text{Vol. \%} \times \text{Molecular Weight of C} \times \text{No. of C Atoms}}{\text{Molecular Weight of Mixture}} \qquad (7)$$

Obviously, the total carbon mass in the mixture is the sum of the carbon mass from each of the carbon-bearing compounds. Thusly:

$$\text{Mass of C in Mixture} = \left(\frac{\text{Mass of Mix.} \times \text{Vol. \%Comp. 1} \times \text{Mol. Wt. of C} \times \text{No. of C Atoms}}{\text{Molecular Weight of Mixture}}\right)_1 + \left(\frac{\text{Mass of Mix.} \times \text{Vol. \%Comp. 2} \times \text{Mol. Wt. of C} \times \text{No. of C Atoms}}{\text{Molecular Weight of Mixture}}\right)_2 + \ldots + \left(\frac{\text{Mass of Mix.} \times \text{Vol. \%Comp. "n"} \times \text{Mol. Wt. of C} \times \text{No. of C Atoms}}{\text{Molecular Weight of Mixture}}\right)_{\text{"n"}}$$

More concisely expressed:

$$\text{Mass of Carbon in Mixture} = \text{Mass of Mixture} \times \frac{\text{Molecular Weight of Carbon}}{\text{Molecular Weight of Mixture}} \times \sum_i \left(\text{No. of Carbon Atoms in Compound (i)} \times \frac{\text{Vol. \%}}{100} \text{ Compound (i)}\right) \qquad (8)$$

necessary to apply the total carbon method to natural gas fueled combustion processes.

As an example, assume that the natural gas fuel contains CH_4, C_2H_6, C_3H_{16}, H_2, He, CO_2, and N_2. The summation term in equation (10) would be:

$$\sum_i \left(\frac{(\%\text{Compound X No. C Atoms})i}{100}\right) = \frac{1}{100}\left(\begin{array}{l}(1X1\%CH_4)+(2X\%C_2H_6)+(3X\%C_3H_8)+(4X\%C_4H_{10})\\ +5X\%C_5H_{12})+(6X\%C_6H_{14})+(1X\%CO_2)\end{array}\right)$$

The summation should include all carbon compounds in fuel whether part of the combustion process or not. The molecular weight of the natural gas is found by summing the product of the mole fraction of each constituent and its molecular weight, for all the constituent gases in the fuel.

$$\text{Molecular Weight} = \left(\frac{\%CH_4}{100} X\ 16.04303\right) + \left(\frac{\%C_2H_6}{100} X\ 30.07012\right)$$
$$+ \left(\frac{\%C_3H_8}{100} X\ 44.09721\right) + \left(\frac{\%C_4H_{10}}{100} X\ 58.12430\right)$$

C_3H_8

$$+ \left(\frac{\%C_5H_{12}}{100} X\ 72.15139\right) + \left(\frac{\%C_6H_{14}}{100} X\ 86.17848\right)$$
$$+ \left(\frac{\%H_2}{100} X\ 2.01594\right) + \left(\frac{\%He}{100} X\ 4.00260\right)$$
$$+ \left(\frac{\%CO_2}{100} X\ 44.0095\right) + \left(\frac{\%N_2}{100} X\ 28.01340\right).$$

E. Application of the General Equation to Emissions from Gasoline Fueled Combustion Sources

Since gasoline is the result of a refining and blending process, it is a much more consistent product than natural gas and for all practical purposes contains only liquid hudrocarbons.

While an analysis of gasoline fuel is not normally available, the generally accepted hydrogen to carbon ratio for gasoline is 1.85. This gives a mass fraction of carbon in gasoline of .86519.

It should be recognized that the summation term in equation (10) divided by the fuel molecular weight, needs only to be multiplied by the molecular weight of carbon to be an expression for the mass fraction of carbon in the fuel. Therefore, the expression could be thought of as the mass fraction of carbon in fuel divided by the molecular weight of carbon.

Substituting the appropriate numerical values in equation (10) gives the equation for gasoline.

$$\text{Emission (Mass/hr)} = \frac{\text{Vol. \% Emission}}{\text{Vol. \% CO} + \text{Vol. \% } CO_2 + \text{Vol. \% HC}} \times \text{Mass of Fuel}$$

$$\times \text{ Molecular Weight of Emission} \times \frac{.86519}{12.000} \qquad (11)$$

As a further example, the equation for mass emissions of NO_x given in the Federal Register (Vol. 37, No. 175, Friday, Sept. 8, 1972) for heavy duty gasoline engines will be derived.

First, note that the Federal Register defines the term TC:

$$TC = \text{Vol. \% } CO_2 + \text{Vol. \% CO} + (1.8 \times 6 \times \text{\% HC})$$

The constant multipliers 1.8 and 6 come from the fact that the Federal procedure uses NDIR measurement with hydrocarbons expressed as hexane, not a flame ionization technique as assumed in this derivation.

From equation (11):

$$NO_x \text{ (grams/hr)} = \frac{\frac{\text{PPM NO}}{10000}}{TC} \times \text{Fuel (grams/hr)} \times 46.0055 \times .0721$$

$$NO_x \text{ (grams/hr)} = \frac{46.0055 \times .0721}{10000} \text{ NO (PPM)} \times \frac{\text{Fuel (grams/hr)}}{TC}$$

$$NO_x \text{ (grams/hr)} = 3.32 \times 10^{-4} \times \text{NO (PPM)} \times \frac{\text{Fuel (grams/hr)}}{TC}$$

APPENDIX A-7. EQUATIONS USED IN COMPUTER PROGRAM

A. Fuel Gas Calculation

1. The fuel gas molecular weight is calculated from the mole percentages of each constituent in the actual fuel gas. These percentages are obtained from the fuel gas analysis taken during the on-site testing.

$$\text{Fuel molecular wt.} = \sum_n \frac{\text{Mole \% of } n}{100} \times \text{Molecular Wt. of } n \qquad (11)$$

2. The fuel percent carbon, FPCTC, is calculated from the mole percentages of each hydrocarbon component in the fuel gas using the equation:

$$\text{FPCTC} = \frac{\sum_n \left(n \times \text{Mole \% } C_nH_{2n+2}\right)}{100} \qquad (12)$$

3. The hydrogen-to-carbon ratio, CHCR, in the case of natural gas can be represented in two ways. The fuel hydrocarbon hydrogen-to-carbon ratio of the hydrocarbon components only is used in the calculation of the mass exhaust emissions.

$$\text{CHCR} = \frac{\sum_n (2n+2) \times \text{Mole \% } C_nH_{2n+2}}{\sum_n \left(n \times \text{Mole \% } C_nH_{2n+2}\right)}$$

The total fuel hydrogen-to-carbon ratio is a measure of all of the hydrogen to all of the carbon in the fuel. This takes into account the portions of diatomic hydrogen gas and carbon dioxide which are in many fuel gases.

$$\text{Total fuel hydrogen-to-carbon ratio} = \frac{\sum_n \left[(2n+2) \times \text{Mole \% } C_nH_{2n+2}\right] + (2 \times \text{Mole \% } H_2)}{\sum_n \left(n \times \text{Mole \% } C_nH_{2n+2}\right) + \text{Mole \% } CO_2}$$

4. In the event that a lower heating value is not obtained with the fuel gas analysis, this value is calculated using the equation:

Lower Heating Value = Higher Heating Value -

$$\Big[\Big(25.21 \times \text{CHCR} \times \sum_n \left(n \times \text{Mole \% } C_nH_{2n+2}\right)\Big) \times$$

$$\Big(\Big(\sum_n (2n+2) \times \text{Mole \% } C_nH_{2n+2}\Big) + 2 \times \text{Mole \% } H_2\Big) \times$$

$$\Big(100 - \text{Mole \% He} - \text{Mole \% } CO_2 - \text{Mole \% } N_2 - 0.87\Big) \div$$

$$\Big(\Big(\sum_n \text{Mole \% } C_nH_{2n+2}\Big) \times \sum_n \Big((2n+2) \times \text{Mole \% } C_nH_{2n+2}\Big) \times 100\Big)\Big]$$

APPENDIX A-7 (CONT'D). EQUATIONS USED IN COMPUTER PROGRAM

$$\text{Measured \% } O_2 = \frac{E_{NO_x} \times (\text{ppm } NO_2 \times \text{MW of } O_2 + \text{ppm NO} \times \text{AW OF O})}{(\text{ppm } NO_2 + \text{ppm NO}) \times \text{MW of } NO_2} +$$

$$\frac{E_{CO_2} \times \text{MW of } O_2}{\text{MW of } CO_2} + \frac{E_{CO} \times \text{AW of O}}{\text{MW of CO}} + E_{O_2} + \frac{E_{H_2O} \times \text{AW of O}}{\text{MW of } H_2O}$$

This is compared to the oxygen content calculated from the intake air. This calculation assumes a correct value for CO_2 in the fuel and in the exhaust and the calculated value for the absolute humidity. The equation is:

$$\text{Calculated \% } O_2 = \frac{\text{Mass Airflow} \times 7000 \times 0.2318}{\text{AH} \times 7000} +$$

$$\frac{\text{Mass Airflow} \times \text{AH} \times 0.8881}{\text{AH} \times 7000} +$$

$$\frac{\text{Mole \% } CO_2^{(\text{fuel})} \times \text{MW of } O_2 \times W_f}{\text{FMW}}$$

The oxygen balance is the percent difference between the measured and the calculated percent oxygen.

$$\text{Oxygen balance} = \frac{\text{measured \% } O_2 - \text{calculated \% } O_2}{\text{measured \% } O_2} \times 100$$

The computer program then calculates the correct oxygen value assuming that the CO_2, CO, and NO and NO_x concentration have been measured correctly.

$$\text{Correct \% } O_2 = \text{\% } O_2 \times \frac{(100 - 0.678) \times \text{AFR} \times \text{Exhaust Specific gravity} \times 7000}{(100 - \text{\% } H_2O) \times (\text{AFR} + 1) \times (7000 + \text{AH})} -$$

$$\left[\left(1 + \frac{\text{HCRT}}{4}\right) \times \left(\text{Volume \% } E_{CO_2} - \frac{0.033 \times \text{AFR}}{1 + \text{AFR}}\right)\right] -$$

$$\left[\left(0.5 + \frac{\text{HCRT}}{4}\right) \times \text{Volume \% } E_{CO}\right] - \left[\left(1 - 0.5 \times \frac{\text{ppm NO}}{\text{ppm } NO_x}\right) \times\right.$$

$$\left.\text{Volume \% } E_{NO_x}\right] + \frac{\text{Mole \% } CO_2^{(\text{fuel})}}{(1 + \text{AFR}) \times SG^{(\text{fuel})}}$$

The equation is based on a constant oxygen concentration in the intake (assumed) and the measured values for each of the oxygen containing emissions. It is a good cross check for the measured oxygen and carbon dioxide concentrations in the exhaust because these are the two major oxygen containing compounds in the exhaust. The water concentration is also included which is calculated from the measured intake humidity and the calculated exhaust moisture content.

T_{WB} = wet bulb temperature

BP = barometric pressure

The relative humidity, RH, is computed from the partial pressure of the water vapor and the saturation vapor pressure at the dry bulb temperature, P_{DB}, with the equation:

$$RH = \frac{(Pv)\ (100)}{P_{DB}} \qquad (14)$$

The specific or absolute humidity on the dry basis of the intake air is defined as

$$H = \frac{(K)\ (P_V)}{BP - P_V} \qquad (15)$$

Where H = specific or absolute humidity

$$K = \frac{0.6220\ g\ H_2O}{g/\text{dry air}} \times \frac{453.6\ g/lb}{0.0648\ g/gr}$$

The absolute humidity can also be determined from the relative humidity. This equation is a rearrangement of equation (14).

$$P_V = \frac{(RH)\ (P_{DB})}{100}$$

This value for the partial pressure of the water vapor is entered into equation (15) to determine the absolute humidity.

E. Miscellaneous Calculation

1. The exhaust duct or stack area is calculated from the measured dimensions of the duct or stack. The equation for a rectangular exhaust duct is

   Area = length x width

   If the exhaust stack is circular, the area is determined with the equation

   Area = C (diameter)^2

   Where $C = \frac{\pi}{4}$

2. A means of verifying the measured oxygen concentration in the exhaust was incorporated into the computer program. The oxygen content of the exhaust is tied up in the combustion products, i.e. CO_2, CO, NO_x and H_2O as well as the excess oxygen. The total measured oxygen content is

APPENDIX A-7 (CONT'D). EQUATIONS USED IN COMPUTER PROGRAM

4. The mass flow rate of the nitrogen/argon in the exhaust is determined with equation 13 where the molecular weight reflects the proportion of argon in the air (i.e., 28.159).

5. The air mass flow rate is the difference between the exhaust mass flow rate and the fuel mass flow rate in lbs/hr.

$$\text{Mass Airflow (lbs/hr.)} = \text{Exhaust Flow (lbs/hr.)} - W_f$$

6. The air to fuel ratio is then calculated from the mass airflow rate using the equation:

$$AFR = \frac{\text{Mass airflow (lbs/hr.)}}{W_f}$$

7. The absolute humidity is calculated with a series of equations. The vapor pressure at the wet and dry bulbs are calculated from the Wexler and Greenspan equation.

$$P = \exp\left(B \ln T + \sum_{i=1}^{10} F_i \, T^{i-3}\right)$$

Where P = saturation vapor pressure of water at the wet or dry bulb temperature in pascals

$B = -12.150799$

T = wet or dry bulb temperature in °K

$F_1 = -8.49922 \times 10^{3}$

$F_2 = -7.4231865 \times 10^{3}$

$F_3 = 96.1635147$

$F_4 = 2.4917646 \times 10^{-2}$

$F_5 = -1.3160119 \times 10^{-5}$

$F_6 = -1.1460454 \times 10^{-8}$

$F_7 = 2.1701289 \times 10^{-11}$

$F_8 = -3.610258 \times 10^{-15}$

$F_9 = 3.8504519 \times 10^{-18}$

$F_{10} = -1.4317 \times 10^{-21}$

The partial pressure of the water vapor is then determined from "Ferrels equation."

$$P_v = P_{WB} - 0.000660\,(T_{DB} - T_{WB})\,BP\,[1+0.00115\,(T_{WB} - 273.15)]$$

Where P_v = partial pressure of the water vapor in pascals

P_{WB} = saturation vapor pressure of water at the wet bulb temperature

T_{DB} = dry bulb temperature

D. Airflow Calculations

The airflow is not a measured value. It is calculated from the measured composition of the exhaust gas, the calculated water vapor content of the exhaust and the remainder is nitrogen and argon in the same proportion to each other as in air.

1. The determination of percent water in the exhaust is not a measured quantity. It is calculated from the water content of the intake air and the water produced from combustion by a double pass through these equations in the computer program:

$$\%\ H_2O = \frac{100\ DC + H_1\ (100 - H_2)}{100 + DC - H_2}$$

Where:

$\%\ H_2O$ = the percent water in the exhaust

$$DC = \frac{HCRT}{2} \times \left(CO_2 + CO - \frac{0.033\ AFR}{AFR + 1}\right)$$

H_1 = Exhaust water content due to inlet air

$$H_1 = \frac{H \times MWR \times AFR \times 100}{(7000 + AH) \times (1 + AFR)}$$

H_2 = Exhaust water content of sample conditioned at 34°F assuming 100% relative humidity.

= 0.678

HCRT = Total fuel hydrogen to carbon ratio

AFR = Air to fuel ratio

H = Absolute or specific humidity

2. The mole fraction of nitrogen/argon combination is determined using the equation:

$$\text{Mole Percent } (N_2 + Ar) = 100 - 0.678 - \text{Mole \% } H_2O + \text{Mole \% } O_2 + \text{Mole \% } CO_2 + \text{Mole \% CO} + \text{Mole \% HC} + \text{Mole \% } NO_x$$

3. The mass flow rate of water in the exhaust is calculated from equation (13):

$$E_w = \frac{\%H_2O \times MW \text{ of } H_2O \times W_f \times FPCTC \times (100 - 0.678)}{TC \times (100 - \%\ H_2O) \times MW \text{ of fuel}}$$

Where:

E_w = the mass flow rate of water, lbs/hr.

APPENDIX A-7 (CONT'D). EQUATIONS USED IN COMPUTER PROGRAM

3. Brake Specific Emissions

The brake specific or work output emissions can also be calculated from the mass emission rates using the equation:

$$BSE = \frac{E \times 453.6 \text{ g/lbs.}}{HP}$$

Where:

BSE = the brake specific emissions g/HP-HR

4. NO_x Correction for 15% O_2

The volumetric NO_x emissions can also be expressed in terms of 15% O_2 using the equation:

$$CNO_x = \frac{E \times (20.9 - 15)}{20.9 - \text{Volume } \% \ O_2}$$

Where:

CNO_x = the corrected NO_x concentration, ppm by volume

This takes into account the established oxygen content of the air and the measured oxygen content of the exhaust. The value is then corrected to an assumed oxygen level of 15% in the exhaust.

5. The exhaust gas mass flow rate in lbs/hr. is the sum of all of the mass flow rates of the components in the exhaust:

Exhaust Flow = NO_x mass (lbs/hr.) + CO_2 mass (lbs/hr.) +
HC mass (lbs/hr.) + CO mass (lbs/hr.) +
O_2 mass (lbs/hr.) + H_2O mass (lbs/hr.)* +
N_2 + Ar mass (lbs/hr.)*

6. The exhaust specific gravity is obtained from the exhaust gas mass flow rate and the molecular weight of air (28.9644) with the equation:

$$\text{Exhaust specific gravity} = \frac{\text{Exhaust Flow}}{28.9644}$$

7. The exhaust velocity in ft/sec. is determined from the exhaust gas mass flow rate and the measured area of the stack with the equation:

$$\text{Exhaust velocity} = \frac{\text{Exhaust flow (lbs/hr.)}}{\text{AREA} \times \text{VOLUME (corrected)} \times 3600 \text{ sec/hr.}}$$

C. Exhaust Emissions

1. The total carbon method of calculating mass exhaust emission rates is based on the assumption that all of the carbon in the exhaust comes from the fuel. The general equation for mass emissions in terms of lbs/hr is:

$$E = \frac{\text{Volume \% E} \times \text{MW of E} \times W_f \times \text{FPCTC}}{\text{TC} \times \text{MW of fuel}} \quad (13)$$

Where:

E = Mass exhaust emission rate constituent under consideration (i.e. HC, CO, or NO_x)

Volume % E = the measured volumetric concentration of E

MW of E = molecular weight of E
= 46.0055 for NO_x
= $12.01 + 1.008 \frac{CHCR}{FPC}$ for HC
= 28.0106 for CO

FPCTC = Fuel percent carbon (equation 12)

TC = Total exhaust carbon (see below)*

FMW = Fuel molecular weight (equation 11)

The measured volumetric concentration of CO is corrected for the humidity at 34°F from the condenser and for the CO_2 removed with the ascarite in the drying column. The equation is:

$$\text{Volume \% } E_{CO} = \frac{\text{ppm CO}}{1000} \times \frac{100}{100 + 0.678} \times \frac{100 - \text{Volume \% } E_{CO2}}{100}$$

Of all of the components present in the intake air, CO_2 is assumed to be the only compound present in significant quantities to affect the exhaust emissions in the carbon balance calculation. This correction is applied because the ambient species are not monitored. The carbon balance equation for total exhaust carbon is expressed as:

$$\text{*TC} = \text{Volume \% } CO_2 + \text{Volume \% CO} + \text{Volume \% HC} - \frac{0.33 \times 180}{180 + \text{Volume \% } CO_2}$$

2. Fuel Specific Emissions

The mass emission rates are converted to fuel specific or heat input emission rates using the equation:

$FSE = E/H_f$

Where:

FSE = the fuel specific emission, lbs./MIL BTU

APPENDIX A-7 (CONT'D). EQUATIONS USED IN COMPUTER PROGRAM

B. Calculation for Fuel Flow

1. The volumetric fuel flow is either calculated from the orifice data using the equation

$$Q = C' \sqrt{h_w P_b}$$

Where:

Q = Fuel flow, SCFH

C' = Orifice Constant

h_w = Orifice differential pressure

P_b = Static Pressure, psia

or is taken directly from the data when another means of measuring the fuel flow is used.

2. The fuel flow in lbs/hr is calculated from the volumetric fuel flow rate with the equation:

$$W_f = Q \times SG \times D$$

Where:

W_f = Fuel flow, lbs/hr.

SG = Fuel gas specific gravity

D = 0.076487 lbs/ft^3 (density of air at standard conditions)

3. The fuel heat flow in lbs/million BTU is obtained from the volumetric fuel flow rate with the equation:

$$H_f = \frac{Q \times HHV}{10^6}$$

Where:

H_f = Fuel heat flow, MIL BTU/SCF

HHV = Higher heating value, BTU/SCF

4. The brake specific fuel consumption is obtained from the equation:

$$BSFC = \frac{H_f \times 10^6}{HP}$$

Where:

BSFC = the brake specific fuel consumption, BTU/HP-HR

HP = the engine brake horsepower

APPENDIX U

ANNUBAR FLOW CALCULATIONS

ANNUBAR FLOW CALCULATIONS

Supplied by Dietrich Standard

Dieterich Standard ANNUBAR Flow Calculation 10-JAN-94

Reference no: EXH1 Item: 7 P.O.:
Customer: REP Tag:
Fluid: Stack gas Serial no:
Model: DCR-25 HA2 CB2SS Exh. @ 4" Hg Press.
Pipe Size: I.D.= 9.760 Wall= .120 O.D.= 10.000 Inche

D.P. Eq'n 2.4 REV 1.0 Gas -- Volume Rate of Flow @ STD Cond

$$C' = Fna \times K \times D^2 \times Fra \times Ya \times Fpb \times Ftb \times Ftf \times Fg \times Fpv \times Fm \times Faa \times Fl$$

$$hw = \frac{1}{Pf} \times \left(\frac{Qs}{C'}\right)^2 \qquad Qs = C' \times \sqrt{hw \times Pf}$$

Description	Term	Value	Units		
Units Conversion Factor	Fna	5.6362			
ANNUBAR Flow Coefficient	K	.6242			
Internal Pipe Diameter	D	9.76	inches		
Base Pressure Factor	Fpb	1	@	14.73	PSIA
Base Temperature Factor	Ftb	1	@	60	F
Specific Gravity Factor	Fg	1.0011	SG =	.9978	
Manometer Factor	Fm	1			
Gage Location Factor	Fl	1			

		MAX	NORM	MIN	
Flowrate	Qs	3100	1856	680	SCFM
Calculation Constant	C'	226.033	226.532	226.781	
Pipe Reynolds Number	RD	0	0	0	
Reynolds Number Factor	Fra	1	1	1	
Gas Expansion Factor	Ya	.9965	.9987	.9998	
Flowing Viscosity	uf		0		Centipoise
Flowing Temperature	Tf		700		F
Flowing Temp Factor	Ftf		.6694		
Supercmprss. Factor	Fpv		1		
Thermal Expansion Factor	Faa		1.01		
Flowing Pressure	Pf		14.559		PSIA
Differential Pressure	hw	12.9	4.61	.618	in H2O

* - Indicates Manual Override

LIMITS

Customer Design P & T:	10	in Hg @60F	&	900	F
Max Allowable DP:	194	in H2O	@	900	F
Flow at Max Allowable DP:	11400	SCFM			
Natural Frequency:	397	CPS			
Max Allowable Pressure:	810	PSIG	@	850	F
and Temperature:	850	F			

CAUTION Model Temp limit exceeded
CAUTION Mounting Hardware required
CAUTION CMH or LMH Req'd, Std=1.313"

Dieterich Standard ANNUBAR Flow Calculation 10-JAN-94

Reference no: EGR1 Item: 8 P.O.:
Customer: REP Tag:
Fluid: Stack gas Serial no:
Model: DCR-15 HA1 CB1 MP2
Pipe Size: 4"SCH 40

EGR @ 4" Hg

D.P. Eq'n 2.4 REV 1.0 Gas -- Volume Rate of Flow @ STD Cond

$$C' = Fna \times K \times D^2 \times Fra \times Ya \times Fpb \times Ftb \times Ftf \times Fg \times Fpv \times Fm \times Faa \times Fl$$

$$hw = \frac{1}{Pf} \times \left(\frac{Qs}{C'}\right)^2 \qquad Qs = C' \times \sqrt{hw \times Pf}$$

Description	Term	Value	Units		
Units Conversion Factor	Fna	5.6362			
ANNUBAR Flow Coefficient	K	.6235			
Internal Pipe Diameter	D	4.026	inches		
Base Pressure Factor	Fpb	1	@	14.73	PSIA
Base Temperature Factor	Ftb	1	@	60	F
Specific Gravity Factor	Fg	1	SG =	1.0000	
Manometer Factor	Fn	1			
Gage Location Factor	Fl	1			

		MAX	NORM	MIN	
Flowrate	Qs	600	150	0	SCFM
Calculation Constant	C'	47.1112	47.2435	0	
Pipe Reynolds Number	RD	0	0	0	
Reynolds Number Factor	Fra	1	1	1	
Gas Expansion Factor	Ya	.997	.9998	.9967	
Flowing Viscosity	uf		0		Centipoise
Flowing Temperature	Tf		300		F
Flowing Temp Factor	Ftf		.8271		
Supercmprss. Factor	Fpv		1		
Thermal Expansion Factor	Faa		1.003		
Flowing Pressure	Pf		14.559		PSIA
Differential Pressure	hw	11.1	.692	0	in H2O

* - Indicates Manual Override

LIMITS

Customer Design P & T:	4	in Hg @60F	&	700	F
Max Allowable DP:	160	in H2O	@	700	F
Flow at Max Allowable DP:	2180	SCFM			
Natural Frequency:	633	CPS			
Max Allowable Pressure:	865	PSIG	@	700	F
and Temperature:	775	F			

Dieterich Standard ANNUBAR Flow Calculation   10-JAN-94

Reference no: AIR2   Item: 2   P.O.:
Customer: REP   Tag:
Fluid: Air   Serial no:
Model: DCR-25   HA2   CA2   MP4
Pipe Size: 8"SCH 40

Air @ 70°F

D.P. Eq'n 2.4 REV 1.0 Gas -- Volume Rate of Flow @ STD Cond

$$C' = Fna \times K \times D^2 \times Fra \times Ya \times Fpb \times Ftb \times Ftf \times Fg \times Fpv \times Fm \times Faa \times Fl$$

$$hw = \frac{1}{Pf} \times \left(\frac{Qs}{C'}\right)^2 \qquad Qs = C' \times \sqrt{hw \times Pf}$$

Description	Term	Value	Units		
Units Conversion Factor	Fna	5.6362			
ANNUBAR Flow Coefficient	K	.6173			
Internal Pipe Diameter	D	7.981	inches		
Base Pressure Factor	Fpb	1	@	14.73	PSIA
Base Temperature Factor	Ftb	1	@	60	F
Specific Gravity Factor	Fg	1	SG =	1.0000	
Manometer Factor	Fn	1			
Gage Location Factor	Fl	1			

		MAX	NORM	MIN	
Flowrate	Qs	3000	1775	680	SCFM
Calculation Constant	C'	219.223	219.399	219.487	
Pipe Reynolds Number	RD	0	0	0	
Reynolds Number Factor	Fra	1	1	1	
Gas Expansion Factor	Ya	.9987	.9995	.9999	
Flowing Viscosity	uf		0		Centipoise
Flowing Temperature	Tf		70		F
Flowing Temp Factor	Ftf		.9905		
Supercmprss. Factor	Fpv		1		
Thermal Expansion Factor	Faa		1		
Flowing Pressure	Pf		22.395		PSIA
Differential Pressure	hw	8.36	2.92	.429	in H2O

* - Indicates Manual Override

LIMITS

Customer Design P & T:	20	in Hg @60F	&	70	F
Max Allowable DP:	327	in H2O	@	70	F
Flow at Max Allowable DP:	17800	SCFM			
Natural Frequency:	508	CPS			
Max Allowable Pressure:	1440	PSIG	@	70	F
and Temperature:	600	F			

Dieterich Standard ANNUBAR Flow Calculation 10-JAN-94

Reference no: AIR1 Item: 1 P.O.:
Customer: REP Tag:
Fluid: Air Serial no:
Model: DCR-25 HA2 CA2 MP4
Pipe Size: 8"SCH 40

Air @ 110°F

D.P. Eq'n 2.4 REV 1.0 Gas -- Volume Rate of Flow @ STD Cond

$$C' = Fna \times K \times D^2 \times Fra \times Ya \times Fpb \times Ftb \times Ftf \times Fg \times Fpv \times Fm \times Faa \times Fl$$

$$hw = \frac{1}{Pf} \times \left(\frac{Qs}{C'}\right)^2 \qquad Qs = C' \times \sqrt{hw \times Pf}$$

Description	Term	Value	Units		
Units Conversion Factor	Fna	5.6362			
ANNUBAR Flow Coefficient	K	.6173			
Internal Pipe Diameter	D	7.981	inches		
Base Pressure Factor	Fpb	1	@	14.73	PSIA
Base Temperature Factor	Ftb	1	@	60	F
Specific Gravity Factor	Fg	1	SG =	1.0000	.98
Manometer Factor	Fn	1			
Gage Location Factor	Fl	1			

		MAX	NORM	MIN	
Flowrate	Qs	3000	1775	680	SCFM
Calculation Constant	C'	211.346	211.558	211.642	
Pipe Reynolds Number	RD	0	0	0	
Reynolds Number Factor	Fra	1	1	1	
Gas Expansion Factor	Ya	.9985	.9995	.9999	
Flowing Viscosity	uf		0		Centipoise
Flowing Temperature	Tf		110		F
Flowing Temp Factor	Ftf		.9551 ✓		
Supercmprss. Factor	Fpv		1		
Thermal Expansion Factor	Faa		1		
Flowing Pressure	Pf		22.395 ✓		PSIA
Differential Pressure	hw	9	3.14 ✓	.461	in H2O

* - Indicates Manual Override

LIMITS

Customer Design P & T:	20	in Hg @60F	&	110	F
Max Allowable DP:	327	in H2O	@	110	F
Flow at Max Allowable DP:	17200	SCFM			
Natural Frequency:	508	CPS			
Max Allowable Pressure:	1420	PSIG	@	110	F
and Temperature:	600	F			

Dieterich Standard ANNUBAR Flow Calculation 10-JAN-94

Reference no: AIR3 Item: 3 P.O.:
Customer: REP Tag:
Fluid: Air Serial no:
Model: DCR-25 HA2 CA2 MP4
Pipe Size: 8"SCH 40

Air @ 150 °F

D.P. Eq'n 2.4 REV 1.0 Gas -- Volume Rate of Flow @ STD Cond

$$C' = Fna \times K \times D^2 \times Fra \times Ya \times Fpb \times Ftb \times Ftf \times Fg \times Fpv \times Fm \times Faa \times Fl$$

$$hw = \frac{1}{Pf} \times \left(\frac{Qs}{C'}\right)^2 \qquad Qs = C' \times \sqrt{hw \times Pf}$$

Description	Term	Value	Units		
Units Conversion Factor	Fna	5.6362			
ANNUBAR Flow Coefficient	K	.6173			
Internal Pipe Diameter	D	7.981	inches		
Base Pressure Factor	Fpb	1	@	14.73	PSIA
Base Temperature Factor	Ftb	1	@	60	F
Specific Gravity Factor	Fg	1	SG =	1.0000	
Manometer Factor	Fn	1			
Gage Location Factor	Fl	1			

		MAX	NORM	MIN	
Flowrate	Qs	3000	1775	680	SCFM
Calculation Constant	C'	204.471	204.696	204.778	
Pipe Reynolds Number	RD	0	0	0	
Reynolds Number Factor	Fra	1	1	1	
Gas Expansion Factor	Ya	.9984	.9995	.9999	
Flowing Viscosity	uf		0		Centipoise
Flowing Temperature	Tf		150		F
Flowing Temp Factor	Ftf		.9232		
Supercmprss. Factor	Fpv		1		
Thermal Expansion Factor	Faa		1.001		
Flowing Pressure	Pf		22.395		PSIA
Differential Pressure	hw	9.61	3.36	.492	in H20

* - Indicates Manual Override

LIMITS

Customer Design P & T:	20	in Hg @60F	&	150	F
Max Allowable DP:	327	in H20	@	150	F
Flow at Max Allowable DP:	16600	SCFM			
Natural Frequency:	508	CPS			
Max Allowable Pressure:	1340	PSIG	@	150	F
and Temperature:	600	F			

Dieterich Standard ANNUBAR Flow Calculation 10-JAN-94

Reference no: AIR6 Item: 6 P.O.:
Customer: REP Tag:
Fluid: Air Serial no:
Model: DCR-25 HA2 CA2 MP4 Air in 11" Pipe
Pipe Size: I.D.= 13.720 Wall= .140 O.D.= 14.000 Inche

D.P. Eq'n 2.4 REV 1.0 Gas -- Volume Rate of Flow @ STD Cond

$$C' = Fna \times K \times D^2 \times Fra \times Ya \times Fpb \times Ftb \times Ftf \times Fg \times Fpv \times Fm \times Faa \times Fl$$

$$hw = \frac{1}{Pf} \times \left(\frac{Qs}{C'}\right)^2 \qquad Qs = C' \times \sqrt{hw \times Pf}$$

Description	Term	Value	Units		
Units Conversion Factor	Fna	5.6362			
ANNUBAR Flow Coefficient	K	.6328			
Internal Pipe Diameter	D	13.72	inches		
Base Pressure Factor	Fpb	1	@	14.73	PSIA
Base Temperature Factor	Ftb	1	@	60	F
Specific Gravity Factor	Fg	1	SG =	1.0000	
Manometer Factor	Fn	1			
Gage Location Factor	Fl	1			

		MAX	NORM	MIN	
Flowrate	Qs	3000	1775	680	SCFM
Calculation Constant	C'	641.096	641.16	641.224	
Pipe Reynolds Number	RD	0	0	0	
Reynolds Number Factor	Fra	1	1	1	
Gas Expansion Factor	Ya	.9998	.9999	1	
Flowing Viscosity	uf		0		Centipoise
Flowing Temperature	Tf		110		F
Flowing Temp Factor	Ftf		.9551		
Supercmprss. Factor	Fpv		1		
Thermal Expansion Factor	Faa		1		
Flowing Pressure	Pf		22.395		PSIA
Differential Pressure	hw	.978	.342	.0502	in H2O

* - Indicates Manual Override

LIMITS

Customer Design P & T:	40	in Hg @60F	&	110	F
Max Allowable DP:	125	in H2O	@	110	F
Flow at Max Allowable DP:	33100	SCFM			
Natural Frequency:	230	CPS			
Max Allowable Pressure:	1420	PSIG	@	110	F
and Temperature:	600	F			

CAUTION Low DP warning @ Min. flow

Dieterich Standard ANNUBAR Flow Calculation 10-JAN-94

Reference no: AIR4 Item: 4 P.O.:
Customer: REP Tag:
Fluid: Air Serial no:
Model: DCR-25 HA2 CA2 MP4
Pipe Size: 8"SCH 40

Air @ 4" Hg Press

D.P. Eq'n 2.4 REV 1.0 Gas -- Volume Rate of Flow @ STD Cond

$$C' = Fna \times K \times D^2 \times Fra \times Ya \times Fpb \times Ftb \times Ftf \times Fg \times Fpv \times Fm \times Faa \times Fl$$

$$hw = \frac{1}{Pf} \times \left(\frac{Qs}{C'}\right)^2 \qquad Qs = C' \times \sqrt{hw \times Pf}$$

Description	Term	Value	Units		
Units Conversion Factor	Fna	5.6362			
ANNUBAR Flow Coefficient	K	.6173			
Internal Pipe Diameter	D	7.981	inches		
Base Pressure Factor	Fpb	1	@	14.73	PSIA
Base Temperature Factor	Ftb	1	@	60	F
Specific Gravity Factor	Fg	1	SG =	1.0000	
Manometer Factor	Fn	1			
Gage Location Factor	Fl	1			

		MAX	NORM	MIN	
Flowrate	Qs	3000	1775	680	SCFM
Calculation Constant	C'	210.944	211.41	211.621	
Pipe Reynolds Number	RD	0	0	0	
Reynolds Number Factor	Fra	1	1	1	
Gas Expansion Factor	Ya	.9966	.9988	.9998	
Flowing Viscosity	uf		0		Centipoise
Flowing Temperature	Tf		110		F
Flowing Temp Factor	Ftf		.9551		
Supercmprss. Factor	Fpv		1		
Thermal Expansion Factor	Faa		1		
Flowing Pressure	Pf		14.559		PSIA
Differential Pressure	hw	13.9	4.84	.709	in H2O

* - Indicates Manual Override

LIMITS

Customer Design P & T:	20	in Hg @60F	&	110	F
Max Allowable DP:	327	in H20	@	110	F
Flow at Max Allowable DP:	13400	SCFM			
Natural Frequency:	508	CPS			
Max Allowable Pressure:	1420	PSIG	@	110	F
and Temperature:	600	F			

111

Dieterich Standard ANNUBAR Flow Calculation 10-JAN-94

Reference no: AIR5 Item: 5 P.O.:
Customer: REP Tag:
Fluid: Air Serial no:
Model: DCR-25 HA2 CA2 MP4
Pipe Size: 8"SCH 40

Air @ 40" Hg Press.

D.P. Eq'n 2.4 REV 1.0 Gas -- Volume Rate of Flow @ STD Cond

$$C' = Fna \times K \times D^2 \times Fra \times Ya \times Fpb \times Ftb \times Ftf \times Fg \times Fpv \times Fm \times Faa \times Fl$$

$$hw = \frac{1}{Pf} \times \left(\frac{Qs}{C'} \right)^2 \qquad Qs = C' \times \sqrt{hw \times Pf}$$

Description	Term	Value	Units		
Units Conversion Factor	Fna	5.6362			
ANNUBAR Flow Coefficient	K	.6173			
Internal Pipe Diameter	D	7.981	inches		
Base Pressure Factor	Fpb	1	@	14.73	PSIA
Base Temperature Factor	Ftb	1	@	60	F
Specific Gravity Factor	Fg	1	SG =	1.0000	
Manometer Factor	Fn	1			
Gage Location Factor	Fl	1			

		MAX	NORM	MIN	
Flowrate	Qs	3000	1775	680	SCFM
Calculation Constant	C'	211.515	211.621	211.664	
Pipe Reynolds Number	RD	0	0	0	
Reynolds Number Factor	Fra	1	1	1	
Gas Expansion Factor	Ya	.9993	.9998	1	
Flowing Viscosity	uf		0		Centipoise
Flowing Temperature	Tf		110		F
Flowing Temp Factor	Ftf		.9551		
Supercmprss. Factor	Fpv		1		
Thermal Expansion Factor	Faa		1		
Flowing Pressure	Pf		32.191		PSIA
Differential Pressure	hw	6.25	2.19	.321	in H20

* - Indicates Manual Override

LIMITS

Customer Design P & T:	40	in Hg @60F	&	110	F
Max Allowable DP:	327	in H20	@	110	F
Flow at Max Allowable DP:	20900	SCFM			
Natural Frequency:	508	CPS			
Max Allowable Pressure:	1420	PSIG	@	110	F
and Temperature:	600	F			

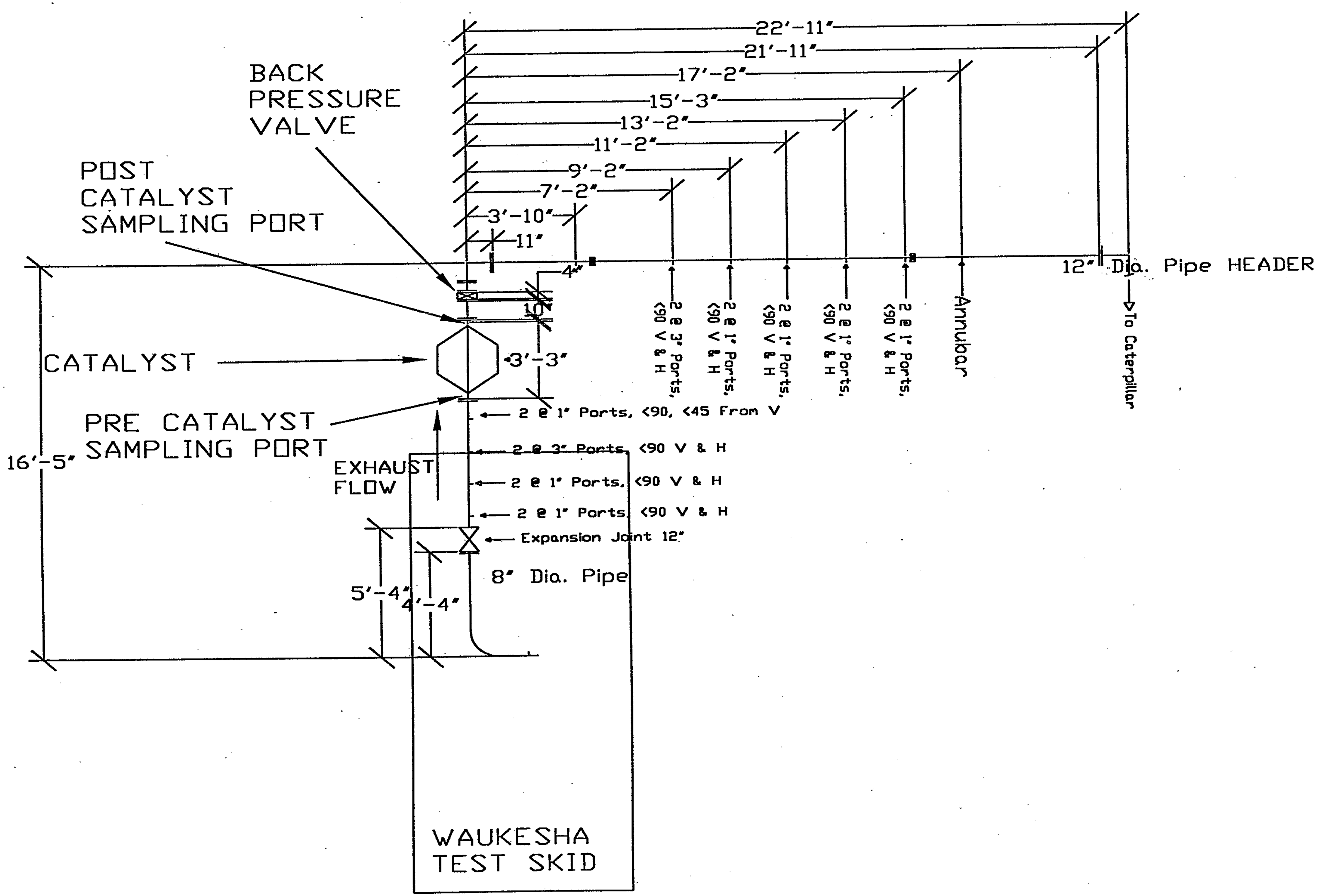
APPENDIX V

ADDITIONAL CALCULATIONS

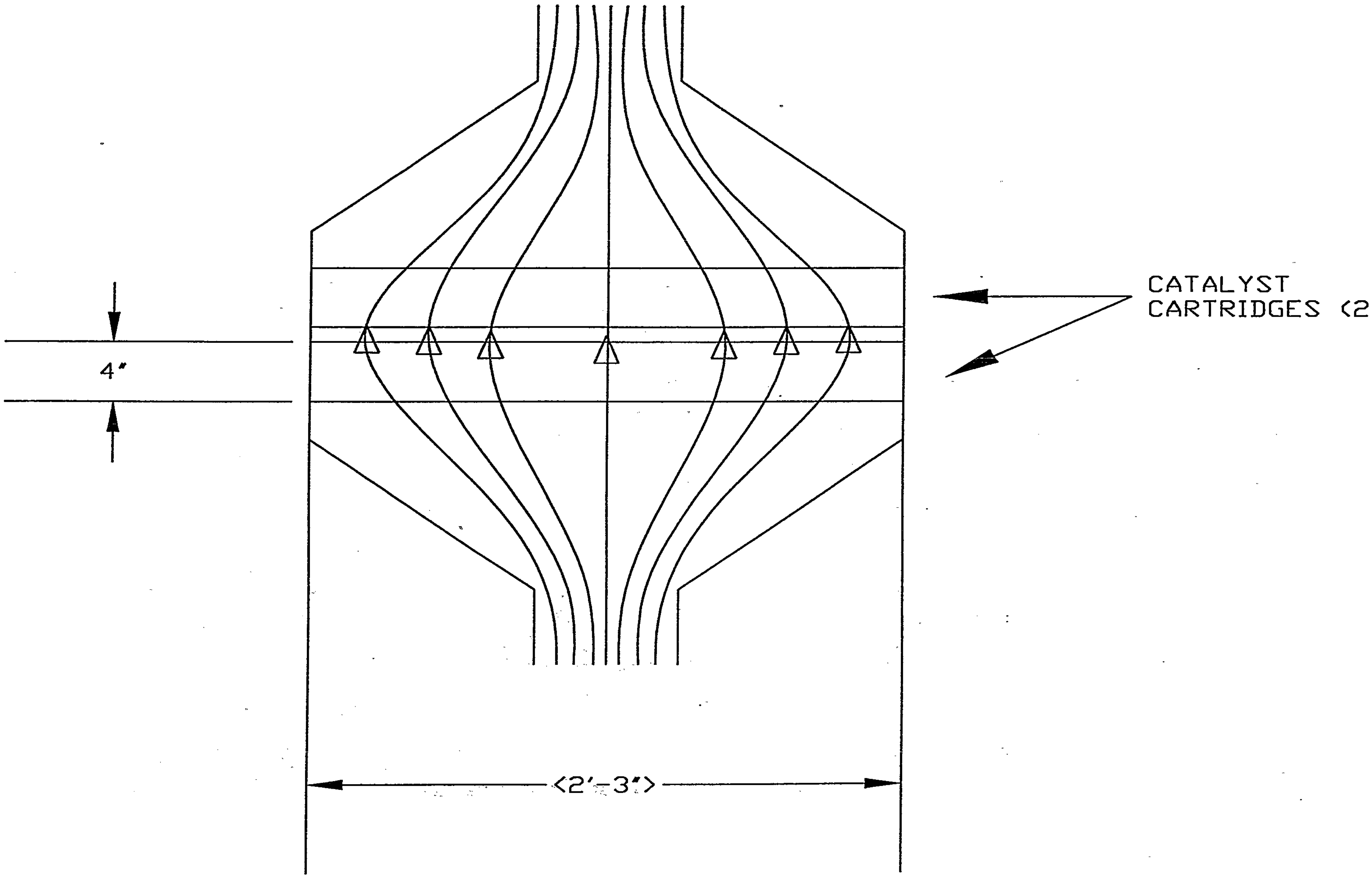
APPENDIX W

EXHAUST PIPING SCHEMATIC

WAUKESHA EXHAUST SYSTEM



CATALYST EXHAUST FLOW
(WAUKESHA)



APPENDIX B

EXAMPLE CALCULATIONS
RELATED CORRESPONDENCE

Example Calculations for Pollutant Mass Flow Rates
Waukesha 3521GL Engine
(shown using data from Run 1)

***NOTE: Calculated results may not agree exactly with spreadsheet results due to rounding.

Part I – Determination of Volumetric Flow.

Volumetric flow rate was calculated by multiplying the heat applied to the engine by an oxygen-based combustion products (F_d) factor:

<u>Heat Applied to engine:</u>

Heat Rate (MMBtu/hr) = [Fuel Flow Rate (scfh) * Higher Heating Value (Btu/cf)] / 10^6 Btu/MMBtu

Heat Rate (MMBtu/hr) = [5418 scfh * 1135.1 Btu/cf] / 10^6

Heat Rate = 6.15 MMBtu/hr

<u>Volumetric Flow Rate</u>

Volumetric Flow Rate (dscfm) = F_d (dscf/MMBtu) * Heat Rate (MMBtu/hr) * [20.9/(20.9-O_2)] / 60 min/hr

Volumetric Flow Rate (dscfm) = 8654 dscf/MMBtu * 6.15 MMBtu/hr * [20.9/(20.9-9.8)] / 60 min/hr

Volumetric Flow Rate (dscfm) = 1670 dcsfm

Part II – Determination of Pollutant Mass Flow.

The concentration of the target pollutant was converted to units of lb/cf, and multiplied by the calculated volumetric flow rate to obtain a mass flow rate. The example shows the calculation of mass flow rate of carbon monoxide (CO) at the pre-catalyst location.

<u>Mass Flow Rate – lb/hr</u>

E_{CO} (lb/hr) = C_{CO} (ppmvd) * (MW_{CO} / 385.3 x 10^6)* Volumetric Flow Rate (dscfm) * 60 min/hr

E_{CO} (lb/hr) = 620 ppmvd * (28 / 385.3 x 10^6) * 1670 dscfm * 60 min/hr

E_{CO} = 4.51 lb/hr

<u>Mass Flow Rate – g/bhp-hr</u>

E_{CO} (g/bhp-hr) = E_{CO} (lb/hr) * 453.6 (g/lb) / Engine Load (bhp)

E_{CO} (g/bhp-hr) = 4.51 lb/hr * 453.6 g/lb / 737.29 bhp

E_{CO} = 2.77 g/bhp-hr

Part III – Determination of Catalyst Removal Efficiency.

Catalyst removal efficiency was determined by subtracting the mass flow rate at the outlet from the mass flow rate at the inlet, then dividing by the mass flow rate at the inlet.

<u>Catalyst Destruction Efficiency</u>

%DE = [E_{CO} Inlet (g/bhp-hr) – E_{CO} Outlet (g/bhp-hr)] / E_{CO} Inlet (g/bhp-hr) * 100

%DE = (4.51 g/bhp-hr – 0.301 g/bhp-hr) / 4.51 g/bhp-hr * 100

DE = 93.3%

ENGINES & ENERGY CONVERSION Laboratory

Colorado State University

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Fax: (970) 493-6403
E-mail: bryan@engr.colostate.edu

Energy Lab Memo

To: Mr. Terry Harrison, U.S. Environmental Protection Agency
Mr. Michael Maret, Pacific Environmental Services, Inc.

From: Dr. Bryan Willson
Research Director, Engines & Energy Conversion Laboratory

Date: July 13, 2001

Subject: Modifications to Report on 4-Stroke Lean Burn Engine (Waukesha)

The following modifications / errata apply to the "Four-Stroke, Lean-Burn, Natural Gas Fired Internal Combustion Engine" report (i.e. the "Waukesha Report") submitted to PES in April, 2000.

2 *"Waukesha stated that certain values in Table 2.2 of the draft report appeared to be incorrect, specifically the value for oxygen at the catalyst inlet for Run Nos. 3 and 13."*

This was discussed in Section 3.4 of the CSU report. As noted in Section 3.4, the pre-catalyst oxygen data for Run #3 is incorrect. The paramagnetic oxygen analyzer failed during the test. As noted in Section 3.4, the air/fuel ratio is 28:1 for the oxygen value of 9.81% measured at the catalyst outlet.

The pre-catalyst oxygen value of 10.44% measured during Run No. 13 is higher than the 9.81% value measured at the catalyst outlet. The pre-catalyst value is suspect, but as the analyzer passed a QC check, a pre-test calibration check, and and a post-test calibration check, CSU has no justification to "invalidate" the oxygen reading.

15 *"This comment states that the air/fuel ratios shown in the baseline run on August 5 are in error, and that the correct air/fuel ratio should be closer to 28.6."*

Due to a failure with the oxygen analyzer, the air/fuel ratio is incorrect. Using an air/fuel ratio of 9.9%, the value at the catalyst outlet, the air/fuel ratio is calculated at 28.6.

18 *"This comment notes that the units of barometric pressure reported in the CSU reports are in inches of mercury, but the values appear to be in psia."*

The comment is correct. The units of barometric pressure should be modified to read "psia"

19 *"Waukesha noted that the tabulated "Air Manifold" temperatures are always about 99.5 °F, and noted that this does not make sense."*

The "Air Manifold" temperature is actually the temperature of the air in the air supply manifold to the engine, and not on the engine itself. The air supply temperature is maintained at this value by a closed-loop control system.

20 *"Waukesha noted that the values for the "Average Cylinder Exhaust Temperature" are always in the low to mid 700 °F range, and that this value is too low."*

A thermocouple was added at an intermediate point in the exhaust between the pre-catalyst

Annubar™ flow meter and the catalyst. The parameter was mis-labeled on the engine test run summary.

21 *"Waukesha commented that a value for "In-cylinder Temperature" was also given and that this value was typically 25 – 35 °F."*

This measurement is made during testing of other types of engines at the EECL. It was not used during testing of the Waukesha. Its inclusion on the datasheet was in error.

22 *"This comment notes that the removal efficiencies for formaldehyde were presented in decimal format instead of percent format."*

The comment is correct. The efficiency values are listed in decimal format, and not in percent format as indicated in Appendix A.

24 *"Waukesha noted that the inlet air humidity in CSU's Table 3 is incorrect."*

The comment is correct. The inlet air humidity baseline should written as ".015 lb H_2O/lb Air", not the ".0015 lb H_2O/lb Air" listed in Table 3.

DRESSER Waukesha
WAUKESHA ENGINE DIVISION
DRESSER EQUIPMENT GROUP, INC.
A Halliburton Company
1000 West St. Paul Avenue • Waukesha, Wisconsin 53188-4999 • 414-547-3311

September 1, 2000

Mr. Terry Harrison
United States Environmental Protection Agency
Emission Measurement Center
MD 19
Research Triangle Park, NC 27711

Reference: Draft Final Report; Waukesha F3521GL Engine Test

Dear Mr. Harrison,

Thank you for sending me a copy of the draft final report on the HAPs testing of a 4-stroke, lean burn, gas-fired, reciprocating internal combustion engine (the Waukesha F3521GL) at Colorado State University (CSU) to review. I have been able to review the main Pacific Environmental Services (PES) text and the text and Appendices A and B of the CSU report (part of Appendix A of the PES document). I will provide most of my comments in this letter. However, as you suggested, I am also attaching copies of pages from the report with notations made in the margins. In no specific order I offer the following comments and suggestions for your consideration:

- To answer your first question, the engine appears to be operating normally during all of the 16 data runs. To further verify engine operation I compared the performance summary in Table 2.2 with our published performance at two load points, data runs #1 and #3. Our published data are reference Waukesha document S-06124-62.

  Run #1: 1200 rpm, rated 738 bhp

	Table 2.2	S-06124-62
Fuel consumption	7468 Btu/bhp-hr	7377 Btu/bhp-hr
Exhaust temperature	735° F	703° F
Exhaust gas flow	1660 dscfm	1616 dscfm

  Run #3: 1000 rpm, 432 bhp

	Table 2.2	S-06124-62
Fuel consumption	7718 Btu/bhp-hr	7528 Btu/bhp-hr
Exhaust temperature	677° F	666° F
Exhaust gas flow	914 dscfm	966 dscfm

  These values agree within a normally expected tolerance.

- Having said that, there are certain values in Table 2.2 (and, of course, the CSU Appendix A values from which they were obtained) that appear to be incorrect. These incorrect values can result in subsequent erroneous calculated values. Specifically, the catalyst inlet oxygen values appear to be in error – too high – for runs #3 and #13. In both cases the value should be closely 9.8%. Run #3 in the CSU Appendix A data actually indicates 100.0% oxygen. This was, apparently, interpreted by PES as being 10.0%. The catalyst outlet oxygen values are correct. You can confirm these errors by comparing the catalyst inlet and outlet values. The normal difference is measured in hundredths of a percentage point. In addition, the oxygen value for these runs was to have been set to 9.8%, the standard value. In run #13 this oxygen error is seen to noticeably affect the calculated catalyst inlet gas flow value. The 1703 dscfm value is too high.

- In general, the criteria emittant (NOx, CO, and THC) values agree with Waukesha experience. However, the NOx values are a bit lower and the total hydrocarbon values a bit higher than expected. This would be consistent with the engine running slightly leaner than our standard setting.

- The non-methane hydrocarbon values are about twice Waukesha's normal value. This is directly due to the fuel gas composition at CSU having about twice the ethane and heavier components than our normal, Midwestern natural gas.

- The formaldehyde levels presented in the report are higher than those measured at Waukesha on a similar engine.

- It should be noted in the report – and considered by the EPA during the HAPs MACT rulemaking – that NOx universally **increased** across the oxidizing catalyst. Reference Table 2.3 values. The average increase was just over 8%. I assume that the NOx values given for both the catalyst inlet and outlet are on the same basis, i.e., as NO_2 per EPA convention. This characteristic will result in increased difficulty for lean burn engine sources fitted with an oxidizing catalyst to comply with existing NOx standards, some of which are now at very stringent levels.

- I understand that the methane / non-methane values and the total hydrocarbons values were measured with different instrumentation (reference Table 5.1 and Figure 5.1). There is a noticeable discrepancy between the two measurements. Table 2.3 shows both methane and non-methane hydrocarbons decreasing across the catalyst (with one exception that likely represents erroneous values). The total hydrocarbon values, however, increase across the catalyst for 12 of the 16 runs. Of the other four runs, one showed no change and the remaining three showed very minimal decrease. There may be little change in methane across the catalyst due to methane's high "light off" temperature, but, in our experience, non-methanes and, therefore, total hydrocarbons should decrease across an oxidizing catalyst.

- The non-methane hydrocarbon value at the catalyst outlet in run #8 appears to be in error in Table 2.3. It shows a very unusual large increase over the inlet value. See also Table 2.4.

- The total hydrocarbon instrumentation is not described in the text in section 5.

- Why are the NOx and methane (catalyst inlet) and NOx (catalyst outlet) values given to only one place after the decimal (tenths) for runs 10 – 16 in Table 2.3? The reduced precision of these values versus the other nine runs makes accurate comparisons difficult.

- Comparing runs #1, #2, and #5 with runs #4, #3, and #8, respectively, (speed reduction at constant loading) I note that the brake specific NOx decreased with the decrease in speed. Waukesha's experience indicates the opposite response. Typically – with all other factors constant – reducing speed leads to an increase in brake specific NOx rate.

- Runs #15 and #16 do not appear to give any significant information. Here, engine unbalance / misadjustment was simulated by retarding / advancing the spark timing of one cylinder relative to the remaining five. At most, these changes would be expected to yield 17% (1/6) of the changes seen in runs #13 and #14 where the timing of all six cylinders was changed. The results seem to indicate that the changes in engine performance were masked, i.e., were less than normal run-to-run variation.

- Table 2.3 in the report gives different emission rate values across the board for all specie – criteria and HAPs – than those in the Colorado State tabulation in CSU Appendix A. I assume that the g/bhp-hr and lb/hr values were recalculated from the raw data by PES using a different methodology resulting in the different values. However, since this apparent discrepancy can result in confusion to anyone reading the report, this situation should be specifically addressed and explained in the report.

Comments specifically regarding the CSU data presented in CSU Appendix A:

- In general, all of the CSU air / fuel ratio values in CSU Appendix A seem a bit high – typically running above 28.5:1. With the fuel used at CSU and the standard 9.8% oxygen nominal carburetor setting I would expect values about 1 AFR lower, i.e., about 27.5:1 nominal.

- The air / fuel ratio values given in the August 5 baseline in CSU Appendix B are in error. Instead of the indicated 32.70 figure, the "correct" value should be closer to the 28.6 figure shown in the August 6 baseline.

- CSU Appendix B does not include the 1000 rpm baseline run that was also taken on August 6.

- As noted earlier, CSU Appendix A, run #3 shows pre-catalyst oxygen as 100% and A/F ratio (wet) as 31.5. Both are obviously wrong. The oxygen level should be about 9.8% and the A/F ratio about 28.8:1. The 100% oxygen level appears to have resulted in all the F-factor Emissions Calculations (down to acetaldehyde) being listed as negative and significantly reduced in absolute value.

- The barometric pressure values in CSU Appendix A are listed as inches of mercury while the numerical values appear to be psia. If not noticed and corrected, this could affect calculated values.

- The tabulated "Air Manifold" temperatures are always about 99.5° F. This does not make sense unless the air manifold referred to is not the air manifold on the engine but, rather, a duct bringing air to the turbocharger. The engine mounted air manifold (intake manifold) temperature should be about that of the intercooler air out.

- The "Average Cylinder Exhaust Temperature" is always in the low to mid 700° F range. This is too low. It should have about the same value as the average given in the exhaust temperature block of data, i.e., in the mid 900° F range typically. The lower temperature is more compatible with an exhaust stack temperature post-turbocharger. An "Exhaust Header Temperature" in the mid-700° F range is also listed. This temperature must also be at a location downstream of the turbocharger.

- An "In-Cylinder Temperature" (just above the F-Factor Emissions values) is also given. This value is typically 25° - 35° F and is nowhere near an engine in-cylinder temperature.

- The CSU tabulated catalyst conversion efficiencies for formaldehyde are given in a decimal format, not the percent value as indicated.

- As previously mentioned, the 10.44% value for pre-catalyst oxygen given for run #13 is incorrect. It should be about 9.8%. The air/fuel ratio listed is compatible with a 9.8% oxygen level.

Text and typographical comments:

- The inlet air humidity level in CSU Table 3 is incorrect. It should be .015 lb H_2O / lb air.

- PES report, page 3-1, §3.1, first paragraph. "Air is delivered to the engine via a supercharged air delivery system…". This is confusing since the F3521GL engine is, itself, turbocharged but superchargers are used on smaller engines. If this sentence is referring to a *facility* air delivery system I suggest use of an alternative word, e.g., "pressurized", to eliminate confusion. If this sentence does, in fact, refer to the engine's air delivery system the text should be corrected to read "… turbocharged air delivery system …".

- PES report, page 3-1, §3.1, second paragraph. "During the expansion stroke ...". This is incorrect and should read "During the intake stroke ...". In the context of a 4-stroke cycle engine, the expansion stroke is identical to – and is an alternative term for – the power stroke.

- PES report, page 3-4, §3.2, first paragraph (and other places). The correct units of torque are pound-feet or lb-ft (force x distance). This is entirely analogous to the SI system of units where torque is specified in Newton-meters or N-m.

- PES report, page 3-4, §3.2, first paragraph. "... engine timing (the location of the cylinder, relative to top dead center, at the time of peak pressure in the combustion chamber, measured in degrees) ...". This is incorrect in several respects. It should properly read "... engine timing (the location of the piston, relative to its top dead center, at the time the spark plug fires in the pre-combustion chamber, measured in degrees) ...".

Waukesha appreciates the opportunity to review and comment on this draft report before it is finalized. If you have any question, or if I can clarify any of my comments, please do not hesitate to contact me at 262.549.2753 or by e-mail at bob_stachowicz@wed.dresser.com.

Sincerely,

WAUKESHA ENGINE DIVISION
A HALLIBURTON COMPANY

R.W. Stachowicz

Robert Stachowicz, PE
Senior Development Engineer

Enclosures: annotated pages from draft report

CC (letter only): Mr. Sims Roy – USEPA
Mr. J.M. Derra – WED
Mr. R.A. Schleifer – WED
Mr. M.W. McCormick – WED

Lb-FT

TABLE 2.2

SUMMARY OF EXHAUST GAS FLOW RATES

ok based on CSU BSFC values

Run ID	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8
Engine Speed, rpm	1197	1197	1002	1002	1197	1197	1197	1001
Engine Torque, ft-lb	3236	2263	2264	3234	3235	3234	2263	3234
Horsepower, bhp	737	516	432	617	737	737	516	617
Fuel Flow Rate, scfh	5378	4083	3205	4368	5523	5337	4040	4424
Equivalence Ratio, ϕ	0.56	0.56	0.55	0.56	0.52	0.59	0.59	0.53
Lower Heating Value, Btu/cf	1024	1040	1040	1040	1040	1040	1040	1040
Heat Rate, MMBtu/hr	5.51	4.24	3.33	4.54	5.74	5.55	4.20	4.60
Dry Fuel Factor, F_d dscf/MMBtu	9607	9088	8657	9088	8657	8657	9088	9088
Catalyst Inlet Not Right - should be ~9.8%								
Gas Temperature, °F	735	706	677	685	711	759	728	663
Oxygen, % d.b.	9.8	9.82	10	9.8	10.51	9.1	9.2	10.5
Carbon Dioxide, % d.b.	6.29	6.23	6.37	6.24	5.86	6.65	6.65	5.86
Moisture, %	12.25	11.73	12.53	12.02	11.56	12.71	12.35	11.55
Gas Flow Rate, dscfm	1660	1213	922	1295	1666	1418	1136	1400
Catalyst Outlet								
Gas Temperature, °F	740	710	679	688	718	760	731	669
Oxygen, % d.b.	9.8	9.83	9.81	9.8	10.44	9.01	9.09	10.5
Carbon Dioxide, % d.b.	6.46	6.42	6.4	6.41	5.96	6.83	6.79	5.99
Moisture, %	12.42	11.92	12.25	12.19	11.60	12.86	12.46	11.66
Gas Flow Rate, dscfm	1660	1214	906	1295	1655	1407	1126	1400

rpm - revolutions per minute
ft-lb - foot-pounds
bhp - brake horsepower
scfh - standard cubic feet per hour @ 68°F and 29.92 in. Hg
ϕ - reciprocal of % Excess Air
Btu/cf - British Thermal Units per cubic foot of natural gas

MMBtu/hr - million British Thermal units per hour
dscf/MMBtu - dry standard cubic feet of exhaust products per million Btu of heat input @ 0% excess air
°F - degrees Fahrenheit
% vol d.b. - % volume dry basis
dscfm - dry standard cubic feet per minute @ 68 °F and 29.92 in. Hg

TABLE 2.2 (CONCLUDED)

SUMMARY OF EXHAUST GAS FLOW RATES

Run ID	Run 9	Run 10	Run 11	Run 12	Run 13	Run 14	Run 15	Run 16
Engine Speed, rpm	1197	1197	1197	1197	1197	1197	1197	1197
Engine Torque, ft-lb Lb-FT	3234	3237	3238	3236	3236	3235	3236	3235
Horsepower, bhp	737	738	738	738	737	737	737	737
Fuel Flow Rate, scfh	5389	5341	5353	5411	5683	5272	5452	5372
Equivalence Ratio, ϕ	0.56	0.56	0.56	0.55	0.53	0.56	0.55	0.56
Lower Heating Value, Btu/cf	1024	1040	1040	1040	1040	1024	1040	1040
Heat Rate, MMBtu/hr	5.52	5.55	5.56	5.63	5.91	5.40	5.67	5.58
Dry Fuel Factor, F_d dscf/MMBtu	9607	9088	9088	9088	8657	9607	8657	8657
Catalyst Inlet					also should be 9.8%			
Gas Temperature, °F	735	737	731	738	767	722	738	730
Oxygen, % d.b.	9.69	9.8	9.81	9.9	10.44	9.81	9.9	9.82
Carbon Dioxide, % d.b.	6.35	6.35	6.29	6.29	6.27	6.24	6.22	6.23
Moisture, %	12.31	12.12	12.19	12.00	12.08	12.11	12.08	12.10
Gas Flow Rate, dscfm	1647	1583	1588	1619	1703	1629	1554	1520
Catalyst Outlet					This value too high			
Gas Temperature, °F	740	741	736	740	771	718	742	733
Oxygen, % d.b.	9.7	9.73	9.79	9.85	9.81	9.89	9.82	9.8
Carbon Dioxide, % d.b.	6.51	6.5	6.47	6.41	6.38	6.41	6.35	6.36
Moisture, %	12.46	12.25	12.36	12.08	12.16	12.26	12.17	12.21
Gas Flow Rate, dscfm	1649	1574	1586	1611	1606	1641	1542	1517

rpm - revolutions per minute
ft-lb - foot-pounds
bhp - brake horsepower
scfh - standard cubic feet per hour @ 68°F and 29.92 in. Hg
ϕ - reciprocal of % Excess Air
Btu/cf - British Thermal Units per cubic foot of natural gas

MMBtu/hr - million British Thermal units per hour
dscf/MMBtu - dry standard cubic feet of exhaust products per million Btu of heat input @ 0% excess air
°F - degrees Fahrenheit
% vol d.b. - % volume dry basis
dscfm - dry standard cubic feet per minute @ 68 °F and 29.92 in. Hg

TABLE 2.3

EMISSION RATES OF DETECTED FTIR AND CEM COMPOUNDS

Run ID		Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8
Catalyst Inlet									
Formaldehyde	mg/bhp-hr	306	343	298	280	353	276	351	316
	mlb/hr	498	390	284	380	574	449	399	429
Acetaldehyde	mg/bhp-hr	ND	ND	ND	ND	ND	ND	ND	ND
	mlb/hr	ND	ND	ND	ND	ND	ND	ND	ND
Acrolein	mg/bhp-hr	3.88	ND	ND	0.388	ND	0.148	ND	ND
	mlb/hr	6.31	ND	ND	0.527	ND	0.241	ND	ND
Nitrogen Oxides (as NO_2)	g/bhp-hr	0.82	0.58	0.51	0.74	0.53	1.28	1.05	0.45
	lb/hr	1.33	0.66	0.48	1.00	0.86	2.09	1.19	0.61
Carbon Monoxide	g/bhp-hr	2.76	2.75	2.42	2.45	3.31	2.55	2.79	2.88
	lb/hr	4.49	3.12	2.30	3.34	5.38	4.14	3.17	3.91
Methane	g/bhp-hr	3.67	4.40	4.58	4.04	4.77	2.76	3.58	5.13
	lb/hr	5.97	5.00	4.36	5.49	7.76	4.49	4.07	6.97
Non-methane Hydrocarbons	g/bhp-hr	1.18	1.33	1.39	0.97	1.47	0.80	1.14	1.36
	lb/hr	1.92	1.51	1.33	1.32	2.39	1.30	1.29	1.85
Total Hydrocarbons	g/bhp-hr	4.54	5.66	5.85	5.14	6.28	3.49	4.53	6.45
	lb/hr	7.38	6.43	5.57	6.99	10.20	5.67	5.16	8.77
Catalyst Outlet									
Formaldehyde	mg/bhp-hr	98	85	56	81	119	65	69	109
	mlb/hr	159	97	53	110	193	106	78	148
Acetaldehyde	mg/bhp-hr	ND	ND	ND	ND	ND	ND	ND	ND
	mlb/hr	ND	ND	ND	ND	ND	ND	ND	ND
Acrolein	mg/bhp-hr	ND	ND	ND	ND	ND	ND	ND	ND
	mlb/hr	ND	ND	ND	ND	ND	ND	ND	ND
Nitrogen Oxides (as NO_2)	g/bhp-hr	0.871	0.631	0.557	0.772	0.570	1.33	1.09	0.485
	lb/hr	1.42	0.717	0.530	1.05	0.927	2.16	1.24	0.659
Carbon Monoxide	g/bhp-hr	0.184	0.125	0.091	0.125	0.238	0.149	0.114	0.161
	lb/hr	0.299	0.142	0.087	0.171	0.387	0.243	0.129	0.219
Methane	g/bhp-hr	3.20	4.00	3.76	3.67	4.26	2.43	3.17	3.42
	lb/hr	5.20	4.55	3.58	4.99	6.92	3.96	3.60	4.65
Non-methane Hydrocarbons	g/bhp-hr	0.94	1.09	1.09	0.84	1.22	0.62	0.85	2.26
	lb/hr	1.53	1.24	1.04	1.14	1.99	1.01	0.97	3.08
Total Hydrocarbons	g/bhp-hr	4.76	5.78	5.83	5.14	6.29	3.44	4.55	6.68
	lb/hr	7.74	6.57	5.55	6.99	10.22	5.59	5.17	9.08

unlikely increase

g/bhp-hr - grams per brake horsepower hour
lb/hr - pounds per hour
mg/bhp-hr - milligrams per brake horsepower hour
mlb/bhp-hr - millipounds per brake horsepower hour
ND - Not Detected. Refer to Table 6.1 for run-by-run summary of detection limits.

THC INCREASE
12 OF 16 RUNS

TABLE 2.3 (CONCLUDED)

EMISSION RATES OF DETECTED FTIR AND CEM COMPOUNDS

Run ID		Run 9	Run 10	Run 11	Run 12	Run 13	Run 14	Run 15	Run 16
Catalyst Inlet									
Formaldehyde	mg/bhp-hr	305	295	291	303	319	299	292	286
	mlb/hr	495	479	474	493	519	486	475	465
Acetaldehyde	mg/bhp-hr	ND	ND	ND	ND	ND	ND	ND	ND
	mlb/hr	ND	ND	ND	ND	ND	ND	ND	ND
Acrolein	mg/bhp-hr	4.82	ND	0.71	ND	ND	4.36	ND	ND
	mlb/hr	7.82	ND	1.15	ND	ND	7.09	ND	ND
Nitrogen Oxides (as NO_2)	g/bhp-hr	0.78	0.9	0.8	0.8	0.5	1.3	0.6	0.7
	lb/hr	1.27	1.5	1.2	1.3	0.8	2.0	1.0	1.2
Carbon Monoxide	g/bhp-hr	2.74	2.66	2.64	2.66	2.83	2.87	2.61	2.56
	lb/hr	4.45	4.32	4.30	4.32	4.60	4.66	4.24	4.16
Methane	g/bhp-hr	3.71	3.0	3.3	3.4	4.1	3.5	3.6	3.5
	lb/hr	6.03	4.9	5.3	5.6	6.7	5.8	5.9	5.6
Non-methane Hydrocarbons	g/bhp-hr	1.17	0.95	1.07	0.98	1.36	1.04	1.19	1.09
	lb/hr	1.89	1.55	1.74	1.60	2.22	1.69	1.94	1.78
Total Hydrocarbons	g/bhp-hr	4.59	4.16	4.48	4.36	4.97	4.43	4.41	4.33
	lb/hr	7.45	6.76	7.28	7.08	8.08	7.20	7.17	7.04
Catalyst Outlet									
Formaldehyde	mg/bhp-hr	95	92.8	93.5	93.0	81.8	100.3	88.0	86.9
	mlb/hr	154	151	152	151	133	163	143	141
Acetaldehyde	mg/bhp-hr	ND	ND	ND	ND	ND	ND	ND	ND
	mlb/hr	ND	ND	ND	ND	ND	ND	ND	ND
Acrolein	mg/bhp-hr	ND	ND	ND	ND	ND	ND	ND	ND
	mlb/hr	ND	ND	ND	ND	ND	ND	ND	ND
Nitrogen Oxides (as NO_2)	g/bhp-hr	0.857	1.0	0.8	0.8	0.5	1.3	0.7	0.8
	lb/hr	1.392	1.5	1.3	1.4	0.8	2.2	1.1	1.3
Carbon Monoxide	g/bhp-hr	0.180	0.177	0.177	0.178	0.192	0.186	0.176	0.171
	lb/hr	0.292	0.288	0.288	0.289	0.312	0.303	0.287	0.278
Methane	g/bhp-hr	3.28	2.96	3.15	3.23	3.50	3.12	3.21	3.09
	lb/hr	5.33	4.82	5.13	5.25	5.69	5.07	5.22	5.02
Non-methane Hydrocarbons	g/bhp-hr	0.92	0.84	0.99	0.83	0.84	0.86	0.85	0.86
	lb/hr	1.49	1.37	1.61	1.35	1.37	1.39	1.38	1.40
Total Hydrocarbons	g/bhp-hr	4.73	4.33	4.60	4.66	4.93	4.57	4.65	4.44
	lb/hr	7.68	7.05	7.48	7.58	8.02	7.43	7.55	7.22

g/bhp-hr - grams per brake horsepower hour
lb/hr - pounds per hour
mg/bhp-hr - milligrams per brake horsepower hour
mlb/bhp-hr - millipounds per brake horsepower hour
ND - Not Detected. Refer to Table 6.1 for run-by-run summary of detection limits.

THC increase across catalyst.

why are runs 10-16 only 1 decimal point? Makes comparisons difficult!

Note - in several cases lb/hr shows an increase while g/bhp-hr does not.

TABLE 2.4

CATALYST HAP REMOVAL EFFICIENCIES

Run ID	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8
Formaldehyde	68%	75%	81%	71%	66%	76%	80%	65%
Carbon Monoxide	93%	95%	96%	95%	93%	94%	96%	94%
Methane	13%	9%	18%	9%	11%	12%	12%	33%
Non-methane Hydrocarbons	20%	18%	21%	13%	17%	23%	25%	~~66%~~

Erroneous — see page 2-6.

Run ID	Run 9	Run 10	Run 11	Run 12	Run 13	Run 14	Run 15	Run 16	Average
Formaldehyde	69%	68%	68%	69%	74%	66%	70%	70%	71%
Carbon Monoxide	93%	93%	93%	93%	93%	94%	93%	93%	94%
Methane	12%	2%	4%	6%	14%	12%	11%	11%	12%
Non-methane Hydrocarbons	21%	12%	8%	16%	38%	18%	29%	21%	14%

3.0 SOURCE DESCRIPTION AND OPERATION

This section presents discussions of the candidate engine and the catalyst used for the test program. The sections that follow describe the engine and the operation of the engine during testing.

turbocharged ??

3.1 ENGINE DESCRIPTION

The Waukesha 3521GL is a 4-stroke stationary internal combustion engine. The engine has six inline cylinders; the total piston displacement is 3520 cubic inches. Each cylinder is 9.375 inches in diameter, and has an 8.5-inch stroke. The compression ratio is 10.5:1. Air is delivered to the engine via a supercharged air delivery system; air manifold pressures are controlled by the EECL process control system. Engine loading is controlled by a computer-controlled water brake dynamometer. Before the test program EECL installed an oxidation catalyst, manufactured by MiraTech Corporation, on the engine. EECL aged the catalyst under its normal operating condition (i.e., burned in the catalyst) before the test program. This procedure ensured that the catalyst's HAP destruction efficiency approximated the HAP destruction efficiency of mature catalysts installed on 4-stroke engines in industry. Table 3.1 presents specifications of the engine and the catalyst. Table 3.2 presents nominal engine operating parameters.

intake

The 4-stroke cycle requires two revolutions of the engine crankshaft for each power stroke. During the expansion stroke, the piston moves down the cylinder and an air/fuel mixture is injected into the piston chamber. On the compression stroke, the piston moves back up the chamber, and the mixture is compressed and ignited. The expanding gas generated upon combustion forces the piston back down the chamber. This stroke is the power stroke. The last stroke of the 4-stroke cycle is the exhaust stroke. The piston travels back up the chamber and the combustion products are vented through the exhaust manifold.

The 3521GL engine was outfitted with lean-burn technology, which controls NO_X emissions. The lean-burn system uses pre-combustion chambers to ignite a lean air/fuel mixture in the main combustion chambers. A rich mixture of air and fuel is drawn into the pre-combustion chamber and is ignited by a spark plug. The resulting flame is then directed into the main combustion chamber, which contains a lean mixture of air and fuel. The flame jet from the pre-combustion chamber ignites the air/fuel mixture in the main chamber.

3.2 ENGINE OPERATION DURING TESTING

As stated in Section 2 of this document, three types of test runs were conducted during the test program: quality assurance runs, sampling runs for FTIRS and CEMS, and baseline runs. The operation of the engine during these various runs is discussed in the following pages and tables. The four-stroke engine test matrix described in the QAPP was based upon estimated operating parameters for a candidate engine to be installed and operated at the EECL. When the engine was received and first operated by EECL the actual operating parameters differed from the estimates. Table 3.3 presents the test matrix for the Waukesha engine based upon the actual engine parameters. During the test program, the six engine operating parameters expected to have the greatest impact on pollutant formation were varied from their baseline values. These parameters were: engine speed (measured in revolutions per minute or rpm), engine torque -FT (~~measured~~ in foot-pounds or ft-lb), air-to-fuel ratio (calculated as an equivalence factor), engine timing (the location of the cylinder relative to top dead center, at the time of ~~peak pressure~~ Spark in the PRE-combustion ~~chamber~~, measured in degrees), air manifold temperature (measured in degrees Fahrenheit), and jacket water outlet temperature (measured in degrees Fahrenheit).

Table 3.4 presents engine parameters recorded during each test run and their percent deviation from the target values. Sixteen sampling runs were conducted on the engine during the two-day period. Except for air/fuel ratios, the actual parameters agreed with the target parameters to within 5%. Although the calculated air/fuel ratios were not within 5% of the target air/fuel ratios, testing was conducted while operating at rich air/fuel ratios (Runs 5 and 8) and at lean air/fuel ratios (Runs 6 & 7). The air/fuel ratio was varied to simulate the range of air/fuel ratios that typcial in field applications.

Before starting Run 7, the humidity control system failed. The humidity system could not be repaired quickly so the run was conducted without inlet air humidity control. Run 2 was also conducted without inlet air humidity control. The set point for the humidity ratio for all test points was 0.015 lb. water / lb. air. The actual humidity ratios for Runs 2 and 7 were 0.0126 and 0.0127 lb. water / lb. air respectively. The engine emissions for Runs 2 and 7 should be similar to engine emissions at the specified humidity ratio. The most dramatic effect will be on NO_x emissions as can be seen from the data and the graphs presented in Appendix S of the CSU test report. At a constant humidity ratio, it would be expected that formaldehyde emissions would either remain constant or increase slightly with similar changes in CO and THC emissions.

TABLE 3

WAUKESHA 3521GL BASELINE CONDITIONS

Engine Operating Parameters	Nominal Value	Acceptable Range	Designation
Engine Torque	3383 ft-lb. to 3230 ft-lb.	± 2% of value	Primary
Engine Speed	1000 RPM	± 5% of value	Primary
Jacket Water Temperature Outlet	180°F	± 5% of value	Primary
Engine Oil Temperature Header	180°F	± 5% of value	Primary
Air Manifold Temperature	85°F to 130°F	± 5% of value	Primary
Air Manifold Pressure	30.0" Hg above Atm.	± 5% of value	Primary
Exhaust Manifold Pressure	5.0" Hg below AMP	± 5% of value	Primary
Ignition Timing	10°BTDC	± 5% of value	Primary
Overall Air:Fuel Ratio	28:1	± 5% of value	Primary
Inlet Air Humidity-Absolute	.0015 lb H_2O/lb Air	± 10% of value	Primary
Engine Fuel Flow SCFH	4460 to 4360 SCFH	± 5% of value	Primary
Engine Oil Pressure Inlet	45 lb.	± 10% of value	Secondary
Inlet Air Flow	1400-1500 SCFM	± 5% of value	Secondary
Average Engine Exhaust Temperature	660° F	± 5% of value	Secondary

should be .015 Lb/Lb

Colorado State University
August 4-6, 1999
EPA RICE Testing
Waukesha
Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Waukesha ENGINE OPERATING PARAMETERS	Run 1	Run 2	Run 3	Run 4
Ignition Type	PCC	PCC	PCC	PCC
Fuel Measurements				
Static Fuel (psia)	46.5	46.6	46.9	46.6
Fuel Differential (in. H_2O)	14.4	8.4	5.1	9.6
Orifice Temperature (°F)	85.6	87.9	84.7	86.1
Fuel Flow (scfh)	5378	4083	3205	4368
Fuel Consumption (BSFC)	7468	8230	7718	7365
Lower Heating Value-Dry (Btu)	1024	1040	1040	1040
Fuel Tube I.D. (in.)	3.068	3.068	3.068	3.068
Fuel Orifice O.D. (in.)	0.5	0.5	0.5	0.5
Annubar Flow Rates				
Inlet Air Flow (scfm)	1713.6	1291.8	1020.5	1377.1
Exhaust Flow (scfm)	2028.9	1557.8	1205.1	1673.1
Ambient Conditions				
Barometric Pressure (in. Hg) psia?	12.08	12.07	12.07	12.07
Dry Bulb Temperature (°F)	64.0	65.0	69.0	62.1
Relative Humidity (%)	80.0	74.6	63.9	78.0
Absolute Humidity (lb/lb)	0.012	0.012	0.012	0.011
Absolute Humidity (gr/lb)	86.668	83.651	82.295	78.961
Air Manifold Conditions				
Boost Pressure (in. Hg)	5.02	5.00	5.00	5.00
Dry Bulb Temperature (°F)	99.5	99.9	99.7	99.3
Relative Humidity (%)	37.8	30.4	37.3	36.1
Relative Humidity (%) - Corrected*	51.2	41.7	50.9	48.7
Absolute Humidity (lb/lb)	0.016	0.013	0.015	0.015
Absolute Humidity (gr/lb)	108.712	88.188	108.105	103.280

These values appear to be psia not in. Hg.

*Air manifold relative humidity corrected to the reference ambient conditions of 90°F, 14.696 psi.

Cylinder Exhaust Temperatures (Degrees °F)				
Cylinder 1	976.9	960.5	884.2	908.3
Cylinder 2	977.8	953.2	880.5	910.3
Cylinder 3	980.4	954.7	877.5	913.0
Cylinder 4	954.3	931.2	861.6	893.0
Cylinder 5	945.3	913.2	850.8	886.8
Cylinder 6	929.7	914.2	843.4	873.4
Engine Average	960.73	937.84	843.41	873.35

? is this the engine air (intake) manifold or a facility air duct?

Colorado State University

August 4-6, 1999

EPA RICE Testing

Waukesha

Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Lb-FT

INCORRECT, SEE OXYGEN Reading.

Waukesha				
ENGINE OPERATING PARAMETERS	Run 1	Run 2	Run 3	Run 4
Ignition Type	PCC	PCC	PCC	PCC
Dynamometer Torque (ft-lb)	3236	2263	2264	3234
Brake Horsepower (bhp)	737	516	432	617
BSFC (btu/bhp-hr)	7468	8230	7718	7365
Engine Speed (rpm)	1197	1197	1002	1002
Timing (Degrees BTDC)	10.00	10.00	10.00	10.00
A/F (Wet)	28.7	28.8	31.5	28.9
Pressures				
Air Manifold (in. Hg)	5.02	5.00	5.00	5.00
Fuel Manifold (psig)	4.12	6.60	6.88	6.21
Fuel Supply (psig)	46.73	47.17	47.45	47.16
Intercooler Air Differential (in. H_2O)	9.26	5.85	4.79	6.59
Post Intercooler Air Manifold (in. Hg)	69.21	66.06	54.27	66.48
Intercooler Water Differential (in. H_2O)	157.45	157.45	157.45	157.45
Intercooler Supply (psi)	3.12	2.72	2.83	2.72
Pre-Turbo Exhaust (in. Hg)	36.51	28.80	21.26	30.55
Post- Turbo Exhaust (in. Hg)	4.82	4.99	4.98	5.16
Turbo Oil (in. Hg)	46.91	47.35	45.32	44.90
Catalyst Differential (in. H_2O)	9.1	5.6	3.9	6.0
Temperatures (°F) and Flows (GPM)				
Air Manifold Temperature	99.5	99.9	99.7	99.3
Fuel Manifold Temperature	85.6	87.9	84.7	86.1
Average Cylinder Exhaust Temperature	707.3	759.4	770.7	760.1
Exhaust Stack Temperature	704.5	676.4	640.4	656.9
Exhaust Header Temperature	704.5	676.4	640.4	656.9
Jacket Water Inlet Temperature	173.1	175.3	176.4	175.4
Jacket Water Outlet Temperature	179.4	179.0	178.8	179.5
Lube Oil Inlet Temperature	81.1	81.5	82.7	76.9
Lube Oil Outlet Temperature	86.7	86.6	86.9	81.6
Lube Oil Flow	129.2	129.2	129.3	128.3
Engine Oil In Temperature	164.6	163.3	162.8	162.4
Engine Oil Out Temperature	185.7	183.2	180.0	181.1
Intercooler Air In Temperature	296.9	280.9	232.3	282.3
Intercooler Air Out Temperature	142.2	137.1	135.2	138.5
Intercooler Water In Temperature	131.6	127.6	130.3	128.5
Intercooler Water Out Temperature	142.9	137.1	135.7	138.7
Intercooler Water Flow	62.6	55.5	58.5	55.5
Pre-Turbo ExhaustTemperature	961.0	926.7	860.6	905.0
Post-Turbo Exhaust Temperature	797.9	750.4	725.6	725.8
Pre-Catalyst Temperature	734.5	705.5	677.0	685.2
Post-Catalyst Temperature	739.56	709.99	679.03	688.42

(ARE THESE THE SAME LOCATION?

IS THIS before OR AFTER TURBOCHARGER? "CYLINDER" TEMPERATURE IMPLIES BEFORE. IF SO THE VALUE SHOULD BE ABOUT THE SAME AS "ENGINE AVERAGE" TEMPERATURE ON PREVIOUS PAGE.

Colorado State University
August 4-6, 1999
EPA RICE Testing
Waukesha
Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Waukesha				
MEASURED EMISSIONS	Run 1	Run 2	Run 3	Run 4
Ignition Type	PCC	PCC	PCC	PCC
Air Manifold Pressure ("Hg)	5.02	5.00	5.00	5.00
Brake Horsepower (bhp)	737	516	432	617
Emissions Measured (Dry)				
NO_x (ppm): Pre-Catalyst	112.26	76.27	72.83	107.78
NO_x (ppm): Post-Catalyst	119.34	82.48	81.66	113.18
CO (ppm): Pre-Catalyst	620.26	590.96	573.32	590.78
CO (ppm): Post-Catalyst	41.32	26.75	21.89	30.19
THC (ppm): Pre-Catalyst	1785.06	2129.30	2424.42	2166.33
THC (ppm): Post-Catalyst	1869.94	2172.32	2458.76	2165.00
O_2 %: Pre-Catalyst	9.80	9.82	100.00 should be about 9.8%	9.80
O_2 %: Post-Catalyst	9.80	9.83	9.81	9.80
CO_2 %: Pre-Catalyst	6.29	6.23	6.37	6.24
CO_2 %: Post-Catalyst	6.46	6.42	6.40	6.41
Emissions Measured (Wet)				
Methane (ppm): Pre-Catalyst	1266.40	1462.36	1661.04	1498.39
Methane (ppm): Post-Catalyst	1100.08	1326.13	1391.50	1358.65
Non-Methane (ppm): Pre-Catalyst	148.47	160.09	183.77	130.64
Non-Methane (ppm): Post-Catalyst	117.90	131.14	147.28	113.19
Carbon Balance Calculations				
Exhaust H_2O% (Pre-Catalyst)	12.25	11.73	12.53	12.02
Exhaust H_2O% (Post-Catalyst)	12.42	11.92	12.25	12.19
O_2 %	10.11	10.20	12.47	10.22
O_2 Balance	-1.44	-1.84	77.06	-1.91
Exhaust Flow (lb/hr)	8326.6	6419.1	5480.8	6875.9
Air Flow (lb/hr)	8046.5	6203.9	5311.9	6645.7
In Cylinder Temperature ? what is this?	26.9	19.1	~~23.7~~	31.6
Air/Fuel Ratio	28.7	28.8	31.5	28.9
F-Factor Emissions Calculations				
NO_x (g/bhp-hr): Pre-Catalyst	0.911	0.615	-0.077	0.777
NO_x (lb/hr): Pre-Catalyst	1.480	0.700	-0.073	1.056
NO_x (g/bhp-hr): Post-Catalyst	0.968	0.665	-0.087	0.815
NO_x (lb/hr): Post-Catalyst	1.573	0.757	-0.082	1.109
THC (g/bhp-hr): Pre-Catalyst	5.128	6.083	-0.910	5.528
THC (lb/hr): Pre-Catalyst	8.334	6.916	-0.866	7.514
THC (g/bhp-hr): Post-Catalyst	5.371	6.206	-0.923	5.524
THC (lb/hr): Post-Catalyst	8.731	7.056	-0.878	7.510
CO (g/bhp-hr): Pre-Catalyst	3.111	2.947	-0.376	2.632
CO (lb/hr): Pre-Catalyst	5.056	3.351	-0.357	3.578
CO (g/bhp-hr): Post-Catalyst	0.207	0.133	-0.014	0.134
CO (lb/hr): Post-Catalyst	0.337	0.152	-0.014	0.183
Methane (g/bhp-hr): Pre-Catalyst	4.192	4.782	-0.717	4.396
Methane (lb/hr): Pre-Catalyst	6.814	5.437	-0.682	5.976
Methane (g/bhp-hr): Post-Catalyst	3.642	4.336	-0.601	3.986
Methane (lb/hr): Post-Catalyst	5.919	4.931	-0.572	5.418
Non-Methane (g/bhp-hr): Pre-Catalyst	1.351	1.439	-0.218	1.053
Non-Methane (lb/hr): Pre-Catalyst	2.196	1.636	-0.208	1.432
Non-Methane (g/bhp-hr): Post-Catalyst	1.073	1.179	-0.175	0.913
Non-Methane (lb/hr): Post-Catalyst	1.744	1.340	-0.166	1.241
Formaldehyde (g/bhp-hr): Pre-Catalyst	0.349	0.372	-0.047	0.303
Formaldehyde (lb/hr): Pre-Catalyst	0.567	0.423	-0.044	0.412
Formaldehyde (g/bhp-hr): Post-Catalyst	0.111	0.094	-0.009	0.089
Formaldehyde (lb/hr): Post-Catalyst	0.181	0.107	-0.008	0.121
Acetaldehyde (g/bhp-hr): Pre-Catalyst	-0.031	-0.037	0.007	-0.031
Acetaldehyde (lb/hr): Pre-Catalyst	-0.051	-0.042	0.006	-0.043
Acetaldehyde (g/bhp-hr): Post-Catalyst	0.000	0.000	0.000	0.000
Acetaldehyde (lb/hr): Post-Catalyst	0.000	0.000	0.000	0.000
Acrolein (g/bhp-hr): Pre-Catalyst	0.004	-0.003	0.001	0.000
Acrolein (g/bhp-hr): Pre-Catalyst	0.007	-0.003	0.000	0.001
Acrolein (g/bhp-hr): Post-Catalyst	0.000	0.000	0.000	0.000
Acrolein (lb/hr): Post-Catalyst	0.0	0.0	0.0	0.0

Colorado State University
August 4-6, 1999
EPA RICE Testing
Waukesha
Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Waukesha				
MEASURED EMISSIONS	Run 1	Run 2	Run 3	Run 4
Ignition Type	PCC	PCC	PCC	PCC
Air Manifold Pressure ("Hg)	5.02	5.00	5.00	5.00
Brake Horsepower (bhp)	737	516	432	617
FTIR Measured Emissions (ppm, Wet)				
Water-H_2O	132315	126394	130933	130209
Carbon Monoxide-CO (ppm): Pre-Catalyst	532.071	512.242	496.451	511.649
Carbon Monoxide-CO (ppm): Post-Catalyst	24.137	11.351	6.267	14.166
Carbon Dioxide-CO_2 (ppm): Pre-Catalyst	56847	55598	56370	55618
Carbon Dioxide-CO_2 (ppm): Post-Catalyst	54430	54281	53813	53975
Nitric Oxide-NO (ppm): Pre-Catalyst	34.762	15.089	16.156	37.505
Nitric Oxide-NO (ppm): Post-Catalyst	90.771	60.962	60.266	85.112
Nitrogen Dioxide-NO_2 (ppm): Pre-Catalyst	52.508	43.941	41.465	47.879
Nitrogen Dioxide-NO_2 (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Nitrous Oxide-N_2O (ppm): Pre-Catalyst	0.491	0.492	0.458	0.483
Nitrous Oxide-N_2O (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Ammonia-NH_3 (ppm): Pre-Catalyst	0.000	0.000	0.000	0.000
Ammonia-NH_3 (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Oxides of Nitrogen-NO_X (ppm): Pre-Catalyst	87.271	59.029	57.621	85.385
Oxides of Nitrogen-NO_X (ppm): Post-Catalyst	90.771	60.962	58.790	85.112
Methane-CH_4 (ppm): Pre-Catalyst	1390.505	1694.023	1883.877	1730.944
Methane-CH_4 (ppm): Post-Catalyst	1394.899	1654.721	1810.803	1668.765
Acetylene-C_2H_2 (ppm): Pre-Catalyst	0.004	0.103	0.363	0.000
Acetylene-C_2H_2 (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Ethylene-C_2H_4 (ppm): Pre-Catalyst	59.778	61.237	59.081	48.021
Ethylene-C_2H_4 (ppm): Post-Catalyst	22.421	15.968	9.756	12.296
Ethane-C_2H_6 (ppm): Pre-Catalyst	154.137	173.349	208.761	155.649
Ethane-C_2H_6 (ppm): Post-Catalyst	208.203	229.031	279.990	203.376
Cyclopropene-C_3H_6 (ppm): Pre-Catalyst	1.527	2.425	1.858	1.289
Cyclopropene-C_3H_6 (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Formaldehyde-H_2CO (ppm): Pre-Catalyst	56.310	60.753	57.630	55.249
Formaldehyde-H_2CO (ppm): Post-Catalyst	17.970	15.326	10.604	16.225
Methanol-CH_3OH (ppm): Pre-Catalyst	1.729	1.843	1.871	1.435
Methanol-CH_3OH (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Propane-C_3H_8 (ppm): Pre-Catalyst	32.908	37.072	43.230	33.995
Propane-C_3H_8 (ppm): Post-Catalyst	27.758	30.019	35.193	27.606
Sulfur Dioxide-SO_2 (ppm): Pre-Catalyst	1.678	2.895	2.303	3.175
Sulfur Dioxide-SO_2 (ppm): Post-Catalyst	1.893	1.191	0.000	1.298
Total Hydrocarbons-THC (ppm): Pre-Catalyst	1897.534	2256.388	2526.730	2222.342
Total Hydrocarbons-THC (ppm): Post-Catalyst	2076.828	2401.490	2675.504	2355.141
Acetaldehyde-CH_3CHO (ppm): Pre-Catalyst	-3.441	-4.132	-5.545	-3.892
Acetaldehyde-CH_3CHO (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Acrolein CH_2=CHCHO (ppm): Pre-Catalyst	0.382	-0.232	-0.345	0.041
Acrolein CH_2=CHCHO (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
1-3 Butadiene (ppm): Pre-Catalyst	0.818	1.246	1.480	1.302
1-3 Butadiene (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Isobutylene (ppm): Pre-Catalyst	0.001	0.000	0.000	0.000
Isobutylene (ppm): Post-Catalyst	0.000	0.000	0.000	0.000
Calculated Catalyst Efficiency				
Carbon Monoxide-CO (%)	95.46%	97.78%	98.74%	97.23%
Formaldehyde-H_2CO (%)	0.680873735	0.748	0.816	0.706

The values - not %
they are Decimal!

Colorado State University
August 4-6, 1999
EPA RICE Testing
Waukesha
Engine Class: Natural Gas Fueled, Spark Ignited, Four-Stroke, Lean Burn Engine

Waukesha				
MEASURED EMISSIONS	Run 13	Run 14	Run 15	Run 16
Ignition Type	PCC	PCC	PCC	PCC
Air Manifold Pressure ("Hg)	5.00	5.02	5.00	5.00
Brake Horsepower (bhp)	737	737	737	737
Emissions Measured (Dry)				
NO_x (ppm): Pre-Catalyst	64.65	174.30	94.19	108.39
NO_x (ppm): Post-Catalyst	70.85	183.80	102.07	117.02
CO (ppm): Pre-Catalyst	619.92	655.62	625.17	627.01
CO (ppm): Post-Catalyst	44.53	42.27	42.56	42.14
THC (ppm): Pre-Catalyst	1904.33	1773.43	1851.82	1859.21
THC (ppm): Post-Catalyst	2002.80	1817.69	1964.55	1911.39
O_2 %: Pre-Catalyst This value should be ~9.8% ?	10.44	9.81	9.90	9.82
O_2 %: Post-Catalyst	9.81	9.89	9.82	9.80
CO_2 %: Pre-Catalyst	6.27	6.24	6.22	6.23
CO_2 %: Post-Catalyst	6.38	6.41	6.35	6.36
Emissions Measured (Wet)				
Methane (ppm): Pre-Catalyst	1377.56	1249.40	1331.48	1306.95
Methane (ppm): Post-Catalyst	1248.62	1088.91	1193.13	1166.45
Non-Methane (ppm): Pre-Catalyst	167.00	133.26	160.15	150.09
Non-Methane (ppm): Post-Catalyst	109.40	108.78	115.08	118.19
Carbon Balance Calculations				
Exhaust H_2O% (Pre-Catalyst)	12.08	12.11	12.08	12.10
Exhaust H_2O% (Post-Catalyst)	12.16	12.26	12.17	12.21
O_2 %	10.14	10.19	10.23	10.23
O_2 Balance	1.02	-1.69	-1.55	-1.84
Exhaust Flow (lb/hr)	8947.4	8209.7	8639.6	8506.0
Air Flow (lb/hr)	8647.9	7935.1	8352.3	8222.8
In Cylinder Temperature	29.3	26.5	28.2	27.7
Air/Fuel Ratio	28.9	28.9	29.1	29.0
F-Factor Emissions Calculations				
NO_x (g/bhp-hr): Pre-Catalyst	0.538	1.388	0.715	0.805
NO_x (lb/hr): Pre-Catalyst	0.874	2.256	1.162	1.308
NO_x (g/bhp-hr): Post-Catalyst	0.589	1.464	0.775	0.869
NO_x (lb/hr): Post-Catalyst	0.958	2.379	1.259	1.413
THC (g/bhp-hr): Pre-Catalyst	5.611	5.003	4.977	4.890
THC (lb/hr): Pre-Catalyst	9.120	8.128	8.090	7.948
THC (g/bhp-hr): Post-Catalyst	5.901	5.128	5.280	5.027
THC (lb/hr): Post-Catalyst	9.592	8.331	8.583	8.171
CO (g/bhp-hr): Pre-Catalyst	3.189	3.229	2.933	2.879
CO (lb/hr): Pre-Catalyst	5.184	5.247	4.769	4.680
CO (g/bhp-hr): Post-Catalyst	0.229	0.208	0.200	0.194
CO (lb/hr): Post-Catalyst	0.372	0.338	0.325	0.315
Methane (g/bhp-hr): Pre-Catalyst	4.665	4.058	4.116	3.954
Methane (lb/hr): Pre-Catalyst	7.582	6.593	6.691	6.428
Methane (g/bhp-hr): Post-Catalyst	4.228	3.537	3.688	3.529
Methane (lb/hr): Post-Catalyst	6.873	5.746	5.996	5.737
Non-Methane (g/bhp-hr): Pre-Catalyst	1.554	1.190	1.361	1.248
Non-Methane (lb/hr): Pre-Catalyst	2.527	1.933	2.212	2.029
Non-Methane (g/bhp-hr): Post-Catalyst	1.018	0.971	0.978	0.983
Non-Methane (lb/hr): Post-Catalyst	1.655	1.578	1.590	1.598
Formaldehyde (g/bhp-hr): Pre-Catalyst	0.363	0.341	0.333	0.326
Formaldehyde (lb/hr): Pre-Catalyst	0.590	0.554	0.541	0.529
Formaldehyde (g/bhp-hr): Post-Catalyst	0.098	0.113	0.101	0.099
Formaldehyde (lb/hr): Post-Catalyst	0.160	0.184	0.164	0.161
Acetaldehyde (g/bhp-hr): Pre-Catalyst	-0.032	-0.026	-0.031	-0.029
Acetaldehyde (lb/hr): Pre-Catalyst	-0.052	-0.042	-0.050	-0.047
Acetaldehyde (g/bhp-hr): Post-Catalyst	0.000	0.000	0.000	0.000
Acetaldehyde (lb/hr): Post-Catalyst	0.000	0.000	0.000	0.000
Acrolein (g/bhp-hr): Pre-Catalyst	-0.006	0.005	-0.002	-0.001
Acrolein (g/bhp-hr): Pre-Catalyst	-0.010	0.008	-0.003	-0.002
Acrolein (g/bhp-hr): Post-Catalyst	0.000	0.000	0.000	0.000
Acrolein (lb/hr): Post-Catalyst	0.0	0.0	0.0	0.0

Colorado State University: Engines and Energy Conversion Laboratory

Test Description: Baseline 8-5 - 736BHP 1200RPM 10BTDC

Data Point Number: Baseline **Date:** 08/05/99 **Time:** 15:11:38

Duration (minutes): 5.00

Description	Average	Min	Max	STDV	Variance
AMBIENT AIR TEMPERATURE (F)	73.00	73.00	73.00	0.00	0.00
AMBIENT AIR PRESSURE (psia)	12.07	12.07	12.07	0.00	0.00
AMBIENT HUMIDITY (%)	61.51	60.00	62.00	0.86	1.40
AIR MANIFOLD PRESSURE ("Hg)	5.01	4.76	5.19	0.09	1.80
AIR MANIFOLD RELATIVE HUMIDITY (%)	37.85	36.00	39.00	1.06	2.81
AIR MANIFOLD HUMIDITY RATIO (lb_W/lb_A)	0.01561	0.01422	0.01669		
AIR MANIFOLD TEMPERATURE (F)	99.63	98.00	101.00	0.60	0.60
INTAKE AIR FLOW (scfm)	1747.25	1734.02	1758.27	5.28	0.30
EXHAUST FLOW (scfm)	-124.87	-124.87	-124.87	0.00	0.00
EXHAUST STACK TEMPERATURE (F)	699.38	698.99	699.79	0.22	0.03
CYLINDER 1 EXHAUST TEMPERATURE (F)	975.36	973.60	976.97	0.71	0.07
CYLINDER 2 EXHAUST TEMPERATURE (F)	974.40	972.61	975.98	0.74	0.08
CYLINDER 3 EXHAUST TEMPERATURE (F)	974.36	972.61	975.98	0.69	0.07
CYLINDER 4 EXHAUST TEMPERATURE (F)	949.03	947.41	950.98	0.78	0.08
CYLINDER 5 EXHAUST TEMPERATURE (F)	939.66	938.08	941.06	0.51	0.05
CYLINDER 6 EXHAUST TEMPERATURE (F)	928.50	927.17	929.95	0.63	0.07
CYLINDER EXHAUST AVERAGE TEMP (F)	956.92	955.94	957.93	0.52	0.05
EXHAUST HEADER TEMPERATURE (F)	699.38	698.99	699.79	0.22	0.03
PRE TURBO EXHAUST PRESSURE ("Hg)	37.63	37.41	37.92	0.13	0.36
PRE TURBO EXHAUST TEMPERATURE (F)	957.21	955.94	958.52	0.64	0.07
POST TURBO EXHAUST PRESSURE ("Hg)	5.06	5.01	5.12	0.02	0.43
POST TURBO EXHAUST TEMPERATURE (F)	772.01	771.02	773.00	0.52	0.07
TURBO OIL PRESSURE ("Hg)	47.10	46.16	47.77	0.31	0.66
ENGINE SPEED (rpm)	1196.86	1191.73	1200.00	1.48	0.12
ENGINE HORSEPOWER (bhp)	737.44	735.01	739.70	1.09	0.15
ENGINE OIL PRESSURE (psig)	52.19	51.64	52.93	0.32	0.61
ENGINE OIL TEMPERATURE IN (F)	165.17	164.86	165.45	0.16	0.10
ENGINE OIL TEMPERATURE OUT (F)	186.07	185.89	186.49	0.14	0.07
SPECIFIC GRAVITY	0.69	0.69	0.69	0.00	0.00
FUEL TEMPERATURE (F)	91.36	91.05	91.64	0.15	0.16
FUEL PRESSURE ("H2O above amp)	4.07	3.44	4.66	0.21	5.15
FUEL SUPPLY PRESSURE (psig)	46.83	46.75	46.90	0.04	0.08
ORIFICE DIFFERENTIAL PRESSURE ("H2O)	15.19	14.65	15.86	0.31	2.06
ORIFICE STATIC PRESSURE (psig)	46.41	46.35	46.48	0.03	0.07
ORIFICE TEMPERATURE (F)	88.18	88.04	88.30	0.05	0.05
FUEL FLOW (SCFH)	5474.35				
CALCULATED FUEL CONSUMPTION (BSFC)	7717.47				
FUEL HEATING VALUE (Btu)	1039.60	1039.60	1039.60	0.00	0.00
AIR FUEL RATIO	**32.70**	**32.70**	**32.70**	0.00	0.00
INTERCOOLER AIR DIFFERENTIAL PRESSURE ("H2O)	9.72	9.43	9.87	0.09	0.90
INTERCOOLER AIR TEMP IN (F)	299.90	299.19	300.38	0.28	0.09
INTERCOOLER AIR TEMP OUT (F)	143.43	142.64	143.83	0.35	0.24
POST INTERCOOLER AIR MANIFOLD PRESSURE ("Hg)	68.79	68.49	68.99	0.09	0.14
INTERCOOLER WATER DIFFERENTIAL PRESSURE ("H2O)	157.45	157.45	157.45	0.00	0.00
INTERCOOLER WATER FLOW (GPM)	57.90	57.20	58.49	0.28	0.49
INTERCOOLER WATER TEMP IN (F)	131.13	129.74	131.72	0.57	0.43
INTERCOOLER WATER TEMP OUT (F)	143.56	142.44	144.02	0.43	0.30
INTERCOOLER SUPPLY PRESSURE (psi)	2.81	2.77	2.87	0.02	0.62
PRE CATALYST TEMPERATURE (F)	730.58	729.75	731.34	0.40	0.05
POST CATALYST TEMPERATURE (F)	734.79	734.11	735.70	0.35	0.05
CATALYST DIFFERENTIAL PRESSURE ("H2O)	9.50	9.43	9.62	0.04	0.47
B.S. CO (g/bhp-hr): Pre-Catalyst	4.16	4.05	4.26	0.04	1.06
B.S. CO (g/bhp-hr): Post-Catalyst	0.29	0.28	0.30	0.00	1.48
B.S. NO (g/bhp-hr): Pre-Catalyst	0.00	0.00	0.00	0.00	0.00

Wrong

Wrong

Gas Research Institute
8600 West Bryn Mawr Avenue
Chicago, Illinois 60631-3562
773/399-8100
FAX: 773/399-8170

GRI®

September 20, 2000

Mr. Terry Harrison
Emissions Measurement Center (MD-19)
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

SUBJECT: Comments on the EPA Draft Report on the Emission Test Results for the Waukesha at the Colorado State University Engines and Energy Conversion Laboratory

Dear Terry:

Thank you for the opportunity to review the EPA draft report, "Testing of a 4-Stroke Lean Burn Gas-Fired Reciprocating Internal Combustion Engine to Determine the Effectiveness of an Oxidation Catalyst System For Reduction of Hazardous Air Pollutant Emissions," dated August 2000. For your information, in April 2000, the Gas Research Institute (GRI) and the Institute of Gas Technology (IGT) combined to form GTI, Gas Technology Institute. This letter provides the comments from GTI and PRC International.

Our specific comments are attached. In general we were pleased to see that the draft report for the 4-Stroke Lean Burn (4SLB) engine used a format and approach similar to the final report for the 2-Stroke Lean Burn (2SLB) engine, which incorporated a number of the comments we had submitted on the draft 2SLB report. Thank you for providing a copy of the comments submitted by Bob Stachowicz of Waukesha. Bob made a number of good points and we have noted our agreement with several of his comments.

If you have questions regarding the comments provided, please contact me at your convenience.

Sincerely,

James M McCarthy

James M. McCarthy
Program Leader, Air Quality
Gas Technology Institute

cc: Sam Clowney, Tennessee Gas Pipeline

GTI and PRC International Comments on the EPA Draft Report

1. As noted above, Bob Stachowicz of Waukesha submitted a number of constructive comments in his September 1, 2000 letter to Terry Harrison of EPA. We particularly note our support of the following issues raised by Bob:
   a) The formaldehyde levels presented in the report are higher than levels measured in field tests on 4SLB engines. For example, for natural gas transmission facilities, field testing shows formaldehyde emissions at 0.23 g/bhp-hr for 4SLB engines running in a low-NOx configuration (see Topical Report GRI-96/0009.1, "Measurement of Air Toxic Emissions from Natural Gas-Fired Internal Combustion Engines at Natural Gas Transmission and Storage Facilities"), whereas the formaldehyde levels in the draft 4SLB report range from 0.28 to 0.35 g/bhp-hr.
   b) NOx does increase across the catalyst and that fact raises issues about the ability of 4SLB engines with oxidation catalysts to comply with NOx requirements. The error bounds of the data may also contribute to the apparent increase in NOx across the catalyst and this issue should be investigated further.
   c) The 4SLB report should include a more detailed explanation of the total hydrocarbon, non-methane hydrocarbons, and methane results, including a discussion of the uncertainties related to the data. In addition, the report should consider the reactions that may occur across the catalyst, such as the partial oxidation of methane or other hydrocarbons, that would impact the measured total hydrocarbons, non-methane hydrocarbons, or methane reduction efficiencies. Finally, given the uncertainties related to the total hydrocarbon and non-methane hydrocarbon data, percent reduction efficiencies for those compounds should not be presented in the report. We also submitted this comment on the draft 2SLB report.
   d) The 4SLB report should include the equations used to calculate the lb/hr and g/bhp-hr emission levels from the ppm values. As Bob noted, the values do not agree with the values presented in the data report provided by CSU (and included in Appendix A).
   e) The 100% oxygen reading reported pre-catalyst for Run 3 clearly is in error and the value affected the g/bhp-hr and lb/hr emission rates reported in the CSU report -- the values are negative. As Bob noted, PES apparently interpreted this value as 10.0%. PES will need to correct the g/bhp-hr and lb/hr values for Run 3 once the correct oxygen reading is available from CSU.
2. Comments related to detection limits:
   a) The detection limits for all compounds should be included in the body of the report. We understand that EPA is awaiting information from Colorado State University regarding the detection limits, by run, for the FTIR measurements. The detection limits should be included in the final 4SLB report.
   b) In Section 2.4, the report notes that removal efficiencies were not included for acetaldehyde based on the in-stack detection limit downstream of the catalyst

since the FTIR detection limits were not available for the draft report. This statement must be in error since acetaldehyde was not detected for any test condition before or after the catalyst. The statement may refer to acrolein, which was detected before the catalyst in 6 of 16 test conditions, and was not detected after the catalyst for any test condition.

As we noted in our September 8, 1999 comments on the draft 2SLB report, destruction efficiency calculations based on the detection limit of a method are misleading. The report should not include emission reduction efficiencies when a pollutant is not detected pre- or post-catalyst. If EPA intends to present emission reduction efficiencies when pollutants are not detected, appropriate consideration should be given to the error band associated with data measured at or near the detection limit. Such consideration would result in a range of efficiencies based on the range of both catalyst inlet and outlet concentrations.

3. Section 6.3 includes a discussion of EPA's Data Quality Objective for the 4SLB emissions test. This discussion states that EPA intended to use the 4SLB emissions test to evaluate the effects of combustion modifications as well as the effectiveness of oxidation catalysts. As we have noted previously, the operating conditions used to conduct the 4SLB emissions test were selected to simulate operating conditions that may be encountered in the normal field operation of natural gas-fired engines. The operating conditions tested are not sufficient to allow EPA to evaluate the effect of combustion modifications on HAP emissions. Also, engines in variable load applications, such as natural gas transmission, must have the flexibility to operate at a variety of conditions. Note that the final 2SLB report includes a similar discussion.

4. On page 5-1, the 4SLB report indicates that FTIR is classified as a Type II method and states: "Type II methods were those that used permanently installed instruments housed in a temperature-controlled environment and operated in the same fashion as continuous monitors used by industry to show compliance with emission regulations. Because these instruments are maintained in a laboratory-type environment (the control room at EECL), fewer QA activities and calibrations adequately show their continuing accuracy." As we noted in our comments on the draft 2SLB report, the second half of the first sentence is not true for FTIR, since there are no instances where FTIR is used for IC engines as a continuous monitor to show compliance with emission regulations. Also, the characterization of FTIR as a continuous compliance monitoring method is not relevant to the point being made that less QA activities and calibrations were necessary for Type II methods. The second half of the first sentence should be deleted, so that it reads "Type II methods were those that used permanently installed instruments housed in a temperature-controlled environment. Because these instruments are maintained in a laboratory-type environment (the control room at EECL), fewer QA activities and calibrations adequately show their continuing accuracy."

MEMORANDUM
July 6, 2001

To: Terry Harrison, US EPA
Bryan Willson, CSU EECL

From: Mike Maret, PES

Re: Response to comments received on the Waukesha Draft Final Report

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This memorandum summarizes the telephone conference between Terry Harrison (EPA EMC), Bryan Willson (CSU EECL), and Mike Maret (PES) that took place on June 11, 2001. The purpose of the telephone conference was to 1) discuss comments that were received by EPA on the draft final report for the Waukesha 3521 reciprocating engine, 2) to decide which comments would necessitate revisions when preparing the final report, and 3) the form of the revisions in the final report.

The call began at approximately 11:10 a.m. EDT. EPA received two sets of comments pertaining to the Waukesha draft final report. The first set of comments that was discussed were those received from Mr. Bob Stachowicz of Waukesha. Mr. Stachowicz's comments were not numbered; the group numbered the comments during the phone call. EPA's response to each comment is summarized below.

1. The first comment compared engine operational data developed by CSU for Runs 1 and 3 with historical Waukesha engine data. Waukesha stated that the values developed by CSU were within normally expected tolerances.

EPA decided that since the comment does not identify an error or omission, no change to the report is required.

2. Waukesha stated that certain values in Table 2.2 of the draft report appeared to be incorrect, specifically the value for oxygen at the catalyst inlet for Run Nos. 3 and 13.

CSU stated that the oxygen data for Run No. 3 was invalid. Together CSU, EPA and PES developed a strategy to correct invalid data. When invalid oxygen data is detected, the oxygen data for the 5-minute Quality Control run will be substituted and used for subsequent calculations. If the QC data is also determined to be invalid, oxygen data from the catalyst outlet will be substituted and used for subsequent calculations. Since for Run No. 3 the oxygen data was invalid EPA directed CSU to recalculate inlet values using the outlet concentration of outlet oxygen value of 9.8%.

CSU recognized that the measured oxygen value of 10.4% during Run No. 13 appeared to be higher that normal. An examination of the raw data did not turn up any reason to invalidate the data. EPA directed PES to use the oxygen value supplied by CSU, but to footnote the value as being suspect.

3. This comment discussed observed criteria emittant (NO_X, CO, and THC) values.

EPA decided that since the comment does not identify an error or omission, no change to the report is required.

4. This comment discussed observed non-methane hydrocarbon (NMHC) values.

EPA decided that since the comment does not identify an error or omission, no change to the report is required.

5. This comment discussed observed formaldehyde values.

EPA decided that since the comment does not identify an error or omission, no change to the report is required.

6. This comment requested that it be noted in the final report that NO_X universally increased across the oxidizing catalyst.

EPA decided that since the comment does not identify an error or omission, no change to the report is required..

7. This comment discussed methane and NMHC data, the fact that these measurements were made with different make and models of analyzers, and perceived discrepancies in the measurements over the 16-run test program.

EPA directed PES not to make any corrections to any data, but to note in a footnote that different models of analyzers were used to measure these values.

8. Waukesha noted that the NMHC value at the catalyst outlet during Run No. 8 is very high compared to the inlet and appears to be in error.

EPA, PES, and CSU examined the NMHC concentration data for Run No. 8. The reported pre-catalyst concentration was 171 ppm. The reported post-catalyst concentration was 284 ppm. The NMHC concentration data for the QC run conducted just prior to Run No. 8 was examined. The NMHC concentrations were 168 ppm and 155 ppm at the pre- and post-catalyst locations, respectively. CSU and PES proposed that NMHC mass flow rates and NMHC destruction efficiency be calculated using the data from the QC run, and that the data from the test run be invalidated. EPA agreed with this approach. These values will be footnoted in the revised table.

9. This comment states that the a description of the total hydrocarbon instrumentation used was not included in the report.

EPA directed PES to include a description of the instrumentation used.

10. This comment states that NO_X and methane values at the catalyst inlet and NOX values at the catalyst outlet were only reported to only one place after the decimal for runs 10 - 16 in Table 2.3.

Upon inspection of the table PES noted an error in the number of significant figures that were reported. EPA directed PES to correct the error in the final report.

11. This comment notes that brake specific NOX emissions during the testing program decreased with the decrease in engine speed, which is contrary to Waukesha's experience.

EPA decided that since the comment does not identify an error or omission, no change to the report is required.

12. This comment states that Runs #15 and #16 did not appear to give any significant information.

EPA decided that since the comment does not identify an error or omission, no change to the report is required..

13. This comment notes that the emissions reported by PES in Table 2.3 differ from the

emission rates reported by CSU in Appendix A.

PES used EPA Method 19 to calculate pollutant mass flow rates at the catalyst inlet and catalyst outlet locations, as specified in the Quality Assurance Project Plan (QAPP). The gas volumetric flow rate at each location was calculated using the fuel factor and flue flow rates supplied by CSU. The mass flow rate for each target compound was calculated using the concentration values reported by CSU, and the calculated volumetric flow rates. PES could not reproduce CSU's calculated values when preparing the draft final report. EPA directed PES to prepare a set of example calculations that were used, and to forward these calculations to CSU and EPA for further review.

The following comments were made specifically regarding the CSU data presented in the CSU report, which was included as Appendix A in the draft final report.

14. Waukesha stated that all of the air/fuel ratios reported by CSU seemed a bit to high compared to Waukesha's expected values.

EPA decided that since the comment does not identify an error or omission, no change to the report is required.

15. This comment states that the air/fuel ratios shown during the baseline run on August 5 are in error, and that the correct air/fuel ratio should be closer to 28.6.

CSU examined the oxygen data presented in the baseline run. The catalyst inlet oxygen monitor failed during this run, therefore the calculated air/fuel ratio is in error. This error was described on Page 3-4 of the CSU report. CSU will recalculate the air/fuel ratio using the oxygen value of 9.8% at the catalyst outlet.

16. This comment notes that CSU's Appendix B does not include data for the 1000 rpm baseline run that was taken on August 6.

The 1000 rpm is an invalid baseline data point. Baseline testing was conducted at an engine speed of 1200 rpm. A 1200 rpm baseline run was conducted on August 5 and 6. EPA directed PES to remove the 1000 rpm baseline run from the final report.

17. Waukesha commented that the pre-catalyst oxygen value observed during testing (100%) is obviously wrong.

This comment is addressed in Item No. 2.

18. This comments notes that the units of barometric pressure reported in the CSU report are in inches of mercury, but the values appear to be in psia.

CSU confirmed that the values are in psia. CSU will generate an errata sheet noting this error. PES will include this error in the final report. Further, PES will make a hand notation on the CSU run data in Appendix A of the CSU report.

19. Waukesha noted that the tabulated "Air Manifold" temperatures are always about 99.5 °F, and noted that this does not make sense.

CSU explained that the "Air Manifold" temperature is the temperature of the air supplied to the engine by the EECL's combustion air blower. CSU will add this mis-labeled parameter to the errata sheet. PES will make a hand notation in the CSU run data.

20. Waukesha noted that the values for the "Average Cylinder Exhaust Temperature" are always in the low to mid 700 °F range, and that this value is too low.

CSU explained that a thermocouple was added at an intermediate point in the exhaust between the pre-catalyst annubar flow meter and the catalyst. The parameter was mis-labeled on the engine test run summary. CSU will add this error to the errata sheet. PES will make a hand notation in the CSU run data.

21. Waukesha commented that a value for "In-cylinder Temperature" was also given and that this value was typically 25 - 35 °F.

CSU stated that this value is an erroneous value for the Waukesha engine set-up. This value is sometimes used during testing of other engines at the facility. CSU will add this error to the errata sheet. PES will make a hand notation in the CSU run data.

22. This comment notes that the removal efficiencies for formaldehyde were presented in decimal format instead of percent format.

CSU will add this error to the errata sheet. PES will make a hand notation in the CSU run data.

23. This comment notes that the pre-catalyst oxygen value for Run #13 is incorrect.

This comment was addressed in Item No. 2.

The following comments are text and typographical comments:

24. Waukesha noted that the inlet air humidity in CSU's Table 3 is incorrect.

CSU will add this error to the errata sheet. PES will make a hand notation in the CSU's Table 3.

25. Waukesha noted that PES' reference to a supercharged air delivery system (page 3-1, Section 3.1, first paragraph of the draft final report) is confusing. Waukesha recommended an alternative word, "pressurized" when referring to the air delivery system at the CSU EECL.

EPA directed PES to incorporate the change.

26. Waukesha noted that PES's usage of "expansion stroke" (page 3-1, Section 3.1, second paragraph of the draft final report) is incorrect. Waukesha recommended using the term "intake stroke".

EPA directed PES or incorporate the change.

27. Waukesha noted that the correct units of torque are pound-feet or lb-ft, instead of foot-pounds, as used in the PES and CSU reports.

EPA directed PES to leave the units of torque as reported in the draft final report unchanged.

28. Waukesha noted several mistakes in the sentence (page 3-4, Section 3.2, first paragraph of the draft final report) "...engine timing (the location of the cylinder, relative to top dead center, at the time of peak pressure in the combustion chamber, measured in degrees)..." Waukesha recommended the following correction: ...engine timing (the location of the *piston*, relative to *its* top dead center, at the time of the *spark plug fires* in the *pre*-combustion chamber, measured in degrees).

EPA directed PES to incorporate the suggested change.

The second set of comments received by EPA were from Mr. James M McCarthy of the Gas Research Institute. The comments were numbered. EPA's response to each comment is presented below.

1a. This comment states that the formaldehyde levels measured during the test program were higher than levels measured in field tests on 4SLB engines.

EPA decided that since the comment does not identify an error or omission, no change to the report is required.

1b. GRI reiterated the fact that NO_X emissions increased across the catalyst, and stated that this phenomenon would raise issues about the ability of 4SLB engines with oxidation catalysts to comply with NO_X requirements.

EPA decided that since the comment does not identify an error or omission, no change to the report is required.

1c. GRI requested that the final report include a more detailed explanation of the total hydrocarbon, non-methane hydrocarbon and methane results, and that chemical reactions across the catalyst (such as partial oxidation reactions) should be considered. The comment also stated that destruction efficiencies for these compounds not be included in the final report.

EPA decided that since the comment does not identify an error or omission, no change to the report is required.

1d. This comment requested that examples of the equations used to calculate mass flow rates and catalyst removal efficiencies be provided.

EPA directed PES to include these calculations in the final report.

1e. This comment notes the error in the measurement of the oxygen concentration for Run 3.

This comment is address in Item No. 2 of the previous section.

2a. This comment requested that FTIR detection limits be included in the final report.

EPA directed PES to include FTIR detection limits in the final report. CSU has provided this data.

2b. The draft final report, in Section 2.4, says that destruction efficiencies for acetaldehyde were not calculated due to a lack of acetaldehyde detection limit data at the catalyst outlet location. This comment states that this statement is in error, and that most likely acrolein is the compound for which estimated destruction efficiency could not be calculated.

EPA directed PES to correct the error.

3. This comment addresses Section 6.3 of the draft final report. The comment states that the range of engine operating conditions during the test program are not sufficient to allow EPA to evaluate the effect of combustion modifications on HAP emissions.

EPA decided that since the comment does not identify an error or omission, no change to the report is required.

4. The comment states that the draft report classified FTIR as a "Type II" methods, and states that "Type II methods were those that used permanently installed instrument housed in a temperature-controlled environment and operated in the same fashion as continuous monitors used by industry to show compliance with emissions regulations." This comments states that this sentence is in error, since there are no cases where FTIR is used by industry to show continuing compliance. The comment states that the last part of the sentence should be deleted.

EPA directed PES to incorporate the change.

TECHNICAL REPORT DATA

Please read instructions on the reverse before completing

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

The United States Environmental Protection Agency (EPA) is investigating Reciprocating Internal Combustion Engines (RICE) to characterize engine emissions and catalyst control efficiencies of hazardous air pollutants (HAPs). This document describes the results of emissions testing conducted on a Waukesha 3521GL natural-gas-fired, 4-stroke, lean burn (4SLB) engine. Early in 1998, several industry and EPA representatives agreed that the Waukesha 3521 GL engine at the Colorado State University's (CSU) Engine and Energy Conversion Laboratory (EECL) is adequately representative of existing and new natural-gas-fired 4SLB engines. The group agreed that a matrix of test results from testing conducted at the EECL could be used to develop Maximum Achievable Control Technology (MACT) standards for RICE. The group further agreed that an oxidation catalyst installed on the Waukesha 3521GL could be used to determine the effectiveness of oxidation catalysts for these engines, and that the EPA could use the results from testing at the 4SLB matrix conditions at CSU as the basis for developing the MACT standard for natural-gas-fired 4SLB engines.

The testing was performed to estimate HAP emissions before and after the oxidation catalyst. Miratech Corporation manufactured the catalyst and CSU personnel installed it on the engine. Fourier transform infrared spectroscopy (FTIRS), owned and operated by CSU, was used to measure formaldehyde, acetaldehyde, and acrolein. Continuous emission monitors (CEMs), owned and operated by CSU, were used to measure oxygen (O_2), carbon dioxide (CO_2), nitrogen oxides (NO_x), carbon monoxide (CO), total hydrocarbons (THC), methane (CH_4), and non-methane hydrocarbons (NMHC).

This document is comprised of 427 pages and consists of the report text, and Appendices A and B.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTIONS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COASTI Field/Group
Emission Testing Hazardous Air Pollutants Oxidation Reduction Catalyst Reciprocating Internal Combustion Engines		

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