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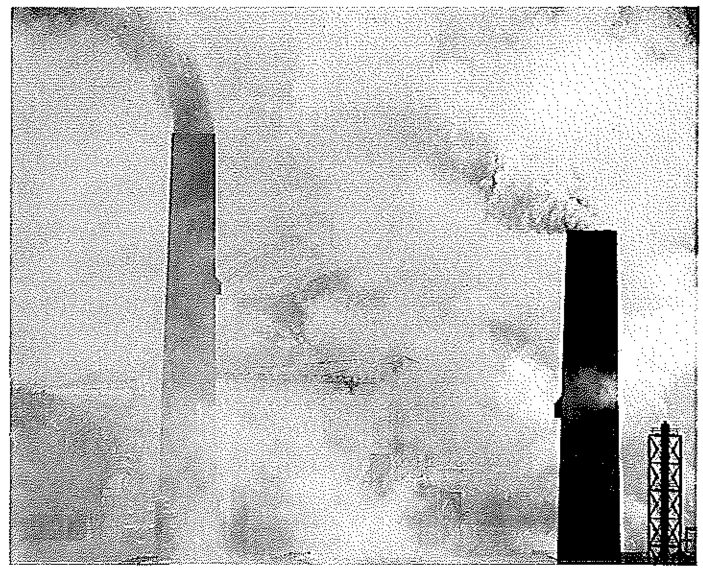

N6989

Final Report

DYNAMOMETER EMISSIONS TEST

AVL Powertrain Engineering, Inc.
Ann Arbor, Michigan

Conestoga-Rovers & Associates
2055 Niagara Falls Boulevard, Suite #3
Niagara Falls, New York 14304

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Partners in Sustainability

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Section 1.0 Introduction

1.1 Project Overview

AVL Powertrain Engineering, Inc. has contracted with Conestoga-Rovers & Associates, Inc. (CRA) to conduct an emission test on three of their dynamometer engine test cells located at their Ann Arbor, Michigan facility.

1.2 Test Program Organization

AVL Powertrain Engineering, Inc. contact is:

Mr. Steve Plewa
EHS Quality Manager
AVL Powertrain Inc.
47519 Halyard Drive
Plymouth, MI 48170-2438
Phone: (734) 446-8305

CRA's Project Manager is:

Mr. Eric Jones
Conestoga-Rovers & Associates, Inc.
14496 North Sheldon Road, Suite 200
Plymouth, MI 48170
Phone: (734) 453-5123

CRA's Field Team Leader was:

Mr. Keith Jaworski
Conestoga-Rovers & Associates, Inc.
2055 Niagara Falls Boulevard
Niagara Falls, NY 14043
Phone: (716) 297-6150

AVL staff coordinated the plant's operations, collected process information and provided CRA with process data. CRA was responsible for all field measurements related to the determination of mass emissions of oxides of nitrogen (NO_x) and carbon monoxide (CO) at each of the dynamometer engine test cells. The testing was performed by Mr. Keith Jaworski, and Mr. Alexander Krause of CRA. The testing was witnessed by Mr. David Patterson and Ms. Diane Kavanaugh of the Michigan Department of Environmental Quality (MDEQ).

1.3 Test Plan

The objectives of this test program were to determine the mass emissions of NO_x and CO from the exhaust stream of three separate dynamometer engine test cells which operated on natural gas, gasoline, and diesel fuel. CRA performed three 1-hour test runs for NO_x and CO at two separate dynamometer engine test cells operating on natural gas and diesel fuel. The test cell which operated on gasoline was not tested.

Testing was conducted according to United States Environmental Protection Agency (USEPA) Reference Methods (RM) outlined in Title 40 of the Code of Federal Regulations, Part 60 (40 CFR 60), Appendix A and 40 CFR 51 Appendix M. A summary of the test methods is presented in Table 1.2.

1.4 Test Plan Deviations

Prior to starting the testing on Test Cell #11(gasoline) CRA discovered that the emissions combined with dilution air was producing a reading of 0 ppm on both the NO_x and CO analyzers. The entire system was sealed up with no dilution air and the CO analyzer was reading 25,000+ ppm. The MDEQ decided that they could not test this way because it wasn't representative of the way AVL normally operates and the previous test cell was operated with the use of dilution air. It was also noted that AVL wanted to use an 8 cylinder engine but only a 4 cylinder was available at the time of the test mobilization. During this test mobilization a standard pitot was used for flow determination in the small duct. The duct size prevented CRA from performing a cyclonic flow check. It was then determined that with the number of duct diameters downstream the flow will be assumed non-cyclonic. All issues were discussed with Mr. David Patterson and Ms. Diane Kavanaugh of the MDEQ, and deviations in operation approved.

Section 2.0 Sampling and Analytical Procedures

This section provides a brief overview of the specific test methods that were used to determine the mass emissions of CO and NO_X at both the natural gas and diesel fuel dynamometer test cells. Details of each method are given in the following sections. Figure 2.1 shows the dynamometer test cell sample point locations and test ports.

2.1 Gas Stream Velocity and Sample Point Location for Small Stacks (RM1A)

The gas stream velocity sampling points were determined using RM1A. The sample duct locations were less than 12" in diameter, but equal to or greater than about 4"in diameter. According to RM 1A, the cross section of the stack is divided into equal areas and a traverse point is then located within each of these areas. The number of traverse points in a cross section was determined by the number of duct diameters upstream and downstream from the test location to a flow disturbance.

2.2 Stack Gas Velocity and Volumetric Flow Rate in Small Stacks (RM2C)

The gas velocity in each duct was determined according to the procedures provided in RM 2C. The average velocity head was determined using an inclined manometer and a standard pitot tube with a pitot coefficient of 0.99. Exhaust gas temperature was measured at each traverse point using a type-K thermocouple. Static pressure was determined using a straight tap and an inclined manometer. One complete velocity traverse was conducted at each test location during each test run. The results were all found to be acceptable and are presented in Appendix A.

2.3 Stack Gas Analysis for CO_2, and O_2 (RM3)

The concentrations of oxygen and carbon dioxide were measured on a dry basis according to the procedures provided in RM 3. O_2 and CO_2. Concentrations were used to determine the molecular weight of each gas stream in the volumetric flow rate calculations. Grab samples were analyzed periodically throughout each test run for O_2 and CO_2 with a Fyrite gas analyzer. The gas concentrations were entered directly into the flow calculation spreadsheets. Field data sheets are included in Appendix A.

2.4 Moisture Determination (RM4)

The determination of effluent moisture was performed according to procedures outlined in Method 4. The sampling train consisted of a sample probe with a glass wool in-stack filter and a series of impingers. Gas was extracted at a constant rate; moisture is removed from the sample stream and determined gravimetrically. Field data sheets are included in Appendix A.

2.5 Total Oxides of Nitrogen (RM 7E)

Total oxides of nitrogen (NO_x) concentrations were measured according to Reference Method 7E. A TECO Model 42I chemiluminescent analyzer was used. NO_x analysis was continuous with 30-second average concentrations recorded on a data acquisition system (DAS). The analyzer operating range was 0-100 ppmvd for natural gas, and 0-500 ppmvd for diesel fuel.

An Environics Model Series 4000 was used to generate appropriate calibration gas concentrations from nitrogen and a USEPA Protocol gas: 4510 ppm NO in nitrogen.

2.6 Carbon Monoxide (RM 10)

Carbon Monoxide (CO) concentrations were measured according to Reference Method 10. A TECO Model 48i non-dispersive infrared (NDIR) analyzer was used. CO analysis was continuous with 15-second average concentrations recorded on a data acquisition system (DAS). The analyzer operating range was 0-100 ppmvd for both fuels.

An Environics Model Series 4000 was used to generate appropriate calibration gas concentrations from nitrogen and a USEPA Protocol gas: 6040 ppm CO in nitrogen.

Section 3.0 Quality Assurance and Quality Control

3.1 Equipment and Sampling Preparation

Sampling equipment is cleaned, functions are checked and calibrated prior to use in the field. The QA/QC procedures for sampling operations include the performing of leak checks before and after each sample run. These are conducted on all train components including vacuum sample trains and pitot lines. If pre-test leak checks do not meet the acceptable criteria for each method, the trains are adjusted and the leaks corrected. Post-test leak checks are mandatory and were performed and recorded on all field data sheets. All post-test calibrations were within method limitations and are summarized in Table 4.1.

3.2 Leak Checks

3.2.1 Moisture Trains

A leak-check is mandatory at the conclusion of each sampling run. A leak-check was conducted in accordance with the procedures outlined in EPA Method 4. The probe tip was plugged, and the sample rate was adjusted until the desired vacuum is reached. If the leakage rate is found to be no greater than 0.02 cubic feet per minute (cfm), the results are acceptable. All leak checks were in the acceptable range and can be found on the field data sheets located in Appendix A.

3.2.2 Pitot Leak Checks

The pitot tubes to be used during the test program were leak checked prior to the test series and following each traverse set. The leak check is performed by placing flexible tubing over the positive pressure side of the pitot tube tip. The tubing is then pressurized to greater than three inches of H_2O and the tubing pinched off. No loss of pressure for fifteen seconds indicates a successful leak check. This procedure was repeated for the negative pressure (vacuum) side of the pitot tube, with vacuum rather than pressure placed on the tubing. All leak check were in the acceptable range and can be found on the field data sheets located in Appendix A.

3.3 Calibrations

Calibration data is included in Appendix B.

3.3.1 Meter Box Calibrations

Following the procedures outlined in EPA Method 5, Section 10.3.2, a standard dry gas meter is substituted for a wet test meter per EPA Method 5, Section 16.1. Primarily, the meter calibration factors (Y and ΔH@) are determined at multipoint calibration runs at a variety of flow rates. Factors calculated at the individual runs must agree within 2 percent of each other. The factors are then averaged and that average is posted on the meter box.

After each sampling run calculations from Alternative Method 5 Post-Test Calibration (ALT-009) are performed. If the average Y_{qa} is within 5 percent of the posted Y the post-test calibration is acceptable. The Alternative Method 5 Post-Test Calibration completed after each RM4 test fell within the acceptable limits of the method. These results can be found on the RM4 field data sheets which are located in Appendix A.

3.3.2 Barometer Calibration

CRA's barometer was compared to the barometer from the National Weather Service (NWS) located at the Niagara Falls International Airport. If the CRA barometer disagrees by more than +/- 2.3 mm (0.1 in.) of Hg from the barometer located at the airport, the CRA barometer is adjusted until it agrees with the NWS barometer. The barometer calibration is included in Appendix B.

3.4 CEMS Sampling Performance Specifications

The CEMs sampling QA/QC activities consist of the following:

3.4.1 System Response Time

The RM system response time was determined during setup activities in accordance with procedures contained in RM 7E. The response time was approximately 2.5 minutes. The measurement data is included in Appendix B.

3.4.2 Determination of Stratification

Gas stratification measurements were performed at the beginning of the test day. The measurements were performed using procedures contained in 40 CFR, Appendix A, RM 7E. During the test, sample gas was extracted from points along a single traverse line across the center of the stack. The traverse consisted of three points located at 1.3, 4.0 and 6.7 inches from the stack wall.

The probe tip was positioned at each point for twice the system response time. The average for each point and the overall average were calculated. Results showed that the NO_x concentration at each point differed from the overall average by less than 5 percent. All subsequent sampling was performed at a fixed point in the centroid of the stack. The data set is included in Appendix A.

3.4.3 Linearity and Calibration Error Determination

The purpose of this procedure was to establish an initial calibration curve and to assure that each calibration point was accurate to within 2 percent of the analyzer span value. This was accomplished by first introducing the zero calibration gas and adjusting the instrument to read zero. Next, the span gas was introduced and the analyzer's response was adjusted to match this calibration gas certified concentration. Following these adjustments, the zero, mid and high-level calibration gases were injected and the responses were recorded to verify instrument linearity. These data is included in Appendix B.

3.4.4 System Bias Check

Following the Calibration Error (CE) check, the calibration gases were introduced to the sample probe prior to the filter. The gases were transported to the analyzers in the same manner as the source sample gas. The system responses were recorded and compared to the CE values. In the event that the two measurements differ by 5 percent or more, the sources of bias are identified and eliminated before repeating the bias check. These data is included in Appendix B.

3.4.5 Post Run Calibration and Drift Check

A drift check was performed immediately after each test run following procedures outlined in Method 7E. Zero gas was introduced into the system and the monitor's response recorded. This procedure was repeated for the upscale calibration gas. The system bias was determined and may not drift from the previous run system bias by more than 3 percent. These data is included in Appendix B.

3.4.6 Gas Dilution System Check

An ENVIRONICS 4040 Series Gas Dilution System was used to generate the multi-point calibration gases. USEPA 40 CFR 51 Method 205 *Verification of Gas Dilution Systems for Field Instrument Calibrations* was performed at the beginning of the test day to insure accurate dilution. Field data from the RM 205 field check is included with the field data sheets in Appendix B.

3.4.7 NO_x Converter Efficiency Test

An NO_2 to NO converter efficiency test was conducted prior to testing as described in Method 7E. A 50.41 ppmv certified NO_2 calibration gas was introduced directly into the NO_x analyzer. The measured concentration was 51.10 ppmv with a resulting converter efficiency of 101.4 percent. This test met the minimum acceptance criterion of is >90 percent. The efficiency test data is included in Appendix B.

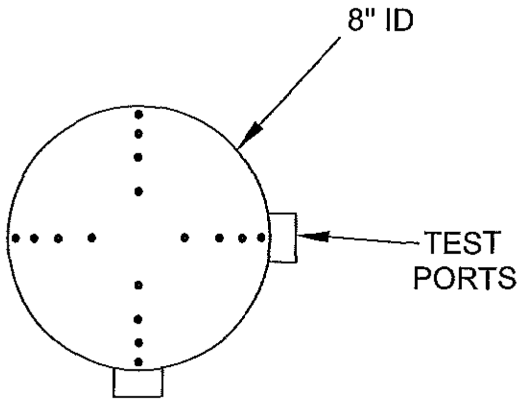
3.5 Data Reduction

The QA/QC procedure for data reduction includes using computer spreadsheet programs to generate tables of results. Data input files and equations were double-checked by a second person, and tables are checked for transposition errors with spot calculations being performed by hand.

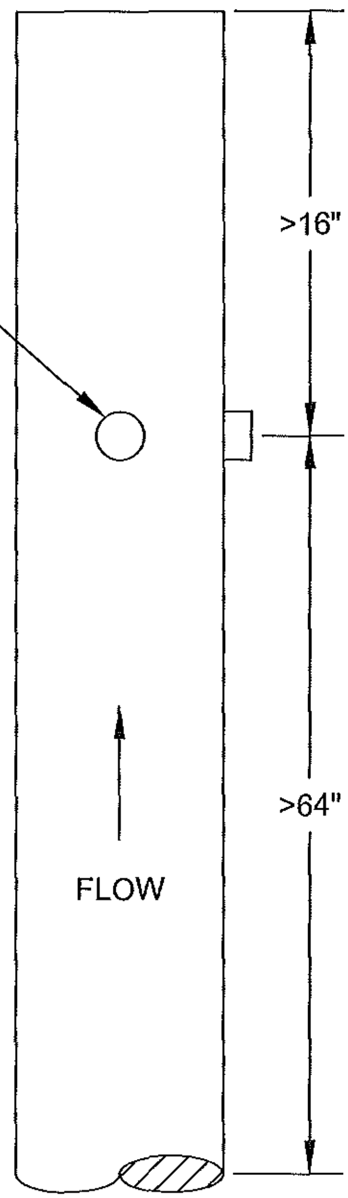
Section 4.0 Results

CRA conducted an emission test to determine the mass emissions of NO_x and CO at AVL Engineering, Inc. located in Ann Arbor, Michigan. On November 13, 2013 CRA performed an emission test on engine test cell #13 which operated on natural gas. On November 14, 2013 CRA performed an emission test on engine test cell #9 which operated on diesel fuel. Tables 4.1 and 4.2 include the summary of both test results. For engine #13 which operated on natural gas the average concentration result for NO_x was 39.0 ppmw, with an average emission rate of 0.63 lbs/hr. CO had an average concentration of 41.0 ppmw, with an average emission rate of 0.4 lbs/hr. For engine #9 which operated on diesel fuel the average concentration result for NO_x was 179.0 ppmw, with an average emission rate of 2.67 lbs/hr. CO had an average concentration of 32.0 ppmw, with an average emission rate of 0.3 lbs/hr. Test results for each individual sampling location are presented in Tables 4.1 and 4.2.

Field data sheets and calculation spreadsheets are provided in Appendix A. Appendix B contains the calibration data and calibration gas certification data sheets. Plant process data is provided in Appendix C.



STACK TEST PORT
CROSS SECTION



TRAVERSE POINT	DISTANCE FROM STACK WALL (INCHES)
1	0.50*
2	0.84
3	1.55
4	2.58
5	5.42
6	6.45
7	7.16
8	7.50*

* ADJUSTED PER RM1

figure 2.1

DYNAMOMETER SAMPLING LOCATIONS
AVL POWERTRAIN ENGINEERING, INC.
Ann Arbor, Michigan

TABLE 1.1

TEST METHODS
AVL ENGINEERING, INC.
ANN ARBOR, MICHIGAN
NOVEMBER 13 & 14, 2013

Parameter	*Reference Method*	*Runs*	*Duration*	*Comments*
Flow	RMs 1-2	3	N/A	One per run, per fuel.
Molecular Weight	RM-3	3	N/A	One per run, per fuel.
Moisture	RM-4	3	35 Minutes	One per run, per fuel.
Nox	RM-7E	3	60 Minutes	Natural Gas/Diesel Fuel
CO	RM-10	3	60 Minutes	Natural Gas/Diesel Fuel

TABLE 3.1

EQUIPMENT CALIBRATION SUMMARY
AVL ENGINEERING, INC.
ANN ARBOR, MICHIGAN
NOVEMBER 13-14, 2013

Equipment	*Reference*	*Calibrated With*	*Limit*	*Equipment ID*	*Calibration Date*	*Calibration Within Limit?*
Barometer	Method 2 Section 4.4	NWS Barometer (a)	± 0.1 in. Hg	BE04199	11/19/2013	Yes
Meter Box	Method 5	ALT-009	Y: within	BE04905	11/13-14/2013	Yes
Pre-Test	Section 5	Gas Meter	±0.02 of avg.	BE04905	7/10/2013	Yes

NWS = National Weather Service

Notes:
(a) The elevations of CRA and the National Weather Service (at the Buffalo Niagara International Airport) are within 10' of each other, thus eliminating the need for elevation correction. The barometer is calibrated within one month prior to field use. The date above refers to the post-test calibration date. Refer to the calibration report for pre-test calibration date.

TABLE 4.1

NATURAL GAS EMISSION TEST RESULTS
AVL ENGINEERING, INC.
ANN ARBOR, MICHIGAN
NOVEMBER 13, 2013

Stack Parameters	*Units*	*Run 1*	*Run 2*	*Run 3*	*Average*
Stack Flow	dscfm	2330	2220	2300	2283.3
Stack Moisture	%	1.0	1.0	1.0	1.0
Stack Temperature	^{o}F	79	78	84	80
Emission Data					
Nox	ppmw	31.5	31.7	54.0	39.1
	lb/hr	0.53	0.50	0.89	0.64
CO	ppmw	32.0	35.7	56.4	41.4
	lb/hr	0.32	0.35	0.57	0.41

TABLE 4.2

DIESEL FUEL EMISSION TEST RESULTS
AVL ENGINEERING, INC.
ANN ARBOR, MICHIGAN
NOVEMBER 14, 2013

Stack Parameters	*Units*	*Run 1*	*Run 2*	*Run 3*	*Average*
Stack Flow	dscfm	2220	2070	1990	2093.3
Stack Moisture	%	1.0	2.0	2.0	1.7
Stack Temperature	°F	72	127	155	118
Emission Data					
Nox	ppmw	67.0	234.0	237.1	179.4
	lb/hr	1.07	3.47	3.38	2.64
CO	ppmw	24.2	30.7	42.5	32.5
	lb/hr	0.23	0.28	0.37	0.29