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New Technology Research & Development Program
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Final Report

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Evaluation of a Pre-Combustion Fuel Catalytic Converter for Heavy-Duty On-Road Diesel Engine Applications

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Introduction

Researchers at the West Virginia University (WVU) Engine and Emissions Research Laboratory (EERL) conducted engine dynamometer testing in order to evaluate a pre-combustion fuel catalyst device intended for use on heavy-duty on-road diesel engines. A 1995 model-year Mack E7-400 V-Mac II engine was coupled to a 550 hp General Electric DC Dynamometer and operated over the EPA Engine Dynamometer Schedule for Heavy Duty Diesel Engines as set out in the Code of Federal Regulations Volume 40 "Protection of the Environment", Part 86 (the "FTP" test) [1], while emissions, performance, and fuel consumption were recorded. Three sets of tests (one warm-start followed by three hot-start FTPs) were performed with the first and third set of tests with the engine in its stock configuration, second set with the pre-combustion fuel catalyst device installed and the third set with the catalyst installed but electrically isolated from the engine.

All regulated emissions (carbon monoxide, oxides of nitrogen, hydrocarbons and particulate matter), as well as carbon dioxide, were continuously monitored and recorded and are reported for each test in specific units of grams per brake-horsepower hour (g/bhp-hr). Fuel consumption was monitored both using a fuel flow measurement system, and through a carbon balance calculation of the exhaust emissions.

Objective

It was proposed that a pre-combustion fuel catalyst device has the ability to reduce emissions and improve performance of a heavy-duty diesel engine. This research measured the effect of the Clean Air Associated Inc. pre-combustion catalytic converter on the exhaust emissions and fuel economy of a Mack E7-400 diesel engine. Emissions and fuel economy were measured both with and without the device in place.

Description of Test Engine

A 1995 Mack E7-400 V-Mac II was employed for this testing. The test engine bears the model number E7-400 V-Mac II and serial number 5A0796. As specified by the engine manufacturer the engine should produce 400 brake horsepower (bhp) at a rated speed of 1800 revolutions per minute (rpm), and 1460 foot-pounds (ft-lb) of torque at 1250 rpm. The recommended cruise rpm for this engine is 1600 ± 50 rpm. The low idle speed for the engine is 650 ± 25 rpm. The high idle speed for the engine is 2100 ± 50 rpm. The engine is a 6 cylinder turbocharged engine with a 12 L displacement. The engine was originally built as an E7-350 V-Mac II engine in 1995. It was upgraded to E7-400 V-Mac II specifications in March of 1999. It should be noted that the injection pump and turbocharger are the same for the E7-350 and the E7-400.

Table 1 Engine Description

Engine Manufacturer	Mack Trucks Inc
Engine Model	E7-400-V-MAC II
Model Year	1995
Displacement (liters)	12
Power Rating (hp)	400 @ 1800rpm
Configuration	Inline 6
Bore (in.) x Stroke (in.)	4.875 x 6.500
Induction	Turbocharger with Aftercooler
Fuel Type	Diesel
Engine Strokes per Cycle	Four
Injection	Direct, Electronic

Description of Laboratory

Engine and Dynamometer Installation

The engine was attached to a General Electric Direct Current dynamometer, capable of motoring 500hp and absorbing 550hp, through a Vulkan® vibration-damping coupler. The exhaust was plumbed to the dilution tunnel via a butterfly-type throttle valve, using steel tubing.

Fuel System

The WVU engine test cell was equipped with a conditioning system to control the temperature and measure the delivery rate of the fuel in accordance with the Code of Federal Regulations. Fuel temperature was maintained between 90°F and 100°F through out the engine testing procedure.

Fuel and Oil

Standard No.2 diesel pump fuel was used as a fuel for the entire test program. One hundred and ten gallons of diesel fuel was obtained by WVU for use during the testing. This quantity of fuel was sufficient to allow for flushing the fuel system, performing engine mapping, executing the FTP test program, and running the 6-hour aging routine. Samples of the fuel were collected. Engine oil and filters were changed prior to initiating the test program.

Instrumentation and Data Recording

Engine fuel temperature and flow rate, manifold air pressure (MAP) and exhaust temperature were monitored continuously. The engine was also instrumented to measure coolant temperature, intake air temperature and humidity, oil temperature, and intake air mass flow rate.

The dilute engine exhaust was characterized both continuously and with the collection of an integrated bag sample, for oxides of nitrogen (NO_X), hydrocarbons (HC), carbon monoxide (CO) and carbon dioxide (CO_2). Integrated particulate matter (PM) levels were determined gravimetrically. All emissions were corrected for background emissions levels.

Test Cycle

Emissions, performance, and fuel consumption were measured while the engine was operated over the EPA Engine Dynamometer Schedule for Heavy Duty Diesel Engines (CFR Volume 40, Part 86), the "FTP". The test sequence comprised a warm-start FTP, followed by three hot-start FTPs. A twenty minute soak was observed between tests during which time the engine was shut down.

Full-Flow Exhaust Dilution Tunnel

The primary goal of engine emissions testing is to determine the effects that exhaust constituents have on the environment. In order to simulate "real world" conditions and produce accurate data, it is necessary to simulate the dilution process that occurs when hot exhaust gases mix with ambient air. The primary reason for dilution is to allow any in-use exhaust-air interactions to take place, but it also quenches post-cylinder combustion reactions and lowers the exhaust gas dew point, thus inhibiting condensation. Exhaust line quenching is necessary to prevent measurement inconsistencies. The elimination of water in the sampling stream is of utmost importance as certain gaseous components, such as nitrogen dioxide (NO_2), are soluble in water. Uncontrolled condensation in the sampling system could adversely affect measurement accuracy. Water presence in sample lines can also physically affect certain instruments, and reduce the accuracy of particulate matter measurement.

The dilution tunnel system used for this research was based upon the Constant Flow Venturi (CFV) principle, where a large centrifugal blower draws the diluted exhaust gas mixture from the tunnel through a critical flow venturi. When the critical flow venturi reaches sonic conditions (also known as "choked flow"), a constant mass flow rate is maintained in the dilution tunnel. Under this choked condition, the flow rate of the gas through the venturi is directly proportional to the diameter of the throat of the venturi, and the pressure and temperature of the gas entering the venturi.

In these tests, the exhaust gases were led from the outlet of the engine's turbocharger to the tunnel through 5" diameter steel tubing and entered the mouth of the tunnel at its centerline. They then passed through a mixing orifice plate located approximately three feet from the entrance. The orifice opening was 8" in diameter and was used to create turbulence in the flow path to promote thorough mixing. The dilution tunnel itself was constructed of stainless steel to prevent oxidation contamination and degradation, and was 18" in diameter and approximately 20 ft long.

The constant flow blower was driven by a 75hp electric motor and was capable of flowing about 4000cfm under standard conditions. Four venturis were connected in parallel at the entrance to the blower, three of which flow a nominal 1000 cubic feet per minute (cfm) and the fourth a nominal 400cfm. (By allowing flow through various combinations of these venturis, it is possible to obtain nominal flow rates, albeit in discrete steps, from 400cfm to 3400cfm with which the operator can provide a suitable dilution ratio for the engine under test.) Each venturi has been calibrated with a subsonic venturi traceable to the standards set forth by the National Institute of Standards and Technology (NIST). The flow for this testing was set nominally at 2400cfm.

Dilution Air

The dilution air passed through an air-handling system, capable of producing about 4000cfm of HEPA-filtered air. The CFR mandates the temperature to be held between 68°F and 86°F (40CFR§86.1333-84(b)). Although no CFR standard is given for humidity, the air handler also

regulates this throughout the testing day. For consistency, the ambient air used in the main dilution tunnel was maintained near 50%RH.

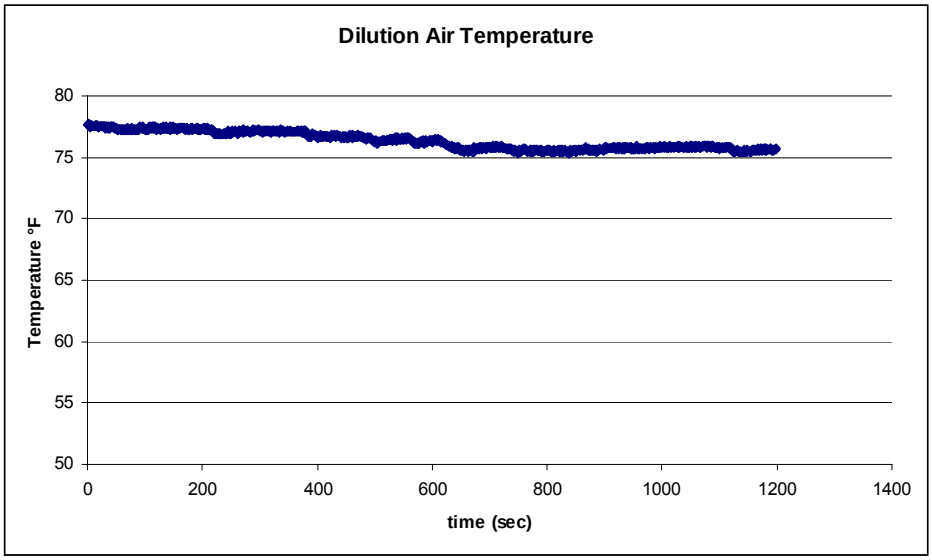


Figure 1: Typical Dilution Air Temperature (E01091-03)

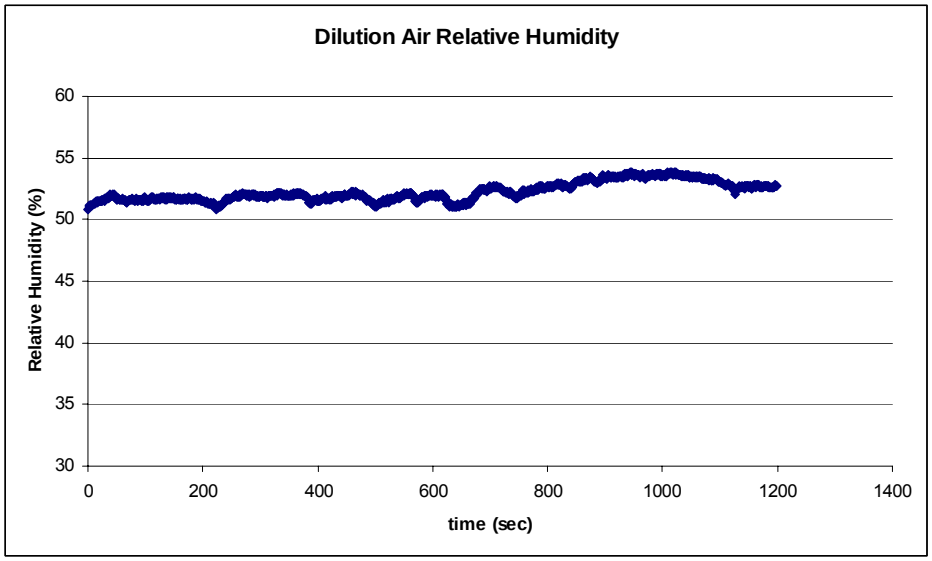


Figure 2: Typical Dilution Air Relative Humidity (E01091-03)

Particulate Sampling System

The particulate sampling system used for this work incorporated a secondary dilution tunnel which was constructed of stainless steel, 4” in diameter and 30” long. This provided a double dilution, proportional-sampling method for particulate matter collection and analysis. Diluted exhaust from the sampling region of the primary dilution tunnel was drawn into the secondary dilution tunnel. This flow rate was continuously adjusted to keep it in fixed proportion to the flow rate occurring in the primary tunnel. The sample then flowed through a stainless steel

filter holder containing two Pallflex 70mm diameter Model T60A20 fluorocarbon-coated glass microfiber filters, mounted one above the other with an intermediate spacer. These two filters, referred to as “primary” and “secondary” respectively, were used in combination to extract the maximum amount of PM from the sample stream for analysis. In order to prevent any damage to the filter face, the temperature of the stream impinging on the face of the particulate sampling filters must not exceed 125°F. If it becomes necessary to add secondary dilution air to keep the filter face temperature down, this is also done in proportion to the main tunnel flow. (No secondary dilution air was necessary during this testing.)

The sample filters collected the PM from the diluted exhaust to enable the determination of the amount of particulate matter (PM) emitted by the engine during a test cycle with a gravimetric analysis. The PM collected consists primarily of elemental carbon as well as sulfates, the soluble organic fractions (SOF), engine wear metals, and bound water.

A rotary vane pump was used to pull sample air through a Sierra 740-L-1 mass flow controller (MFC), which maintains the total secondary dilution tunnel flow. The total diluted flow can be set in the range 0 to 7 standard cubic feet per minute (scfm). Up to 3scfm of secondary dilution air can be regulated through a second Sierra MFC. The MFCs are routinely recalibrated by the manufacturer and additionally checked with a Merriam Instruments Model No. 50MW20 laminar flow element (LFE) rated at 0 - 23scfm.

The sample filters were conditioned in an environmentally controlled enclosure where the temperature and relative humidity was maintained to 70°F and 45% respectively, (the allowable conditions given in 40CFR§86.1312-88 are 66.2°F to 77.0°F and 37% to 53%RH) and were weighed before and after sample collection using a Mettler-Toledo UMX2 microbalance.

After each test sequence was completed, an additional sample filter was used to collect any particulates that may have been present in the dilution air. This collection was run for 20 minutes.

Gaseous Emission Sampling System

The gaseous sampling system used for this work consisted of heated probes located in the dilution tunnel and heated sampling lines connecting the probes with the gas analyzer bench. There were three heated sampling probes. The tips of the probes projected six inches into the tunnel and were oriented so the opening was directed upstream toward the entrance of the tunnel. The connection between the sampling probes and the analyzer bench was made with electrically heated sampling lines. The hydrocarbon (HC) sampling line was maintained at a temperature of 375° ±10°F using Fuji model No. 223-1806 temperature controllers. This prevented the high molecular weight hydrocarbons from condensing in the sample line. The sample lines and probes for the oxides of nitrogen (NO_X) and carbon monoxide (CO) / carbon dioxide (CO_2) sampling systems were maintained at 235°F ±10°F to prevent the condensation of water in the line which could induce measurement error as well as cause damage to the analyzers.

The gas analysis bench housed four major analyzer components: an HC analyzer, high and low range CO analyzers, a CO_2 analyzer, and NO_X analyzers. The analyzers will be described in more detail in the following sections. The bench also housed the sample flow meters and the temperature controllers for the heated sampling components.

Exhaust Gas Analyzers

A brief description of each analyzer and its components as well as theory of operation is included in this section. The gas analyzers used during this testing meet or exceed the recommendations set forth in EPA CFR40 Part 86 Subpart N.

Oxides of Nitrogen Analyzers

The NO/NO_x analyzers used for testing were a Rosemount 955 Heated chemiluminescent analyzer and an Eco Physics CLD 822 chemiluminescent analyzer. These analyzers are capable of detecting either the concentration of NO alone or that of NO and NO_2 together, more commonly referred to as NO_X. When measurement of NO is desired, the sample NO is converted into NO_2 by gas-phase oxidation with molecular ozone (O_3). During this reaction, about 10% of the NO_2 becomes electrically excited, followed by an immediate return to the non-excited state, during which a photon is released. This phenomenon is known as Photon Emission. A photomultiplier tube (PMT) is used to detect these photon emissions, the rate of production of which is proportional to the amount of NO present in the sample. For the detection of NO_X, the sample is first passed through a NO_X converter that converts the NO_2 into NO. This is then measured with the principle just described. If the determination of NO concentration only is desired, the sample can bypass the converter and be measured directly by selecting the NO mode of the analyzer. In the case of NO_X detection, the total analyzer response would determine the amount of NO present in the original sample, as well as the NO created through the dissociation of NO_2 in the converter. A Beckman NO_X efficiency tester was used to ensure that the converter in both the model 955 and the CLD822 analyzers was operating optimally above 90% converter efficiency, in accordance with requirements of CFR Part 86.

Hydrocarbon Analyzer

The hydrocarbon analyzer used was a Rosemount model 402 Heated Flame Ionization Detector (HFID) analyzer. The hydrocarbon level in the exhaust stream is determined by counting the elemental carbon atoms in the sample. The sample gas flow is regulated and combusted in a hydrogen/helium-fueled flame. The combustion produces ions that are collected on polarized electrodes in the analyzer. This absorption of ions by the electrodes produces a current flow in the analyzer's measurement circuitry, which is quantified and related to the hydrocarbon concentration in the sample.

Carbon Monoxide/Carbon Dioxide Analyzers

The gaseous constituents of CO and CO_2 were measured using Horiba, Inc. non-dispersive infrared (NDIR) gas analyzers. CO in the range of 0 - 100ppm was measured with a Horiba Inc. model AIA-210LE, while higher concentrations (up to 1000ppm) were measured with a Horiba Inc. model AIA-210 gas analyzer. Exhaust CO_2 concentration levels were measured with a Horiba Inc. model AIA-210 NDIR gas analyzer.

NDIR analyzers operate using the principle of infrared light absorption. In its simplest form, the NDIR analyzer uses the fact that a particular gas will absorb a certain wavelength of light somewhere within the infrared spectrum, with the other spectral wavelengths still being able to transmit through the gas. The analyzer detects the amount of infrared energy able to pass through the sample gas and uses it in the determination of the amount of the measured absorbent gas in the sample stream.

Table 2: Gaseous Emissions Instrumentation

Gaseous Emission	Calibration Concentration	Analyzer Manufacturer	Model	Serial Number
CO	0 – 500.5 ppm	Horiba	AIA-210	41469090011
CO	0 – 1001 ppm	Horiba	AIA-210LE	4283805005
CO_2	0 - 4%	Horiba	AIA-210	41600730022
NO_x	0 – 303.5 ppm	Rosemount	955	1000645
HC	0-20 ppm C_3H_8	Rosemount	402	1000438
NO_x	0-303.5 ppm	Eco Physics	CLD 822	822CMh0272

Bag Sampling

In addition to being sampled by the analyzers during the test, a portion of the diluted exhaust was also collected in 80ℓ Tedlar bags. One bag was used to collect a diluted exhaust gas sample and a second bag was used to collect a sample of the dilution air to account for any trace gas concentrations. This allowed for the background concentrations contained in the dilution air to be subtracted from the analyzer measurements to quantify actual exhaust stream concentrations. The dilute sample bag was analyzed to allow comparison between it and the integrated sample for a quality control/quality assurance check of the data.

Instrumentation Control/Data Acquisition

All electrical signals from the various dynamometer and engine parameter-measuring transducers were lead to the main data acquisition system. These signals were sent through Analog Devices 3B Signal Conditioning Modules and then to one of three RTI815F data acquisition boards, mounted in the Main Acquisition and Control Computer. The collection of the data signals and the execution of the test cycles were performed by this microcomputer. All analog-to-digital and digital-to-analog conversions were performed with a resolution of 12 bits.

Equipment Check-out and Calibration

(Applicable calibration worksheets are included in the Appendix)

In the days immediately preceding testing, the dynamometer torque arm was calibrated and the speed sensor checked. All the gas analyzers were checked in accordance with the CFR40. The following pretests were performed:

NO_x Analyzers

Efficiency and drift tests:

Instrument Serial No.	Conversion Efficiency (Limit: >90 %)	Drift: (Limit: <2% per hour)
1000645	97.8%	-0.2% over 97mins
822CMh0272	97.8%	+0.2% over 90mins

HC Analyzer

Flame ionization detector (FID) peaking, drift, oxygen interference and methane response tests:

Instrument Serial No.	Methane Response	O2 Interference	Drift
1000438	35.22%	0.33%	+0.1% in 90mins

CO_2 Analyzer

Water interference and drift:

Instrument Serial No.	H_2O interference	Drift: (Limit: <2% per hour)
41600730022		+0.3% in 90mins

CO Analyzers

H_2O and CO_2 interference and drift:

Instrument Serial No.	H_2O and CO_2 interference Limits: <=300ppm: <3ppm >300ppm: <1%full scale	Drift: (Limit: <2% per hour)
57777102 on 100ppm	+0.1% or +0.1ppm	-0.3% over 90mins
4254937005 on 500ppm	+0.1% or 0.5ppm	+0.1% over 90mins

Propane Injection

In order to confirm the integrity of the tunnel, venturis, blower, and sample train, pure propane was injected through a calibrated nozzle into the emissions-gathering system at the entrance to the dilution tunnel, for a period of 300 seconds. The response of the hydrocarbon analyzer was recorded during this period, while a Tedlar bag of background air was simultaneously collected. From these values, the quantities of propane injected and recovered were compared. The 40CFR86 allows for a “spread in results” of up to 2%. As can be seen in the Appendix, the difference between the injected and recovered values for each injection in this case was within 0.5%.

Engine Mechanical Output

A full-power performance map was obtained for the engine in stock configuration. The torque output of the engine was measured while the engine speed was increased from curb idle to 105% of the speed range at 8rpm per second (as set out in 40CFR§86.1332-90). The power and torque curve are shown in the following figure.

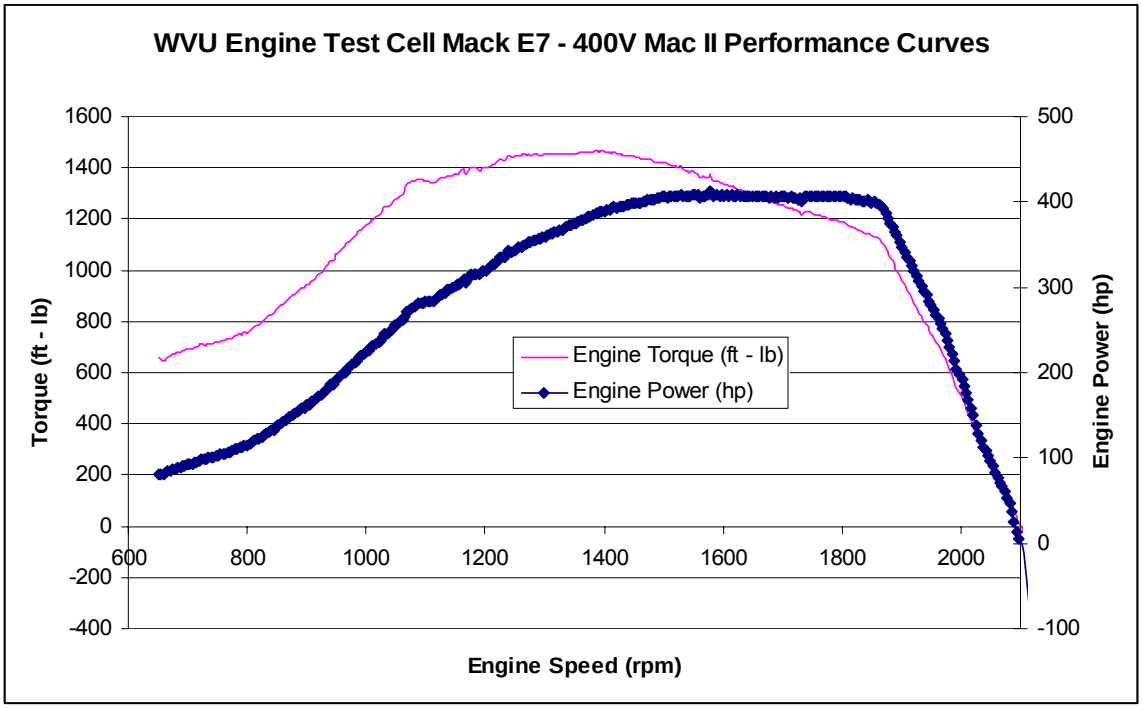


Figure 3: Engine MAP

This engine map curve showed the actual mechanical output to be as follows:

Table 3: Engine Mechanical Output

Maximum Torque	1465	ft-lb
Speed at Maximum Torque	1397	rpm
Rated Speed	1578	rpm
Power at Rated Speed	413	hp
Curb Idle Speed	655	rpm
High Idle Speed	2147	rpm

These parameters were then used to convert the percentage speed and load setpoints, given in Appendix 1 of 40CFR Part 86, into engineering units for the subsequent FTP tests, using the method given in §86.1333-90.

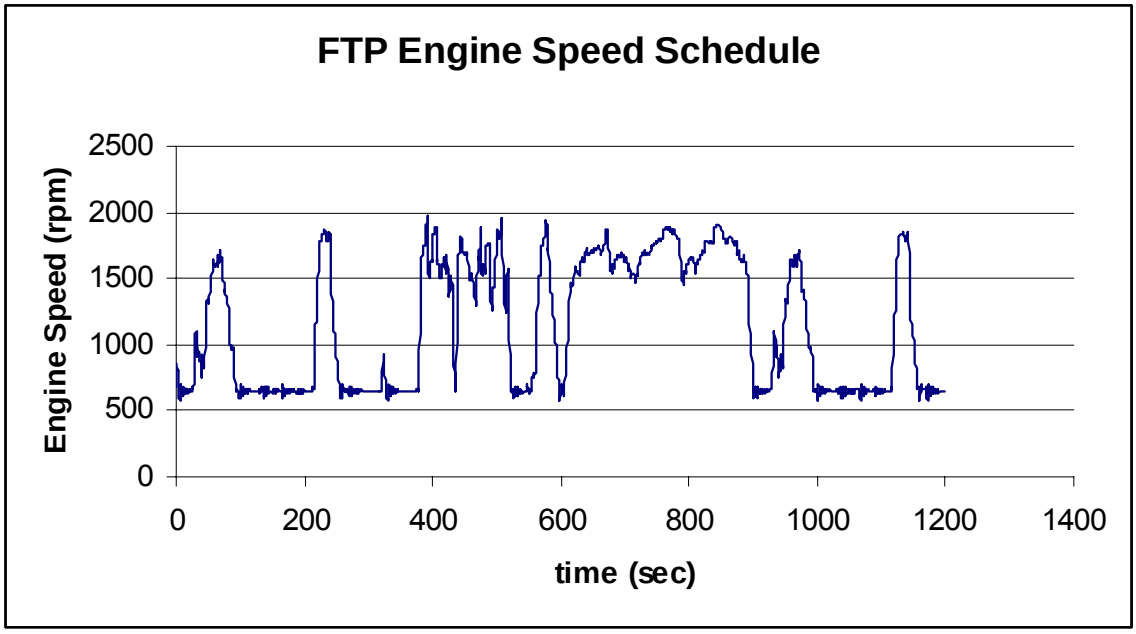


Figure 4: FTP Engine Speed Schedule

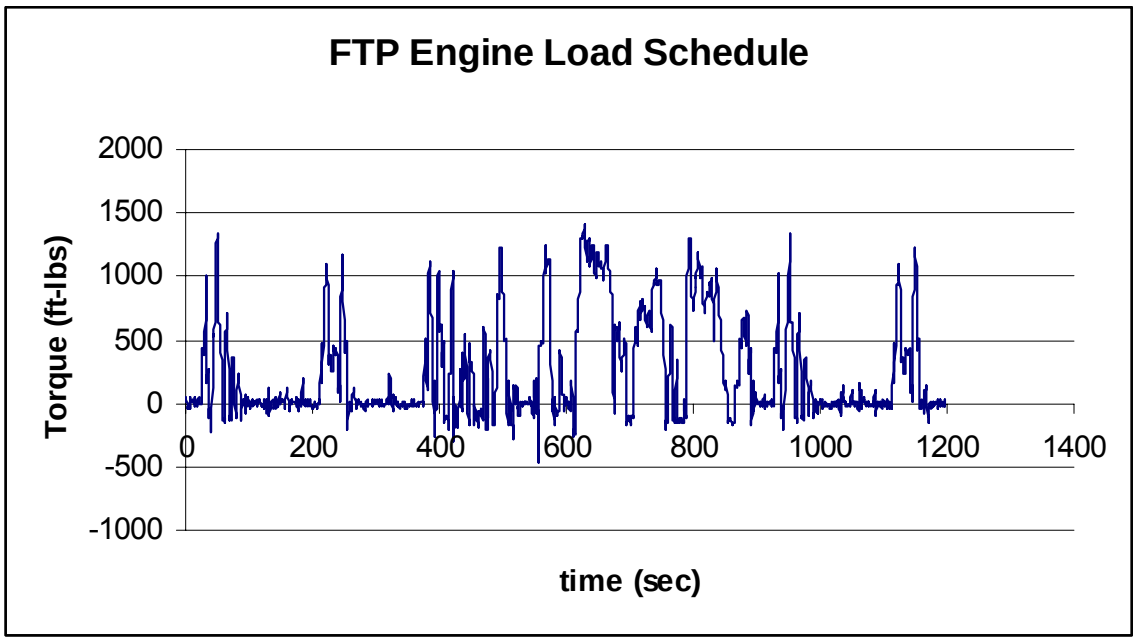


Figure 5: FTP Engine Load Schedule

Test Procedure

The engine was operated in its stock configuration through one warm-start FTP followed by three hot-start FTPs. Clean Air Associates then fit the pre-combustion fuel catalytic converter device to the engine. The engine was operated for a period of 6 hours over a run-in cycle comprised of a repeating series of steady-state speed and torque set-points.

The engine was then operated in this configuration through a further set of one warm FTP and three hot FTPs. The pre-combustion catalytic converter device was then removed from the engine and the engine remapped. A complete set of engine maps is shown below.

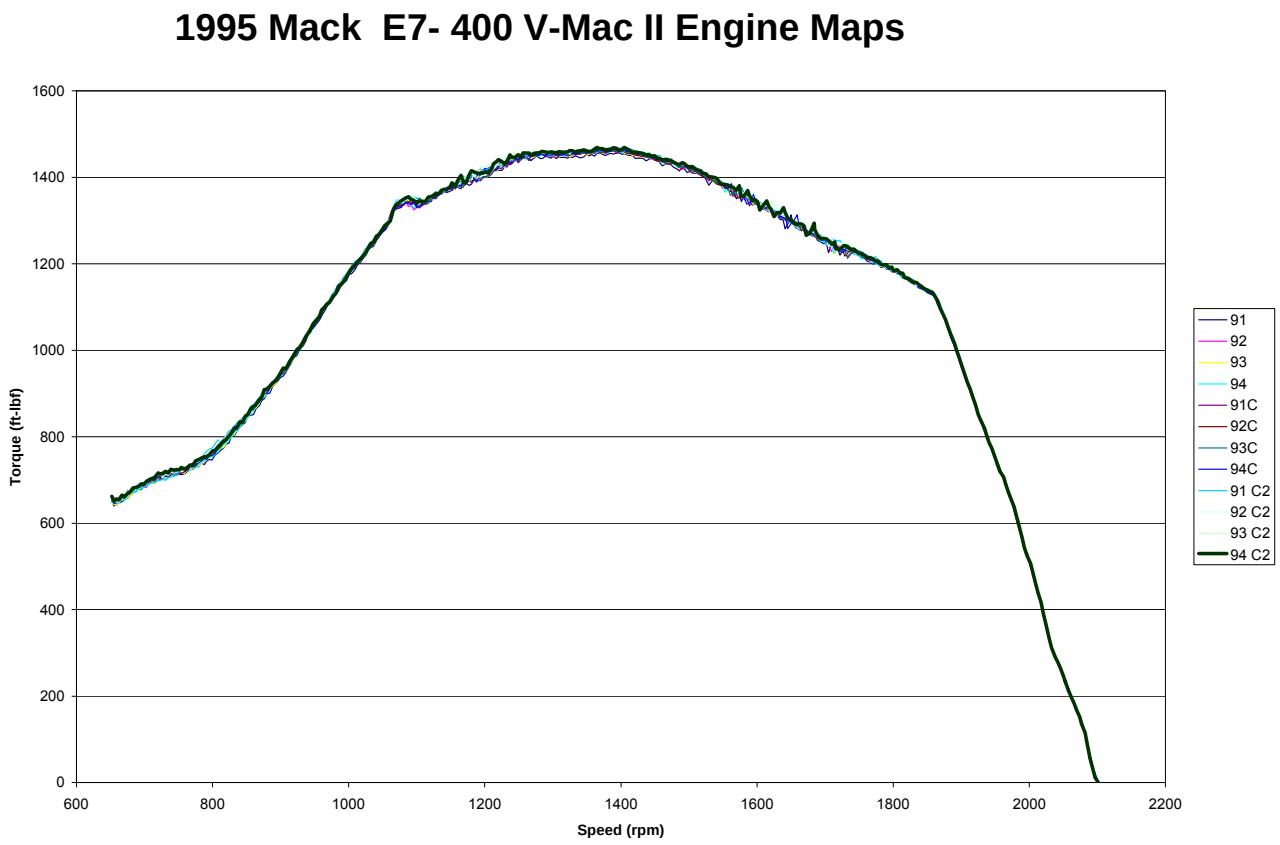


Figure 6: Engine Maps with and without Catalyst Installed

In Figure 6, lines labeled 91, 92, 93, and 94 represent the engine torque of the stock configuration. The lines labeled 91C, 92C, 93C, and 94C represent the engine torque with the pre-combustion fuel catalytic converter installed. The lines labeled 91 C2, 92 C2, 93 C2, and 94 C2 represent the engine torque with the pre-combustion fuel catalytic converter installed and electrically isolated from the engine.

Results

Detailed results from each run are included in Appendix 3 and 4. Summaries of the results are shown in the following figures:

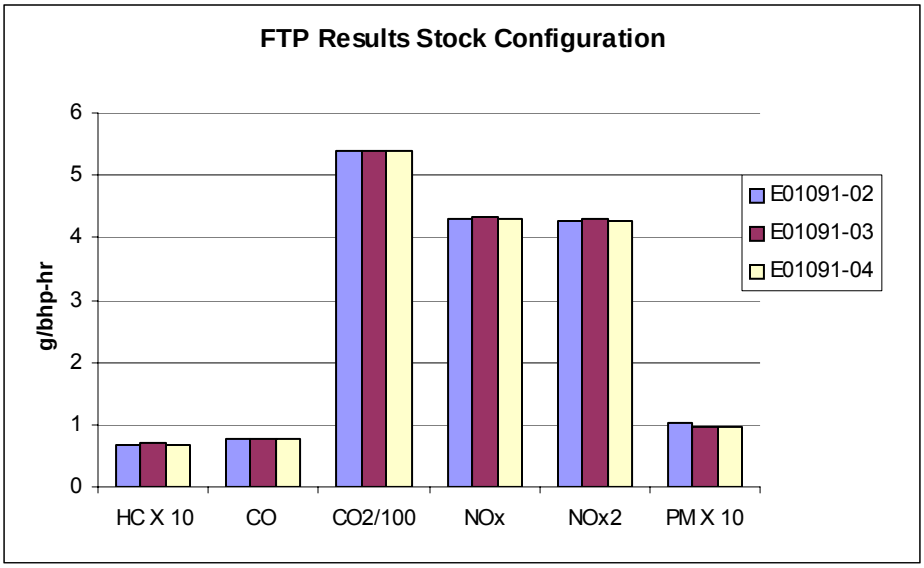


Figure 7: Summary of FTP Test Results Stock Configuration

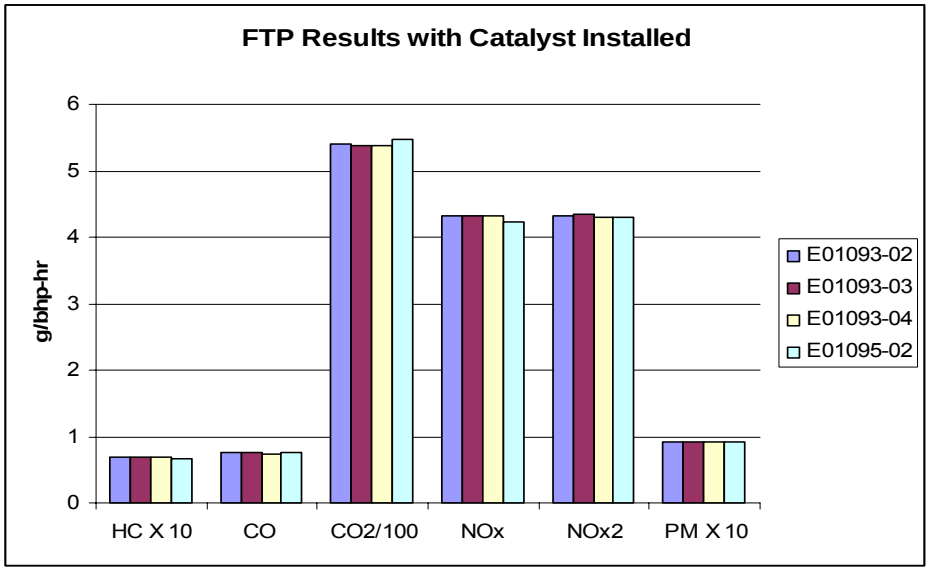


Figure 8: FTP Test Results with Catalyst Installed

Each column of Figure 7 and Figure 8 is the average value in terms of g/bhp-hr for each of the emissions components of the three hot-start tests. Figure 7 displays the results with the engine in its stock configuration. Figure 8 shows the results with the catalyst installed. Run E01095-02 in Figure 8 illustrates the hot run results with the catalyst electrically isolated from the engine.

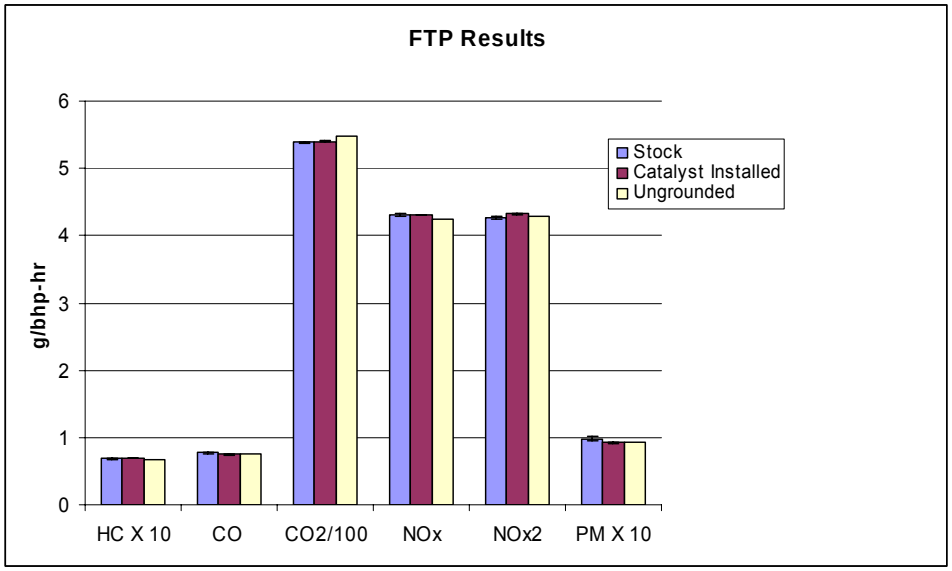


Figure 9: Summary of FTP Test Results

Each column of Figure 9 is the average for each of the emissions components of the three Hot Starts for that configuration. The "Error Bars", shown at the top of each respective column, represent the 95% Confidence Index of that component for all three runs. (A shorter error bar reflects more consistency within a given batch of tests.)

The 95% confidence value is widely used when expressing consistency of emissions results, and is given by the equation:

$$95\%\ Confidence\ Index = \bar{x} \pm 1.96\left(\frac{\sigma}{\sqrt{n}}\right) \qquad (1)$$

where $\bar{x}$ is the average of the three Hot Start runs, σ is the value of one standard deviation, and n is the number of tests: 3, in this case.

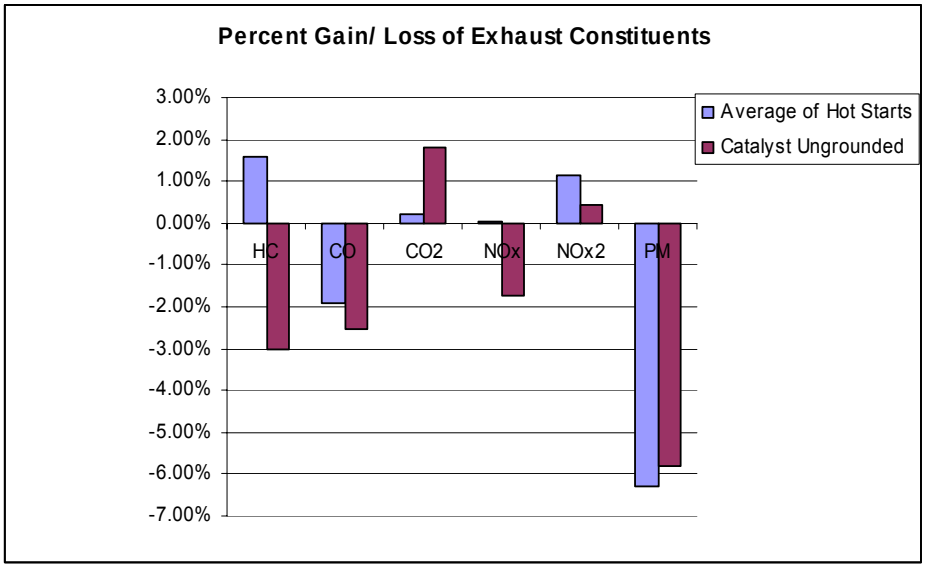


Figure 10: Percentage Change in Emissions after Catalyst Installation

Figure 10 shows the percentage difference between the averages of the three hot runs of the stock and modified configurations. Any exhaust constituent found to have a negative percentage illustrates a reduction in that constituent.

References

1. Code of Federal Regulations, Title 40, Part 86, “Protection of Environment,” US Government Printing Office, 2005.

Appendix 1

Instrument Calibrations

Dynamometer Tachometer

Calibration Date: 4/19/2006 **Time:** 13:03:28

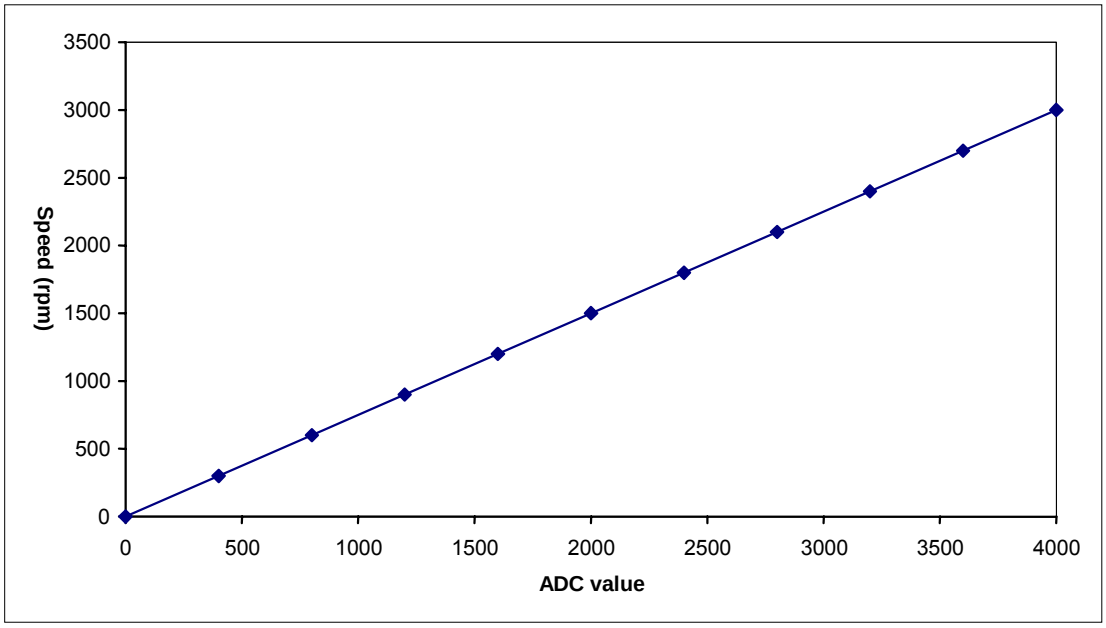
Manufacturer: GE **Type:** AN-DG-A

Serial Number: NP36A424873AT

Span: 3000rpm

Calibration Results:

ADC:	Speed:
0.3	0
400.1	300
800.2	600
1200.0	900
1600.5	1200
2000.1	1500
2399.8	1800
2799.8	2100
3199.5	2400
3600.1	2700
3999.7	3000



Speed (rpm) = 0.7500 x ADC

R^2 = 1.0000

Torque Arm Load Cell

Calibration Date: 04-19-2006 **Time:** 13:16:51

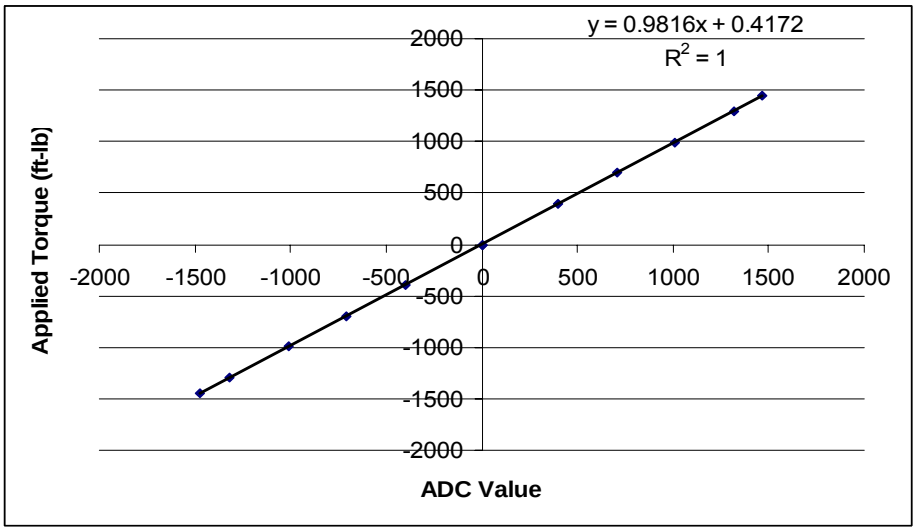
Manufacturer: Eaton Lebow **Type:** 6214-112

Serial Number: 11315

Span: 1000 lb

Calibration Results:

ADC Value	Applied Torque
53	0
398.55	393
705.12	693
1010.52	993
1316.46	1293
1469.55	1443
0.27	0
-397.46	-393
-704.66	-693
-1012.6	-993
-1319.1	-1293
-1472.3	-1443



Applied Load = .9816*ADC+0.4172

R^2=0.9999

CO_2 Analyzer

Calibration Date: 04-19-2006 **Time:** 11:19:36

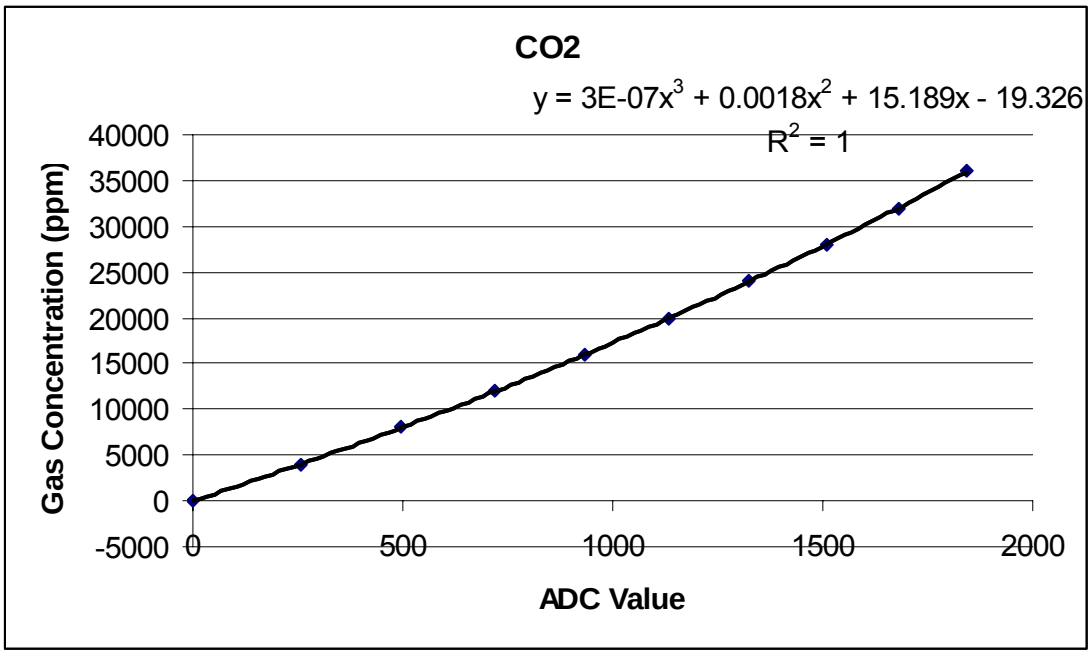
Manufacturer: Horiba **Type:** AIA - 210

Serial Number: 41600730022

Span: 36000 ppm

Calibration Results:

ADC Value	Gas Con.
1843.5	36000
1682.8	32000
1507.5	28000
1325.25	24000
1134.65	20000
933.65	16000
720	12000
496.95	8000
258.05	4000
0.1	0



$CO_2(ppm)=3E\text{-}07*ADC^3 + 0.0018*ADC^2 + 15.189*ADC - 19.326$

$R^2 = 0.99999$

High CO Analyzer

Calibration Date: 04-19-2006 **Time:** 8:43:13

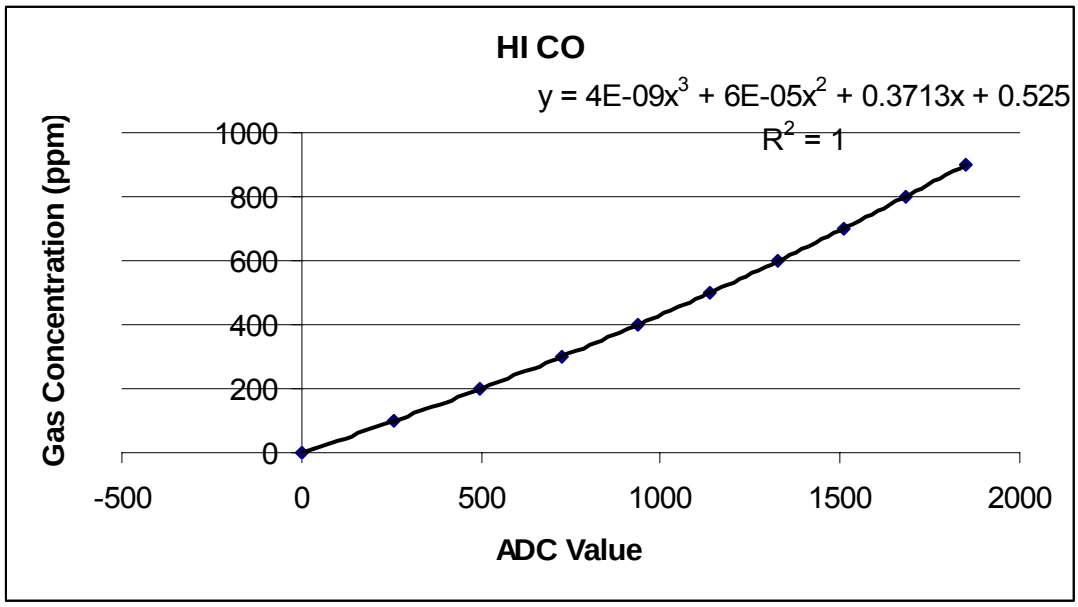
Manufacturer: Horiba **Type:** AIA - 210

Serial Number: 4254937005

Span: 900.9 ppm

Calibration Results:

ADC Value	Gas Con.
1848.55	900.9
1681.25	800.8
1508.85	700.7
1327.85	600.6
1138.05	500.5
936.85	400.4
724.75	300.3
498.6	200.2
258	100.1
-1.25	0



CO(ppm)= $4E\text{-}09ADC^3 + 6E\text{-}05ADC^2 + 0.3713ADC + 0.525$

$R^2 = 0.9999$

LOW CO Analyzer

Calibration Date: 04-19-2006 **Time:** 8:37:12

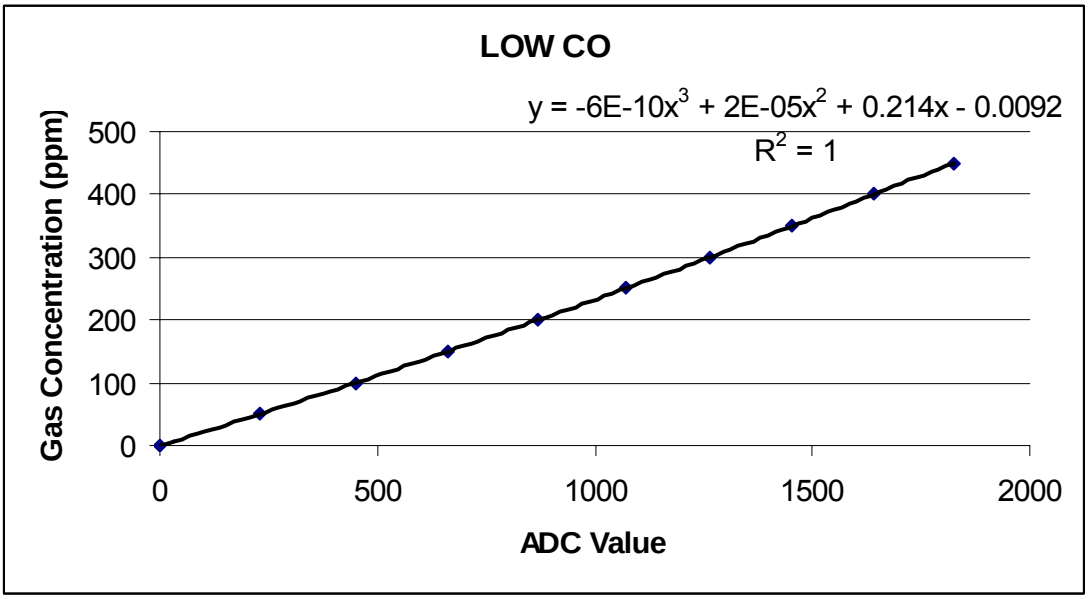
Manufacturer: Horiba **Type:** AIA - 210

Serial Number: 57777102

Span: 500.3 ppm

Calibration Results:

ADC Value	Gas Conc
1823.6	450.2
1641.5	400.2
1454.95	350.2
1265.5	300.1
1069.8	250.1
869.35	200.1
663.25	150.0
449.65	100.0
228.75	50.0
0.3	0



$CO(ppm) = -6E\text{-}10ADC^3 + 2E\text{-}05ADC^2 + 0.214ADC - 0.0092$

$R^2 = 0.9999$

NO_x Analyzer

Calibration Date: 04-19-2006 **Time:** 9:45:18

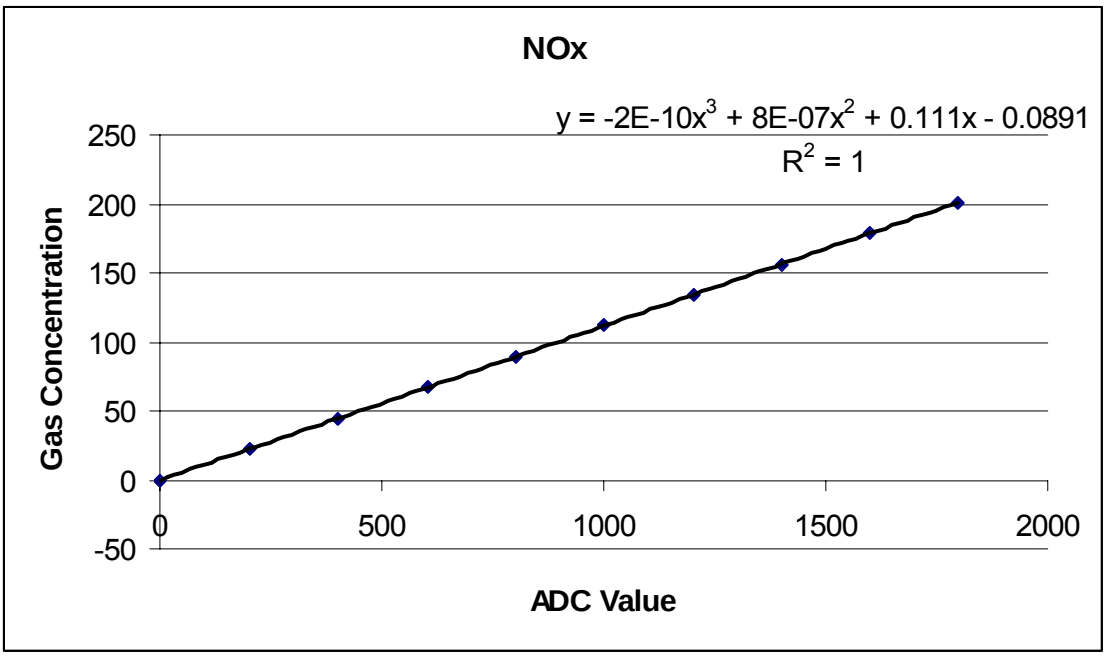
Manufacturer: Rosemount **Type:** 955

Serial Number: 1000645

Span: 303.5ppm

Calibration Results:

ADC Value	Gas Conc
1798.55	201.0
1598.3	178.7
1399.65	156.3
1202.55	134.0
1001.25	111.6
800.4	89.3
601.7	67.0
403.05	44.6
202.35	22.3
0.3	0



$NO_x(ppm) = -2E\text{-}10*ADC^3 + 8E\text{-}07ADC^2 + 0.111ADC - 0.0891$

$R^2 = 1$

HC Analyzer

Calibration Date: 5-2-2006 **Time:** 11:48:51

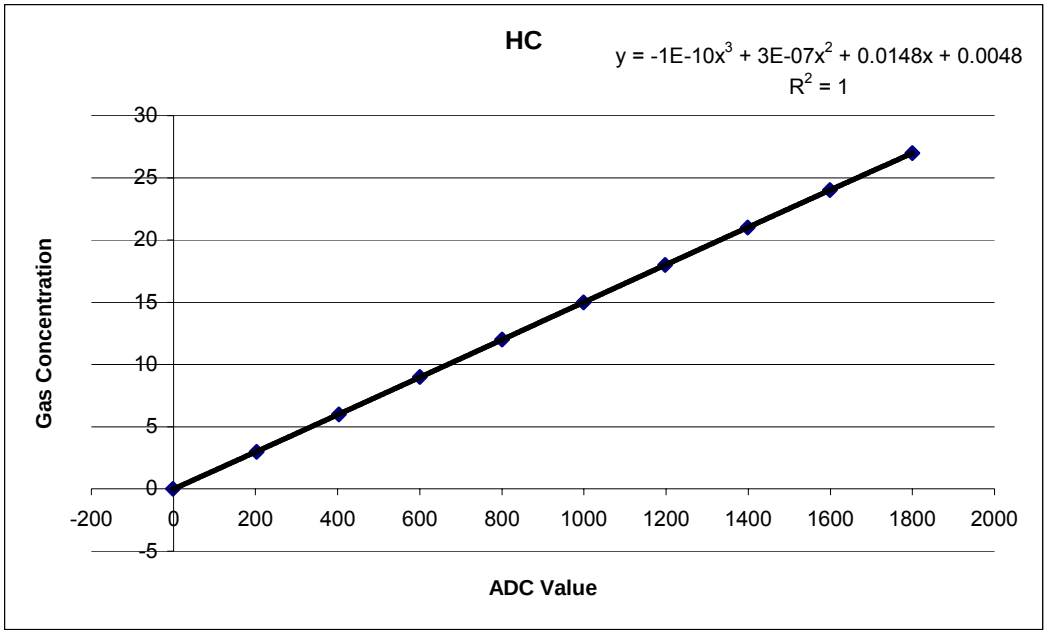
Manufacturer: Rosemount **Type:** 402

Serial Number: 100438

Span: 27ppmC

Calibration Results:

ADC Value	Gas Con.
1799.7	27
1599	24
1398.55	21
1197.95	18
999.1	15
800.2	12
600.25	9
402.7	6
202.9	3
-1.25	0



HC(ppm)= $-1E-10ADC^3+3E-07ADC^2+0.0148ADC-0.0048$

$R^2=1$

Appendix 2

Propane Injections

WEST VIRGINIA UNIVERSITY ENGINE AND EMISSIONS RESEARCH LABORATORY

PROPANE INJECTION 05-04-2006 13:51:47

Volume of mixing air: 11,412.2 scf

Barometric Pressure: 28.81 in. Hg

Propane kit pressure: 64.90 psig

Propane kit temperature: 71.50 deg F

Measured propane (avg.): 146.38 ppm of Propane

Measured HC back ground: 0.92 ppm of Propane

Volume of propane recovered: 1.66009 scf

Volume of propane injected : 1.63809 scf

Propane Volume difference: -0.02200 scf

Percent error in propane volumes: -1.343 %

2,400 scfm Blower venturis and 3,000 scfm Injection kit nozzle used.

Venturis used : BCD Kv of venturis : 26.1254

Test period: 300 Seconds

HC Analyzer Channel: 15

Kit nozzle coefficients used in calculations:

A = -5.478353D-02
B = 9.166537D-02
C = 5.750750D-05

WEST VIRGINIA UNIVERSITY ENGINE AND EMISSIONS RESEARCH LABORATORY

PROPANE INJECTION 05-04-2006 14:03:17

Volume of mixing air: 11,405.2 scf

Barometric Pressure: 28.80 in. Hg

Propane kit pressure: 65.00 psig

Propane kit temperature: 72.40 deg F

Measured propane (avg.): 146.89 ppm of Propane

Measured HC back ground: 1.02 ppm of Propane

Volume of propane recovered: 1.66367 scf

Volume of propane injected : 1.63878 scf

Propane Volume difference: -0.02489 scf

Percent error in propane volumes: -1.519 %

2,400 scfm Blower venturis and 3,000 scfm Injection kit nozzle used.

Venturis used : BCD Kv of venturis : 26.1254

Test period: 300 Seconds

HC Analyzer Channel: 15

Kit nozzle coefficients used in calculations:

A = -5.478353D-02
B = 9.166537D-02
C = 5.750750D-05

WEST VIRGINIA UNIVERSITY ENGINE AND EMISSIONS RESEARCH LABORATORY

PROPANE INJECTION 05-04-2006 14:12:19

Volume of mixing air: 11,401.6 scf

Barometric Pressure: 28.80 in. Hg

Propane kit pressure: 65.00 psig

Propane kit temperature: 72.70 deg F

Measured propane (avg.): 146.70 ppm of Propane

Measured HC back ground: 1.06 ppm of Propane

Volume of propane recovered: 1.66048 scf

Volume of propane injected : 1.63832 scf

Propane Volume difference: -0.02217 scf

Percent error in propane volumes: -1.353 %

2,400 scfm Blower venturis and 3,000 scfm Injection kit nozzle used.

Venturis used : BCD Kv of venturis : 26.1254

Test period: 300 Seconds

HC Analyzer Channel: 15

Kit nozzle coefficients used in calculations:

A = -5.478353D-02
B = 9.166537D-02
C = 5.750750D-05

WEST VIRGINIA UNIVERSITY ENGINE AND EMISSIONS RESEARCH LABORATORY

PROPANE INJECTION 05-04-2006 14:22:02

Volume of mixing air: 11,401.8 scf

Barometric Pressure: 28.79 in. Hg

Propane kit pressure: 65.00 psig

Propane kit temperature: 73.00 deg F

Measured propane (avg.): 146.65 ppm of Propane

Measured HC back ground: 1.09 ppm of Propane

Volume of propane recovered: 1.65969 scf

Volume of propane injected : 1.63775 scf

Propane Volume difference: -0.02194 scf

Percent error in propane volumes: -1.340 %

2,400 scfm Blower venturis and 3,000 scfm Injection kit nozzle used.

Venturis used : BCD Kv of venturis : 26.1254

Test period: 300 Seconds

HC Analyzer Channel: 15

Kit nozzle coefficients used in calculations:

A = -5.478353D-02
B = 9.166537D-02
C = 5.750750D-05

WEST VIRGINIA UNIVERSITY ENGINE AND EMISSIONS RESEARCH LABORATORY

PROPANE INJECTION 05-04-2006 14:31:03

Volume of mixing air: 11,399.1 scf

Barometric Pressure: 28.79 in. Hg

Propane kit pressure: 65.00 psig

Propane kit temperature: 73.10 deg F

Measured propane (avg.): 146.40 ppm of Propane

Measured HC back ground: 1.03 ppm of Propane

Volume of propane recovered: 1.65700 scf

Volume of propane injected : 1.63759 scf

Propane Volume difference: -0.01940 scf

Percent error in propane volumes: -1.185 %

2,400 scfm Blower venturis and 3,000 scfm Injection kit nozzle used.

Venturis used : BCD Kv of venturis : 26.1254

Test period: 300 Seconds

HC Analyzer Channel: 15

Kit nozzle coefficients used in calculations:

A = -5.478353D-02
B = 9.166537D-02
C = 5.750750D-05

Appendix 3

Baseline

FTP Results

FTP Test Validity Analysis Table

Cold start diesel cycle FTP test taken on 05/02/06 at 3:18 PM for MACK EM7-300L Engine

SPEED	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	13.45	0 -- 100	pass
Slope of Reg.	0.9968	0.97 -- 1.03	pass
Y Intercept	9.41	±50	pass
Coeff. of Reg.	0.9990	0.97 -- 1	pass

TORQUE	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	78.15	0 -- 190.03	pass
Slope of Reg.	0.9569	0.77 -- 1.03	pass
Y Intercept	-2.39	±15	pass
Coeff. of Reg.	0.9627	0.85 -- 1	pass

BHP	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	27.68	0 -- 32.72	pass
Slope of Reg.	0.9691	0.87 -- 1.03	pass
Y Intercept	-2.11	±5	pass
Coeff. of Reg.	0.9531	0.91 -- 1	pass
Integrated BHP	26.741	23.960 -- 29.597	pass

D:\Mack 1989-95 EM7 - Clean Air Associates\E01091\01\

E01091-01 Taken on 05/02/06 at 3:18 PM

	Background Bag		Dilute Bag		Continuous Sampling	
	PPM	g/BhpHr	PPM	g/BhpHr	PPM	g/BhpHr
HC	3.159	0.077	5.035	0.053	5.597	0.0666
CO	-0.627	-0.031	16.088	0.876	16.252	0.852
CO2	386.703	30.122	7352.176	576.474	7468.940	541.997
NOx	0.125	0.010	51.735	4.555	50.791	4.258
NOx2	-0.029	-0.002	51.460	4.543	50.836	4.272
PM						0.1164

FTP01 Warm Start, BP D2, Baseline

Engine Name:	MACK EM7-300L
Start Type:	Cold Start
Volume of total mixture:	43,091.3 SCF
Dilution factor:	17.89
Work actual/reference:	27.06/28.19 BhpHr
Brake specific fuel con.:	0.3681 lb/BhpHr
Fuel consumption:	9.961 lb
Fuel recovered:	10.190 lb
MT temp Ave/Max/Min:	223/398/107 °F
Fltr face temp Ave/Max/Min:	88/99/79 °F
Fuel temp Ave/Max/Min:	92/95/88 °F
MA temp Ave/Max/Min:	94/134/86 °F
Intake Air Temp Ave/Max/Min:	77/78/76 °F
Exhaust Temp Ave/Max/Min:	527/912/227 °F
Cat Inlet temp Ave/Max/Min:	82/96/76 °F
Cat Outlet temp Ave/Max/Min:	77/80/74 °F
Average Intake Air Mass:	481.3 lb
Average Humidity Factor:	1.023
Average Relative Humidity:	55.24%
Intake Absolute Humidity:	83.7 grain/lb
Barometric Pressure:	28.80 in. Hg
Total Flow Through Filter:	33.39 SCF
Split Ratio:	1.000
Channel 50:	0.00 SCF
Channel 51:	0.00 litres

FTP Test Validity Analysis Table

Hot start diesel cycle FTP test taken on 05/02/06 at 3:58 PM for MACK EM7-300L Engine

SPEED	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	14.20	0 -- 100	pass
Slope of Reg.	0.9966	0.97 -- 1.03	pass
Y Intercept	9.63	±50	pass
Coeff. of Reg.	0.9989	0.97 -- 1	pass

TORQUE	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	79.36	0 -- 190.03	pass
Slope of Reg.	0.9583	0.83 -- 1.03	pass
Y Intercept	-2.82	±15	pass
Coeff. of Reg.	0.9619	0.88 -- 1	pass

BHP	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	28.01	0 -- 32.72	pass
Slope of Reg.	0.9689	0.89 -- 1.03	pass
Y Intercept	-1.87	±5	pass
Coeff. of Reg.	0.9523	0.91 -- 1	pass
Integrated BHP	26.807	23.960 -- 29.597	pass

D:\Mack 1989-95 EM7 - Clean Air Associates\E01091\02\

E01091-02 Taken on 05/02/06 at 3:58 PM

	Background Bag		Dilute Bag		Continuous Sampling	
	PPM	g/BhpHr	PPM	g/BhpHr	PPM	g/BhpHr
HC	3.416	0.083	5.342	0.055	5.871	0.0673
CO	-0.638	-0.032	14.546	0.793	14.964	0.784
CO2	399.837	31.057	7314.160	570.635	7455.924	538.852
NOx	0.070	0.006	51.626	4.522	51.650	4.308
NOx2	0.117	0.010	51.599	4.516	51.169	4.261
PM						0.1017

FTP02 Hot Start BP D2, Baseline

Engine Name:	MACK EM7-300L
Start Type:	Hot Start
Volume of total mixture:	43,056.5 SCF
Dilution factor:	17.92
Work actual/reference:	27.12/28.19 BhpHr
Brake specific fuel con.:	0.3658 lb/BhpHr
Fuel consumption:	9.919 lb
Fuel recovered:	10.151 lb
MT temp Ave/Max/Min:	224/398/107 °F
Fltr face temp Ave/Max/Min:	88/99/79 °F
Fuel temp Ave/Max/Min:	91/95/80 °F
MA temp Ave/Max/Min:	93/133/86 °F
Intake Air Temp Ave/Max/Min:	77/78/77 °F
Exhaust Temp Ave/Max/Min:	530/900/265 °F
Cat Inlet temp Ave/Max/Min:	81/96/75 °F
Cat Outlet temp Ave/Max/Min:	77/80/74 °F
Average Intake Air Mass:	481.5 lb
Average Humidity Factor:	1.020
Average Relative Humidity:	54.53%
Intake Absolute Humidity:	82.5 grain/lb
Barometric Pressure:	28.80 in. Hg
Total Flow Through Filter:	35.23 SCF
Split Ratio:	1.000
Channel 50:	0.00 SCF
Channel 51:	0.00 litres

FTP Test Validity Analysis Table

Hot start diesel cycle FTP test taken on 05/02/06 at 4:38 PM for MACK EM7-300L Engine

SPEED	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	18.14	0 -- 100	pass
Slope of Reg.	0.9985	0.97 -- 1.03	pass
Y Intercept	6.82	±50	pass
Coeff. of Reg.	0.9981	0.97 -- 1	pass

TORQUE	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	78.87	0 -- 190.03	pass
Slope of Reg.	0.9626	0.83 -- 1.03	pass
Y Intercept	-1.69	±15	pass
Coeff. of Reg.	0.9625	0.88 -- 1	pass

BHP	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	27.31	0 -- 32.72	pass
Slope of Reg.	0.9731	0.89 -- 1.03	pass
Y Intercept	-1.55	±5	pass
Coeff. of Reg.	0.9547	0.91 -- 1	pass
Integrated BHP	26.946	23.960 -- 29.597	pass

D:\Mack 1989-95 EM7 - Clean Air Associates\E01091\03\

E01091-03 Taken on 05/02/06 at 4:38 PM

	Background Bag		Dilute Bag		Continuous Sampling	
	PPM	g/BhpHr	PPM	g/BhpHr	PPM	g/BhpHr
HC	2.941	0.072	5.083	0.060	5.509	0.0695
CO	-0.620	-0.031	14.332	0.782	14.600	0.766
CO2	373.679	29.062	7267.378	569.275	7402.068	537.765
NOx	-0.101	-0.008	52.587	4.557	52.618	4.335
NOx2	0.104	0.008	52.513	4.534	52.323	4.294
PM						0.0974

Hot Start, Clean Air Associates, before catalyst

Engine Name:	MACK EM7-300L
Start Type:	Hot Start
Volume of total mixture:	43,095.2 SCF
Dilution factor:	18.05
Work actual/reference:	27.12/28.19 BhpHr
Brake specific fuel con.:	0.3654 lb/BhpHr
Fuel consumption:	9.909 lb
Fuel recovered:	10.131 lb
MT temp Ave/Max/Min:	223/395/108 °F
Fltr face temp Ave/Max/Min:	87/98/78 °F
Fuel temp Ave/Max/Min:	92/94/87 °F
MA temp Ave/Max/Min:	93/132/87 °F
Intake Air Temp Ave/Max/Min:	76/78/75 °F
Exhaust Temp Ave/Max/Min:	529/903/266 °F
Cat Inlet temp Ave/Max/Min:	81/96/75 °F
Cat Outlet temp Ave/Max/Min:	77/79/74 °F
Average Intake Air Mass:	482.2 lb
Average Humidity Factor:	1.005
Average Relative Humidity:	52.26%
Intake Absolute Humidity:	76.9 grain/lb
Barometric Pressure:	28.82 in. Hg
Total Flow Through Filter:	35.27 SCF
Split Ratio:	1.000
Channel 50:	0.00 SCF
Channel 51:	0.00 litres

FTP Test Validity Analysis Table

Hot start diesel cycle FTP test taken on 05/02/06 at 5:19 PM for MACK EM7-300L Engine

SPEED	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	13.65	0 -- 100	pass
Slope of Reg.	0.9977	0.97 -- 1.03	pass
Y Intercept	7.90	±50	pass
Coeff. of Reg.	0.9989	0.97 -- 1	pass

TORQUE	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	78.76	0 -- 190.03	pass
Slope of Reg.	0.9580	0.83 -- 1.03	pass
Y Intercept	-1.95	±15	pass
Coeff. of Reg.	0.9624	0.88 -- 1	pass

BHP	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	27.80	0 -- 32.72	pass
Slope of Reg.	0.9699	0.89 -- 1.03	pass
Y Intercept	-1.95	±5	pass
Coeff. of Reg.	0.9529	0.91 -- 1	pass
Integrated BHP	26.847	23.960 -- 29.597	pass

D:\Mack 1989-95 EM7 - Clean Air Associates\E01091\04\

E01091-04 Taken on 05/02/06 at 5:19 PM

	Background Bag		Dilute Bag		Continuous Sampling	
	PPM	g/BhpHr	PPM	g/BhpHr	PPM	g/BhpHr
HC	3.092	0.075	5.151	0.058	5.596	0.0680
CO	-0.529	-0.026	14.196	0.769	14.600	0.761
CO2	385.144	29.902	7319.614	571.841	7432.052	538.761
NOx	-0.061	-0.005	52.870	4.542	52.569	4.298
NOx2	0.107	0.009	52.708	4.515	52.291	4.261
PM						0.0963

FTP04 Hot Start BP D2 CAA Baseline

Engine Name:	MACK EM7-300L
Start Type:	Hot Start
Volume of total mixture:	43,013.9 SCF
Dilution factor:	17.98
Work actual/reference:	27.11/28.19 BhpHr
Brake specific fuel con.:	0.3661 lb/BhpHr
Fuel consumption:	9.925 lb
Fuel recovered:	10.145 lb
MT temp Ave/Max/Min:	226/396/110 °F
Fltr face temp Ave/Max/Min:	87/98/77 °F
Fuel temp Ave/Max/Min:	92/95/87 °F
MA temp Ave/Max/Min:	94/132/87 °F
Intake Air Temp Ave/Max/Min:	78/78/76 °F
Exhaust Temp Ave/Max/Min:	530/908/266 °F
Cat Inlet temp Ave/Max/Min:	82/96/76 °F
Cat Outlet temp Ave/Max/Min:	77/80/74 °F
Average Intake Air Mass:	482.0 lb
Average Humidity Factor:	0.999
Average Relative Humidity:	48.76%
Intake Absolute Humidity:	74.5 grain/lb
Barometric Pressure:	28.82 in. Hg
Total Flow Through Filter:	35.23 SCF
Split Ratio:	1.000
Channel 50:	0.00 SCF
Channel 51:	0.00 litres

Appendix 4

FTP Results with Pre-Catalyst Installed

FTP Test Validity Analysis Table

Cold start diesel cycle FTP test taken on 05/03/06 at 10:58 AM for MACK EM7-300L Engine

SPEED	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	13.14	0 -- 100	pass
Slope of Reg.	0.9980	0.97 -- 1.03	pass
Y Intercept	7.26	±50	pass
Coeff. of Reg.	0.9990	0.97 -- 1	pass

TORQUE	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	78.75	0 -- 190.49	pass
Slope of Reg.	0.9569	0.77 -- 1.03	pass
Y Intercept	-1.66	±15	pass
Coeff. of Reg.	0.9621	0.85 -- 1	pass

BHP	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	27.76	0 -- 33.12	pass
Slope of Reg.	0.9696	0.87 -- 1.03	pass
Y Intercept	-2.00	±5	pass
Coeff. of Reg.	0.9529	0.91 -- 1	pass
Integrated BHP	26.785	23.960 -- 29.597	pass

D:\Mack 1989-95 EM7 - Clean Air Associates\E01093\01\

E01093-01 Taken on 05/03/06 at 10:58 AM

	Background Bag		Dilute Bag		Continuous Sampling	
	PPM	g/BhpHr	PPM	g/BhpHr	PPM	g/BhpHr
HC	3.088	0.076	4.992	0.054	5.753	0.0726
CO	-0.534	-0.027	15.724	0.853	15.504	0.811
CO2	369.965	28.852	7388.235	581.207	7420.335	540.798
NOx	0.002	0.000	52.153	4.607	51.156	4.311
NOx2	0.110	0.009	52.514	4.630	51.234	4.308
PM						0.0964

FTP01 Warm Start BP D2, With catalyst

Engine Name:	MACK EM7-300L
Start Type:	Cold Start
Volume of total mixture:	43,137.3 SCF
Dilution factor:	18.01
Work actual/reference:	27.07/28.19 BhpHr
Brake specific fuel con.:	0.3677 lb/BhpHr
Fuel consumption:	9.952 lb
Fuel recovered:	10.169 lb
MT temp Ave/Max/Min:	223/395/108 °F
Fltr face temp Ave/Max/Min:	87/98/76 °F
Fuel temp Ave/Max/Min:	91/95/82 °F
MA temp Ave/Max/Min:	94/135/86 °F
Intake Air Temp Ave/Max/Min:	78/79/77 °F
Exhaust Temp Ave/Max/Min:	527/911/229 °F
Cat Inlet temp Ave/Max/Min:	82/97/76 °F
Cat Outlet temp Ave/Max/Min:	77/80/74 °F
Average Intake Air Mass:	481.8 lb
Average Humidity Factor:	1.023
Average Relative Humidity:	54.20%
Intake Absolute Humidity:	83.8 grain/lb
Barometric Pressure:	28.85 in. Hg
Total Flow Through Filter:	35.31 SCF
Split Ratio:	1.000
Channel 50:	0.00 SCF
Channel 51:	0.00 litres

FTP Test Validity Analysis Table

Hot start diesel cycle FTP test taken on 05/03/06 at 11:38 AM for MACK EM7-300L Engine

SPEED	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	12.13	0 -- 100	pass
Slope of Reg.	0.9991	0.97 -- 1.03	pass
Y Intercept	5.57	±50	pass
Coeff. of Reg.	0.9992	0.97 -- 1	pass

TORQUE	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	78.32	0 -- 190.49	pass
Slope of Reg.	0.9604	0.83 -- 1.03	pass
Y Intercept	-2.85	±15	pass
Coeff. of Reg.	0.9628	0.88 -- 1	pass

BHP	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	27.74	0 -- 33.12	pass
Slope of Reg.	0.9727	0.89 -- 1.03	pass
Y Intercept	-2.25	±5	pass
Coeff. of Reg.	0.9533	0.91 -- 1	pass
Integrated BHP	26.811	23.960 -- 29.597	pass

D:\Mack 1989-95 EM7 - Clean Air Associates\E01093\02\

E01093-02 Taken on 05/03/06 at 11:38 AM

	Background Bag		Dilute Bag		Continuous Sampling	
	PPM	g/BhpHr	PPM	g/BhpHr	PPM	g/BhpHr
HC	3.122	0.077	5.228	0.059	5.656	0.0693
CO	-0.935	-0.046	13.759	0.770	14.250	0.767
CO2	387.697	30.276	7332.739	576.050	7426.703	541.031
NOx	-0.050	-0.004	51.935	4.544	51.626	4.311
NOx2	0.113	0.009	52.329	4.565	51.869	4.318
PM						0.0926

Hot Start, CleanAir Associates Inc, post catalyst

Engine Name:	MACK EM7-300L
Start Type:	Hot Start
Volume of total mixture:	43,137.3 SCF
Dilution factor:	17.99
Work actual/reference:	27.03/28.19 BhpHr
Brake specific fuel con.:	0.3673 lb/BhpHr
Fuel consumption:	9.928 lb
Fuel recovered:	10.158 lb
MT temp Ave/Max/Min:	225/397/107 °F
Fltr face temp Ave/Max/Min:	87/99/77 °F
Fuel temp Ave/Max/Min:	92/96/87 °F
MA temp Ave/Max/Min:	95/134/87 °F
Intake Air Temp Ave/Max/Min:	77/78/77 °F
Exhaust Temp Ave/Max/Min:	530/910/267 °F
Cat Inlet temp Ave/Max/Min:	82/98/77 °F
Cat Outlet temp Ave/Max/Min:	78/80/75 °F
Average Intake Air Mass:	482.7 lb
Average Humidity Factor:	1.011
Average Relative Humidity:	52.57%
Intake Absolute Humidity:	79.3 grain/lb
Barometric Pressure:	28.87 in. Hg
Total Flow Through Filter:	35.32 SCF
Split Ratio:	1.000
Channel 50:	0.00 SCF
Channel 51:	0.00 litres

FTP Test Validity Analysis Table

Hot start diesel cycle FTP test taken on 05/03/06 at 12:18 PM for MACK EM7-300L Engine

SPEED	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	12.29	0 -- 100	pass
Slope of Reg.	0.9985	0.97 -- 1.03	pass
Y Intercept	6.52	±50	pass
Coeff. of Reg.	0.9991	0.97 -- 1	pass

TORQUE	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	78.58	0 -- 190.49	pass
Slope of Reg.	0.9573	0.83 -- 1.03	pass
Y Intercept	-2.89	±15	pass
Coeff. of Reg.	0.9625	0.88 -- 1	pass

BHP	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	27.81	0 -- 33.12	pass
Slope of Reg.	0.9686	0.89 -- 1.03	pass
Y Intercept	-2.09	±5	pass
Coeff. of Reg.	0.9528	0.91 -- 1	pass
Integrated BHP	26.772	23.960 -- 29.597	pass

D:\Mack 1989-95 EM7 - Clean Air Associates\E01093\03\

E01093-03 Taken on 05/03/06 at 12:18 PM

	Background Bag		Dilute Bag		Continuous Sampling	
	PPM	g/BhpHr	PPM	g/BhpHr	PPM	g/BhpHr
HC	3.147	0.077	5.237	0.059	5.705	0.0697
CO	-0.763	-0.038	13.973	0.771	14.169	0.753
CO2	373.679	29.095	7315.149	573.870	7403.675	539.061
NOx	-0.061	-0.005	52.688	4.580	52.042	4.321
NOx2	0.110	0.009	53.119	4.604	52.397	4.336
PM						0.0921

Hot Start, CleanAir Associates Inc., post catalyst

Engine Name:	MACK EM7-300L
Start Type:	Hot Start
Volume of total mixture:	43,084.9 SCF
Dilution factor:	18.05
Work actual/reference:	27.08/28.19 BhpHr
Brake specific fuel con.:	0.3659 lb/BhpHr
Fuel consumption:	9.910 lb
Fuel recovered:	10.140 lb
MT temp Ave/Max/Min:	227/398/109 °F
Fltr face temp Ave/Max/Min:	88/99/77 °F
Fuel temp Ave/Max/Min:	92/95/87 °F
MA temp Ave/Max/Min:	95/134/86 °F
Intake Air Temp Ave/Max/Min:	78/79/77 °F
Exhaust Temp Ave/Max/Min:	530/904/267 °F
Cat Inlet temp Ave/Max/Min:	82/97/76 °F
Cat Outlet temp Ave/Max/Min:	77/80/74 °F
Average Intake Air Mass:	481.8 lb
Average Humidity Factor:	1.008
Average Relative Humidity:	50.02%
Intake Absolute Humidity:	78.0 grain/lb
Barometric Pressure:	28.87 in. Hg
Total Flow Through Filter:	35.26 SCF
Split Ratio:	1.000
Channel 50:	0.00 SCF
Channel 51:	0.00 litres

FTP Test Validity Analysis Table

Hot start diesel cycle FTP test taken on 05/03/06 at 12:58 PM for MACK EM7-300L Engine

SPEED	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	13.85	0 -- 100	pass
Slope of Reg.	0.9964	0.97 -- 1.03	pass
Y Intercept	10.00	±50	pass
Coeff. of Reg.	0.9989	0.97 -- 1	pass

TORQUE	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	78.35	0 -- 190.49	pass
Slope of Reg.	0.9613	0.83 -- 1.03	pass
Y Intercept	-3.20	±15	pass
Coeff. of Reg.	0.9628	0.88 -- 1	pass

BHP	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	27.67	0 -- 33.12	pass
Slope of Reg.	0.9716	0.89 -- 1.03	pass
Y Intercept	-1.98	±5	pass
Coeff. of Reg.	0.9534	0.91 -- 1	pass
Integrated BHP	26.853	23.960 -- 29.597	pass

D:\Mack 1989-95 EM7 - Clean Air Associates\E01093\04\

E01093-04 Taken on 05/03/06 at 12:58 PM

	Background Bag		Dilute Bag		Continuous Sampling	
	PPM	g/BhpHr	PPM	g/BhpHr	PPM	g/BhpHr
HC	2.877	0.070	4.948	0.058	5.425	0.0690
CO	-0.803	-0.040	13.897	0.768	14.035	0.747
CO2	382.178	29.725	7375.013	577.579	7413.343	539.056
NOx	-0.039	-0.003	53.129	4.588	52.464	4.314
NOx2	0.109	0.009	53.540	4.611	52.562	4.310
PM						0.0921

Hot Start, CleanAir Associates Inc., post catalyst

Engine Name:	MACK EM7-300L
Start Type:	Hot Start
Volume of total mixture:	43,066.2 SCF
Dilution factor:	18.03
Work actual/reference:	27.10/28.19 BhpHr
Brake specific fuel con.:	0.3664 lb/BhpHr
Fuel consumption:	9.929 lb
Fuel recovered:	10.146 lb
MT temp Ave/Max/Min:	227/392/109 °F
Fltr face temp Ave/Max/Min:	89/100/79 °F
Fuel temp Ave/Max/Min:	92/96/87 °F
MA temp Ave/Max/Min:	95/134/88 °F
Intake Air Temp Ave/Max/Min:	78/79/77 °F
Exhaust Temp Ave/Max/Min:	531/911/268 °F
Cat Inlet temp Ave/Max/Min:	82/97/76 °F
Cat Outlet temp Ave/Max/Min:	77/80/75 °F
Average Intake Air Mass:	482.6 lb
Average Humidity Factor:	1.002
Average Relative Humidity:	48.96%
Intake Absolute Humidity:	75.9 grain/lb
Barometric Pressure:	28.87 in. Hg
Total Flow Through Filter:	35.25 SCF
Split Ratio:	1.000
Channel 50:	0.00 SCF
Channel 51:	0.00 litres

Appendix 5

FTP Results with Pre-Catalyst Isolated

FTP Test Validity Analysis Table

Cold start diesel cycle FTP test taken on 05/04/06 at 10:21 AM for MACK EM7-300L Engine

SPEED	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	13.14	0 -- 100	pass
Slope of Reg.	0.9970	0.97 -- 1.03	pass
Y Intercept	8.81	±50	pass
Coeff. of Reg.	0.9990	0.97 -- 1	pass

TORQUE	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	79.02	0 -- 190.03	pass
Slope of Reg.	0.9567	0.77 -- 1.03	pass
Y Intercept	-2.18	±15	pass
Coeff. of Reg.	0.9619	0.85 -- 1	pass

BHP	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	27.87	0 -- 32.72	pass
Slope of Reg.	0.9694	0.87 -- 1.03	pass
Y Intercept	-2.14	±5	pass
Coeff. of Reg.	0.9524	0.91 -- 1	pass
Integrated BHP	26.761	23.960 -- 29.597	pass

D:\Mack 1989-95 EM7 - Clean Air Associates\E01095\01\

E01095-01 Taken on 05/04/06 at 10:21 AM

	Background Bag		Dilute Bag		Continuous Sampling	
	PPM	g/BhpHr	PPM	g/BhpHr	PPM	g/BhpHr
HC	2.692	0.066	4.671	0.055	5.164	0.0669
CO	-0.809	-0.040	14.843	0.818	15.245	0.810
CO2	385.251	29.962	7313.239	572.378	7447.113	540.882
NOx	-0.047	-0.004	52.064	4.537	51.948	4.319
NOx2	0.105	0.008	52.219	4.539	52.124	4.322
PM						0.0951

Warm Start, CleanAir Associates, Catalyst isolated

Engine Name:	MACK EM7-300L
Start Type:	Cold Start
Volume of total mixture:	43,008.8 SCF
Dilution factor:	17.94
Work actual/reference:	27.05/28.19 BhpHr
Brake specific fuel con.:	0.3679 lb/BhpHr
Fuel consumption:	9.954 lb
Fuel recovered:	10.166 lb
MT temp Ave/Max/Min:	227/398/109 °F
Fltr face temp Ave/Max/Min:	87/99/77 °F
Fuel temp Ave/Max/Min:	91/95/81 °F
MA temp Ave/Max/Min:	95/135/87 °F
Intake Air Temp Ave/Max/Min:	78/79/77 °F
Exhaust Temp Ave/Max/Min:	530/909/240 °F
Cat Inlet temp Ave/Max/Min:	83/99/76 °F
Cat Outlet temp Ave/Max/Min:	78/80/75 °F
Average Intake Air Mass:	481.7 lb
Average Humidity Factor:	1.011
Average Relative Humidity:	50.75%
Intake Absolute Humidity:	79.3 grain/lb
Barometric Pressure:	28.84 in. Hg
Total Flow Through Filter:	35.17 SCF
Split Ratio:	1.000
Channel 50:	0.00 SCF
Channel 51:	0.00 litres

FTP Test Validity Analysis Table

Hot start diesel cycle FTP test taken on 05/04/06 at 11:01 AM for MACK EM7-300L Engine

SPEED	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	13.11	0 -- 100	pass
Slope of Reg.	0.9975	0.97 -- 1.03	pass
Y Intercept	8.20	±50	pass
Coeff. of Reg.	0.9990	0.97 -- 1	pass

TORQUE	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	78.44	0 -- 190.03	pass
Slope of Reg.	0.9583	0.83 -- 1.03	pass
Y Intercept	-3.13	±15	pass
Coeff. of Reg.	0.9626	0.88 -- 1	pass

BHP	Validation Stat.	EPA Criterion Min - Max	Result
Standard Error	27.61	0 -- 32.72	pass
Slope of Reg.	0.9709	0.89 -- 1.03	pass
Y Intercept	-2.46	±5	pass
Coeff. of Reg.	0.9535	0.91 -- 1	pass
Integrated BHP	26.759	23.960 -- 29.597	pass

d:\Mack 1989-95 EM7 - Clean Air Associates\E01095\02\

E01095-02 Taken on 05/04/06 at 11:01 AM

	Background Bag		Dilute Bag		Continuous Sampling	
	PPM	g/BhpHr	PPM	g/BhpHr	PPM	g/BhpHr
HC	2.827	0.069	4.904	0.058	5.267	0.0662
CO	0.026	0.001	14.943	0.782	14.649	0.751
CO2	384.532	29.936	7280.322	570.061	7399.833	548.082
NOx	-0.050	-0.004	52.411	4.457	52.174	4.239
NOx2	0.109	0.009	52.903	4.486	52.955	4.290
PM						0.0927

Hot Start, CleanAir Associates, Isolated Catalyst

Engine Name:	MACK EM7-300L
Start Type:	Hot Start
Volume of total mixture:	43,026.1 SCF
Dilution factor:	18.06
Work actual/reference:	27.05/28.19 BhpHr
Brake specific fuel con.:	0.3668 lb/BhpHr
Fuel consumption:	9.922 lb
Fuel recovered:	10.297 lb
MT temp Ave/Max/Min:	226/398/109 °F
Fltr face temp Ave/Max/Min:	89/100/79 °F
Fuel temp Ave/Max/Min:	92/96/86 °F
MA temp Ave/Max/Min:	95/134/86 °F
Intake Air Temp Ave/Max/Min:	79/81/77 °F
Exhaust Temp Ave/Max/Min:	531/908/268 °F
Cat Inlet temp Ave/Max/Min:	82/98/76 °F
Cat Outlet temp Ave/Max/Min:	77/80/75 °F
Average Intake Air Mass:	482.0 lb
Average Humidity Factor:	0.986
Average Relative Humidity:	46.34%
Intake Absolute Humidity:	72.8 grain/lb
Barometric Pressure:	28.83 in. Hg
Total Flow Through Filter:	35.22 SCF
Split Ratio:	1.000
Channel 50:	0.00 SCF
Channel 51:	0.00 litres