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AIR EMISSION TEST REPORT
FOR THE VERIFICATION OF
CARBON MONOXIDE AND NITROGEN OXIDES
EMISSION FACTORS
FROM AN ENGINE
DYNAMOMETER TEST CELL

1.0 INTRODUCTION

AVL Powertrain Engineering, Inc. (AVL), State Registration No. N6989, operates an internal combustion engine development and testing facility in Ann Arbor, Michigan. Engine performance testing is conducted within dynamometers located in the facility.

Installation and operation of the equipment is permitted by Michigan Department of Environmental Quality, Air Quality Division (MDEQ-AQD) Renewable Operating (RO) Permit No. MI-ROP-N6989-2014, initially issued to AVL on July 1, 2014. MI-ROP-N6989-2014 requires that performance testing be completed to verify the carbon monoxide (CO) and nitrogen oxides (NOx) emission rates from one of the dynamometer test cells under flexible group FGTESTCELLS burning gasoline fuel, in accordance with Department requirements, within the five-year term of the ROP.

This compliance demonstration consisted of three (3), one-hour test runs for CO, NOx, oxygen (O_2) and carbon dioxide (CO_2) performed on one (1) representative gasoline fueled engine installed within a selected dynamometer test cell.

The compliance testing was performed by Impact Compliance and Testing (ICT), formerly Derenzo Environmental Services (DES), a Michigan-based environmental consulting and testing company. ICT representatives Brad Thome and Blake Beddow performed the field sampling and measurements on January 8, 2019.

The exhaust gas sampling and analysis was performed using procedures specified in the Test Plan dated November 19, 2018 that was reviewed and approved by the Michigan Department of Environmental Quality – Air Quality Division (MDEQ-AQD). MDEQ-AQD representative Mr. Tom Gasloli observed portions of the testing project.

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Report Certification

I certify under penalty of law that I believe the provided in this document is true, accurate, and complete. I am aware that there t civil and criminal penalties, including the possibility of fine or imprisonme knowingly submitting false, inaccurate, or incomplete information.

Report Prepared By:

Blake Beddow
Project Manager
Impact Compliance and Testing

wed by:

usnak, QSTI
al Manager
Compliance and Testing

2.0 SUMMARY OF TEST RESULTS AND OPERATING CONDITIONS

2.1 Purpose and Objective of the Tests

The conditions of MI-ROP-N6989-2014 require AVL to verify the CO and NOx emission factors and emission rates from one of the dynamometer test cells under flexible group FGTESTCELLS burning gasoline fuel, in accordance with Department requirements, within the five-year term of the ROP.

2.2 Operating Conditions During the Compliance Tests

AVL performed three (3) one-hour emissions tests for Test Cell #8 during maximum routine operating conditions.

Gasoline usage for each individual test period is presented in Table No. 6-1.

Appendix 2 provides process operating data recorded during the test periods.

2.3 Summary of Air Pollutant Sampling Results

The gases exhausted from the sampled test cell were each sampled for three (3) one-hour test periods during the compliance testing performed January 8, 2019.

Table 2.1 presents the measured CO and NOx emission factors and emission rates for FGTESTCELLS on a gasoline fueled engine.

Detailed test results for each one-hour sampling period are presented in Section 6.0 of this report.

Table 2.1 Measured CO and NOx emission factors for FGTESTCELLS

	CO Emission Rates		NOx Emission Rates	
Emission Unit	(lb/hr)	(lb/gal)	(lb/hr)	(lb/gal)
EUTESTCELL8	3.24	0.56	2.34	0.43
MI-ROP-N6989-2014 Emission Factor	---	*4.9*	---	*0.31*

Notes for table 2.1:

1. Presented emission factors are an average of three (3) test runs.
2. The presented emission factor is specified in the emission limit table in MI-ROP-N6989-2014 but is not a permitted limit.

3.0 SOURCE AND SAMPLING LOCATION DESCRIPTION

3.1 General Process Description

FGTESTCELLS consists of twenty (20) individual test cells. Emission factor verification was performed in EUTESTCELL8 without a catalyst. EUTESTCELL8 was equipped with a 5.3 liter (L) Chevrolet eight (8) cylinder (V8) gasoline fueled engine for the compliance demonstration.

3.2 Rated Capacities and Air Emission Controls

The 5.3 L Chevrolet V8 internal combustion engine was operated a various engine loads and speeds ranging between 1,200 and 3,500 revolutions per minute (rpm).

MI-ROP- N6989-2014, FGTESTCELLS specifies a catalytic converter is used as a control device when gasoline is used as a fuel source during testing. However, the permit also allows for operation without a catalytic converter. A catalyst was not equipped during this test event.

3.3 Sampling Location

The exhaust gas is released to the atmosphere through a dedicated vertical exhaust stack with a vertical release point.

The exhaust stack sampling ports for EUTESTCELL8 are located in an individual exhaust stack with an inner diameter of 7.5 inches. The stack is equipped with two (2) sample ports, opposed 90°, that provide a sampling location 21.5 inches (2.8 duct diameters) upstream and 19.0 inches (2.5 duct diameters) downstream from any flow disturbance and satisfies the USEPA Method 1 criteria for a representative sample location.

Individual traverse points were determined in accordance with USEPA Method 1.

Appendix 1 provides diagrams of the emission test sampling location.

4.0 SAMPLING AND ANALYTICAL PROCEDURES

Test protocols for the air emission testing were reviewed and approved by the MDEQ. This section provides a summary of the sampling and analytical procedures that were used during the AVL testing periods.

4.1 Summary of Sampling Methods

USEPA Method 1	Exhaust gas velocity measurement locations were determined based on the physical stack arrangement and requirements in USEPA Method 1
USEPA Method 2	Exhaust gas velocity pressure was determined using a Type-S Pitot tube connected to a red oil incline manometer; temperature was measured using a K-type thermocouple connected to the Pitot tube.
USEPA Method 3A	Exhaust gas O_2 and CO_2 content was determined using zirconia ion/paramagnetic and infrared instrumental analyzers, respectively.
USEPA Method 4	Exhaust gas moisture was determined based on the water weight gain in chilled impingers.
USEPA Method 7E	Exhaust gas NOx concentration was measured using a Chemiluminescence instrumental analyzer.
USEPA Method 10	Exhaust gas CO concentration was measured using an NDIR instrumental analyzer.

4.2 Exhaust Gas Velocity Determination (USEPA Method 2)

The EUTESTCELL8 exhaust stack gas velocities and volumetric flow rates were determined using USEPA Method 2 once during each test. An S-type Pitot tube connected to a red-oil manometer was used to determine velocity pressure at each traverse point across the stack cross section. Gas temperature was measured using a K-type thermocouple mounted to the Pitot tube. The Pitot tube and connective tubing were leak-checked prior to the test event to verify the integrity of the measurement system.

The absence of significant cyclonic flow for the exhaust configuration was verified using an S-type Pitot tube and oil manometer. The Pitot tube was positioned at each velocity traverse point with the planes of the face openings of the Pitot tube perpendicular to the stack cross-sectional plane. The Pitot tube was then rotated to determine the null angle (rotational angle as measured from the perpendicular, or reference, position at which the differential pressure is equal to zero).

Appendix 3 provides exhaust gas flowrate calculations and field data sheets.

4.3 Exhaust Gas Molecular Weight Determination (USEPA Method 3A)

CO_2 and O_2 content in the exhaust gas streams were measured continuously throughout each test period in accordance with USEPA Method 3A. The CO_2 content of the exhaust was monitored using a Servomex 4900 single beam single wavelength (SBSW) infrared gas analyzer. The O_2 content of the exhaust was monitored using a Servomex 4900 gas analyzer that uses a paramagnetic sensor.

During each sampling period, a continuous sample of the engine exhaust gas stream was extracted from the stack using a stainless steel probe connected to a Teflon® heated sample line. The sampled gas was conditioned by removing moisture prior to being introduced to the analyzers; therefore, measurement of O_2 and CO_2 concentrations correspond to standard dry gas conditions. Instrument response data were recorded using an ESC Model 8816 data acquisition system that monitored the analog output of the instrumental analyzers continuously and logged data as one-minute averages.

Prior to, and at the conclusion of each test, the instruments were calibrated using upscale calibration and zero gas to determine analyzer calibration error and system bias (described in Section 5.0 of this document). Sampling times were recorded on field data sheets.

Appendix 4 provides O_2 and CO_2 calculation sheets. Raw instrument response data are provided in Appendix 5.

4.4 Exhaust Gas Moisture Content (USEPA Method 4)

Moisture content of the exhaust gas was determined in accordance with USEPA Method 4 using a chilled impinger sampling train. The moisture sampling was performed concurrently with the instrumental analyzer sampling. During each sampling period a gas sample was extracted at a constant rate from the source where moisture was removed from the sampled gas stream using impingers that were submersed in an ice bath. At the conclusion of each sampling period, the moisture gain in the impingers was determined gravimetrically by weighing each impinger to determine net weight gain.

4.5 NOx Concentration Measurements (USEPA Method 7E)

Engine exhaust NOx concentrations were determined during each sampling period using a Thermo Environmental Instruments Inc. Model 42C NO-NO_2- NOx Analyzer that incorporates chemiluminescence technology for the measurement of NOx concentrations in accordance with USEPA Method 7E.

A continuous sample of the engine exhaust gas was delivered to the instrument analyzer using an extractive gas sampling system. The exhaust gas samples were conditioned (i.e., dried) prior to being introduced to the instrument analyzer. Therefore, NOx measurements correspond to standard conditions with moisture correction (dry basis).

The specified instrument analyzer was calibrated using certified NOx concentrations in nitrogen.

Appendix 4 provides NOx calculation sheets. Raw instrument response data are provided in Appendix 5.

4.6 CO Concentration Measurements (USEPA Method 10)

CO in the exhaust gas streams were measured continuously throughout each test period in accordance with USEPA Method 10. The CO content of the exhaust was monitored using a Fuji Model ZRF infrared CO analyzer.

Throughout each test period, a continuous sample of the engine exhaust gas was extracted from the stack using the Teflon® heated sample line and gas conditioning system and delivered to the instrumental analyzers. Instrument response for each analyzer was recorded on an ESC Model 8816 data acquisition system that logged data as one-minute averages. Prior to, and at the conclusion of each test, the instruments were calibrated using upscale calibration and zero gas to determine analyzer calibration error and system bias.

Appendix 4 provides CO calculation sheets. Raw instrument response data are provided in Appendix 5.

5.0 QA/QC ACTIVITIES

5.1 Gas Divider Certification (USEPA Method 205)

A STEC Model SGD-710C 10-step gas divider was used to obtain appropriate calibration span gases. The ten-step STEC gas divider was NIST certified (within the last 12-months) with a primary flow standard in accordance with Method 205. When cut with an appropriate zero gas, the ten-step STEC gas divider delivered calibration gas values ranging from 0% to 100% (in 10% step increments) of the USEPA Protocol 1 calibration gas that was introduced into the system. The field evaluation procedures presented in Section 3.2 of Method 205 were followed prior to use of gas divider. The field evaluation yielded no errors greater than 2% of the triplicate measured average and no errors greater than 2% from the expected values.

5.2 Instrumental Analyzer Interference Check

The instrumental analyzers used to measure NOx, CO, O_2 and CO_2 have had an interference response test preformed prior to their use in the field, pursuant to the interference response test procedures specified in USEPA Method 7E. The appropriate interference test gases (i.e., gases that would be encountered in the exhaust gas stream) were introduced into each analyzer, separately and as a mixture with the analyte that each analyzer is designed to measure. All of analyzers exhibited a composite deviation of less than 2.5% of the span for all measured interferent gases. No major analytical components of the analyzers have been replaced since performing the original interference tests.

5.3 Instrument Calibration and System Bias Checks

At the beginning of each day of the testing program, initial three-point instrument calibrations were performed for the NOx, CO, CO_2 and O_2 analyzers by injecting calibration gas directly into the inlet sample port for each instrument. System bias checks were performed prior to and at the conclusion of each sampling period by introducing the upscale calibration gas and zero gas into the sampling system (at the base of the stainless steel sampling probe prior to the particulate filter and Teflon® heated sample line) and determining the instrument response against the initial instrument calibration readings.

The instruments were calibrated with USEPA Protocol 1 certified concentrations of NOx, CO_2, O_2 and CO in nitrogen and zeroed using hydrocarbon free nitrogen. A STEC Model SGD-710C ten-step gas divider was used to obtain intermediate calibration gas concentrations as needed.

5.4 Sampling System Response Time Determination

The response time of the sampling system was determined prior to the compliance test program by introducing upscale gas and zero gas, in series, into the sampling system using a tee connection at the base of the sample probe. The elapsed time for the analyzer to display a reading of 95% of the expected concentration was determined using a stopwatch.
Results of the response time determinations were recorded on field data sheets. For each test period, test data were collected once the sample probe was in position for at least twice the maximum system response time.

5.5 Determination of Exhaust Gas Stratification

A stratification test for each exhaust stack configuration was performed during the performance test sampling periods. The stainless steel sample probe was positioned at sample points correlating to 16.7, 50.0 (centroid) and 83.3% of the stack diameter. Pollutant concentration data were recorded at each sample point for a minimum of twice the maximum system response time.

The recorded data for each exhaust stack gas indicate that the measured O_2, CO_2 and CO concentrations did not vary by more than 5% of the mean across the stack diameter. Therefore, the stack gas of each emission unit was considered to be unstratified and the compliance test sampling was performed at a single sampling location within each exhaust stack.

5.6 Meter Box Calibrations

The sampling console, which was used for exhaust gas moisture content sampling, was calibrated prior to and after the testing program. This calibration uses the critical orifice calibration technique presented in USEPA Method 5. The metering console calibration exhibited no data outside the acceptable ranges presented in USEPA Method 5.

The digital pyrometer in the Nutech metering consoles were calibrated using a NIST traceable Omega® Model CL 23A temperature calibrator.

Appendix 6 presents test equipment quality assurance data (exhaust gas stratification checks, instrument calibration and system bias check records, calibration gas and gas divider certifications, interference test results, meter box calibration records and Pitot tube calibration records).

6.0 RESULTS

6.1 Test Results and Allowable Emission Limits

Engine operating data and air pollutant emission measurement results for each one-hour test period are presented in Table 6.1.

The measured CO and NOx emission factors (lb/gal) and mass emission rates (lb/hr) for FGTESTCELLS are:

- 3.24 lb/hr, and 0.56 lb/gal CO;
- 2.34 lb/hr, and 0.43 lb/gal NOx.

6.2 Variations from Normal Sampling Procedures or Operating Conditions

The testing for all pollutants was performed in accordance with the approved test protocol.

The first test run was aborted due to an in-stack soot build up from previous diesel emission testing. The engine shut down before 60 minutes of data could be collected.

Each test run was initially planned to be conducted at four (4) operating loads (i.e., steps). Each step (approximately 15 minutes in duration) would represent an increase in operating load. The engine selected for the emissions test was not able to run continuously at the planned 4th operating load (i.e., highest load) without shutting down due to overheating. Therefore, testing was performed at three operating loads. During the second test run the engine shut down for a high exhaust temperature alarm (at the attempt to run at the fourth, highest, operating load). The engine was restarted and testing resumed at the third operating load.

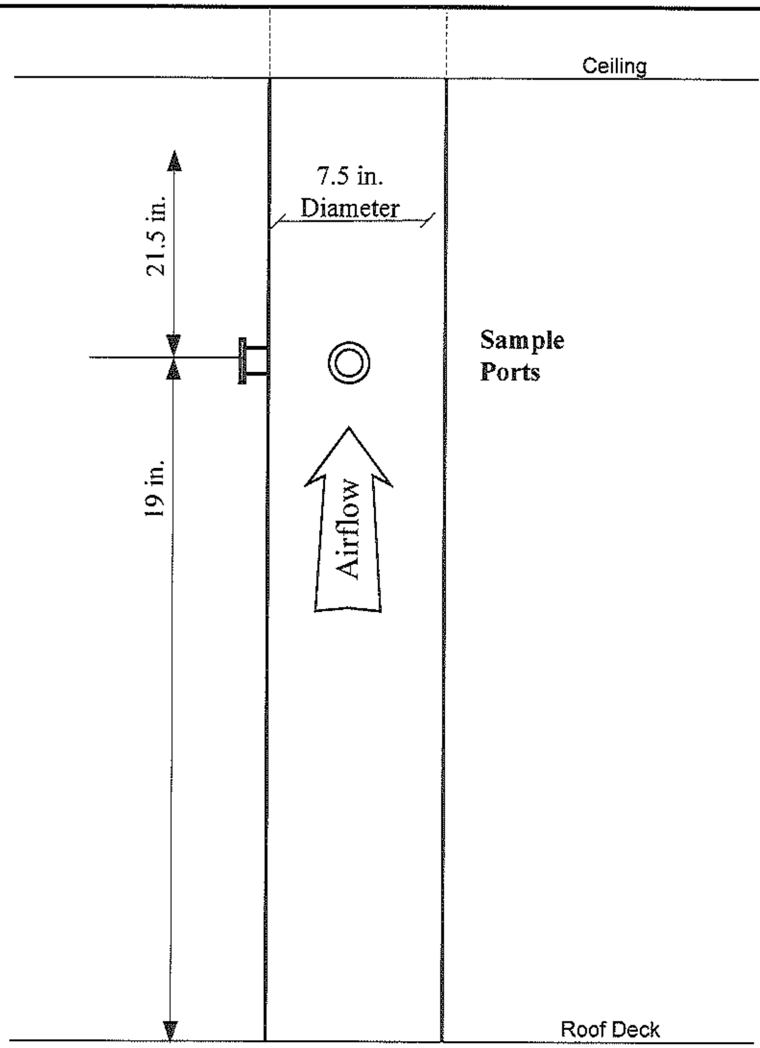
No other variations from the normal operating conditions of the test cell occurred during the engine test periods.

Table 6.1 Measured exhaust gas conditions and CO and NOx air pollutant emission factors and emission rates for EUTESTCELL8 at the AVL facility

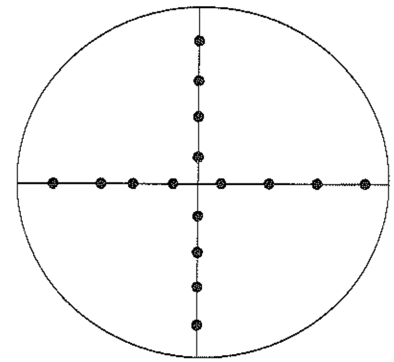
Test No.	1	2	3	Three Test Average
Test date	1/8/19	1/8/19	1/8/19	
Test period (24-hr clock)	1001-1049, 1115-1130	1150-1250	1311-1411	
Average engine speed (rpm)	2,613	2,585	2,590	2,596
Average fuel flowrate (gal/hr)	5.9	5.2	5.2	5.4
Exhaust Gas Composition				
CO_2 content (% vol)	0.60	0.54	0.55	0.56
O_2 content (% vol)	20.6	20.7	20.7	20.6
Moisture (% vol)	1.62	2.08	1.53	1.74
Exhaust gas temperature (^oF)	103	154	104	120
Exhaust gas flowrate (dscfm)	1,963	1,770	1,944	1,893
Carbon Monoxide				
CO conc. (%)	0.100	0.007	0.007	0.038
CO emissions (lb/hr)	8.60	0.55	0.58	3.24
CO emissions (lb/gal gasoline)	1.46	0.11	0.11	0.56
ROP Emission Factor (lb/gal)	-	-	-	*4.9*
Nitrogen Oxides				
NOx conc. (ppmvd)	176	168	173	173
NOx emissions (lb/hr)	2.48	2.14	2.41	2.34
NOx emissions (lb/gal gasoline)	0.42	0.41	0.46	0.43
ROP Emission Factor (lb/gal)	-	-	-	*0.31*

APPENDIX 1

- Figure 1 – EUTESTCELL8 Sample Port Diagram



Stack Diameter 7.5 in.



Traverse Points

Sampling Point	Distance from Stack Wall (in)
1	0.50
2	0.78
3	1.45
4	2.42
5	5.07
6	6.04
7	6.71
8	7.00

EUTESTCELL8 Exhaust

2/20/19	**AVL Powertrain Test Cell Exhaust**		
	Scale None	Sheet 1 of 1	Impact Compliance and Testing

APPENDIX 2

- Process Operational Data

Table 6.2 Summary of Test Cell #8 emissions test steps during the January 8, 2019 AVL Powertrain performance

		Step No. 1	Step No. 2	Step No. 3	**Average**
Test 2	Fuel Use Rate (kg/hr)	10.49	11.25	21.45	**16.43**
	Fuel Use Rate (gal/hr)	3.8	4.0	7.7	**5.9**
	Engine Speed (rpm)	1,195	2,116	3,458	**2,613**

		Step No. 1	Step No. 2	Step No. 3	**Average**
Test 3	Fuel Use Rate (kg/hr)	5.47	9.08	21.25	**14.39**
	Fuel Use Rate (gal/hr)	2.0	3.3	7.6	**5.2**
	Engine Speed (rpm)	1,315	2,104	3,415	**2,585**

		Step No. 1	Step No. 2	Step No. 3	**Average**
Test 4	Fuel Use Rate (kg/hr)	5.80	9.00	21.25	**14.40**
	Fuel Use Rate (gal/hr)	2.1	3.2	7.7	**5.2**
	Engine Speed (rpm)	1,342	2,100	3,436	**2,590**

		Step No. 1	Step No. 2	Step No. 3	**Average**
Avg.	Fuel Use Rate (kg/hr)	7.25	9.78	21.32	**15.07**
	Fuel Use Rate (gal/hr)	2.6	3.5	7.67	**5.4**
	Engine Speed (rpm)	1,284	2,106	3,436	**2,596**