AIR EMISSION TEST REPORT

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Title	AIR EMISSION TEST REPORT FOR THE VERIFICATION OF THE CARBON MONOXIDE EMISSION FACTOR FROM AN ENGINE DYNAMOMETER TEST CELLS
Report Date	August 27, 2015
Test Dates	August 12, 2015

Facility Information	
Name:	Ilmor Engineering, Inc.
Street Address:	43939 Plymouth Oaks Blvd.
City, County:	Plymouth, Wayne County

Facility Permit Information			
State Registration Number:	M4636	Permit to Install No.:	208-98J

Testing Contractor	
Company	Derenzo Environmental Services
Mailing Address	39395 Schoolcraft Road Livonia, MI 48150
Phone	(734) 464-3880
Project No.	1503016

AIR EMISSION TEST REPORT FOR THE VERIFICATION OF THE CARBON MONOXIDE EMISSION FACTOR FROM A ENGINE DYNAMOMETER TEST CELLS

1.0 INTRODUCTION

Ilmor Engineering, Inc. (Ilmor), State Registration No. M4836, operates a vehicle research and testing facility in Plymouth, Michigan. Engine performance testing is conducted within four (4) dynamometers, identified collectively as FGTestCells, located at the facility.

Installation and operation of the equipment is permitted by Michigan Department of Environmental Quality, Air Quality Division (MDEQ-AQD) Permit to Install (PTI) No. 208-98J, issued Ilmor on August 11, 2015. Special Condition No. V.2. of PTI No. 208-98J requires that performance tests be completed to verify the emission factors of carbon monoxide (CO) from a representative engine dynamometer prior to August 17, 2015. The condition requires that a test report be submitted by September 18, 2015.

The compliance testing was performed by Derenzo Environmental Services (Derenzo), a Michigan-based environmental consulting and testing company. Derenzo representatives Jason Logan and Andrew Rusnak performed the field sampling and measurements August 12, 2015.

The exhaust gas sampling and analysis was performed using procedures specified in the Test Plan dated June 25, 2015 that was reviewed and approved by the Michigan Department of Environmental Quality (MDEQ). MDEQ representatives Mr. Mark Dziadosz and Ms. Nazaret Sandoval observed portions of the testing project.

Questions regarding this emission test report should be directed to:

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Report Certification

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

Report Prepared By:

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Responsible Official Certification:

Joseph N. Hoffman 28 AUG. 2015

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Governmental Compliance Specialist
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2.0 SOURCE AND SAMPLING LOCATION DESCRIPTION

2.1 General Process Description

Flexible Group No. FGTestCells consists of four (4) individual test cells, EUTestCellA through EUTestCellD. Compliance testing was performed on test cell EUTestCellA. EUTestCellA was equipped with an in-house, ten (10) cylinder (V10), 675 horsepower (hp), unleaded gasoline fueled engine for the compliance demonstration.

2.2 Rated Capacities and Air Emission Controls

The V10 engine that was tested in EUTestCellA had the following capacities:

- Engine Size: 8.3 liters
- Engine Power Output: 675 horsepower
- Number of Cylinders: 10

The engines operated in EUTestCellA are permitted to operate with and without catalytic converters. The testing condition for EUTestCellA specified that emissions testing shall be conducted during operations without control.

2.3 Sampling Locations

The exhaust gas is released to the atmosphere through dedicated vertical exhaust stacks with vertical release points. The exhaust stack is equipped with a booster fan at the exit point.

The engine in EUTestCellA is equipped with a dual exhaust manifold (i.e., two exhaust pipes). The separate exhaust pipes join together just prior to booster fan. The dual exhaust pipes were connected using ¼-inch stainless steel tubing and the heated sample line connected to a tee that joined the two exhaust pipes together. The exhaust stack sampling ports for EUTestCellA are located in exhaust pipes with an inner diameter of 4.0 inches. Each pipe is equipped with a sample port, that provides a sampling location greater than 120 inches (>30.0 duct diameters) upstream and 12.0 inches (3.0 duct diameters) downstream from any flow disturbance and satisfies the USEPA Method 1 criteria for a representative sample location.

Appendix 1 provides a diagram of the emission test sampling locations.

3.0 SUMMARY OF TEST RESULTS AND OPERATING CONDITIONS

3.1 Purpose and Objective of the Tests

The conditions of Permit to Install No. 208-98J requires Ilmor to verify the CO emission factor from a representative engines during representative operations for FGTestCells prior to August 17, 2015.

3.2 Operating Conditions During the Compliance Tests

Special Condition No. V.2. of FGTestCells requires testing to be performed *...from a representative dynamometer...* Ilmor determined that performing the E4 Emissions Certification Test is the most representative. The E4 Emissions Certification Test steps the engine down from maximum engine output to idle (a total of five different steps) at set time increments (i.e., the engine was held at a specific rpm for approximately 10 to 12 minutes and then decreased to the next step).

Engine operating conditions are summarized in Table 3.1.

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

Appendix 2 contains engine operating records for the test periods.

3.3 Summary of Air Pollutant Sampling Results

The gases exhausted from the sampled test cell were sampled for three (3) test periods during the compliance testing performed August 12, 2015.

Table 3.2 presents the measured CO emission factor for the test pattern.

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

Table 3.1 Average measured engine operating parameters during compliance test periods

Operating Parameter	Measured Three-Test Average	Units
Fuel Use Rate	15.4	gal/hr
Engine Speed	3,210	rpm
Air to Fuel Ratio	14.1	N/A
Engine Torque	241	lb-ft
Engine Power	207	hp

Table 3.2 Average measured CO emission factors during compliance test periods

Emissions Test	Average Measured CO Emission Factor (lb/gal)
Emission Test Period No. 1	2.14
Emission Test Period No. 2	2.09
Emission Test Period No. 3	2.09
Three-Test Average	***2.10***
Permit to Install No. 208-98J Limit	4.977

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 Ilmor testing periods.

4.1 Summary of Sampling Methods

USEPA Method 3A	Exhaust gas O_2 and CO_2 content was determined using paramagnetic and infrared instrumental analyzers, respectively.
USEPA Method 10	Exhaust gas CO concentration was measured using infrared instrumental analyzers.
USEPA Method 19	Exhaust gas velocity pressure was determined based on fuel combustion and exhaust gas oxygen concentration.

4.2 Exhaust Gas Velocity Determination (USEPA Method 19)

The EUTestCellA exhaust stack gas velocities and volumetric flow rates were determined using USEPA Method 19. A dry F factor (F_d) for gasoline was determined by taking a sample of the gasoline combusted in the test cells and performing an ultimate fuel analysis, to determine the component weight percents and the heat content of the fuel.

The exhaust gas flowrate was determined by measuring the exhaust gas oxygen concentration in conjunction with the F factor, heat input rate and the following equation:

$$Q_{dry} = (\text{MMBtu/hr}) * F_d * (20.9\% / (20.9 - O_{2meas})) / (60 \text{ min/hr})$$

Where:

F_d = dry F factor
Q_{dry} = dry exhaust flowrate (dscfm)
O_{2meas} = Measure exhaust stack oxygen concentration

Appendix 3 provides the ultimate fuel analysis laboratory results.

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 Model 1440D infrared (IR) gas analyzer. The O_2 content of the exhaust was monitored using a Servomex Model 1440D 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 the stainless steel manifold 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 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 Horiba Model VIA 510 IR gas 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 previous 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 O_2 and CO_2 have had an interference response test preformed prior to their use in the field (July 26, 2006), 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 3.0% 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 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 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.

The Servomex Model 1440D CO_2 analyzer exhibited the longest system response time at 39 seconds. 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.

Appendix 6 presents test equipment quality assurance data (instrument calibration and system bias check records, calibration gas and gas divider certifications, interference test results).

6.0 RESULTS

6.1 Test Results and Allowable Emission Limits

Engine operating data and air pollutant emission measurement results for each test period are presented in Tables 6.1 and 6.2.

The average measured CO emission factor (lb/gal) was less than the allowable limit specified in Permit to Install No. 208-98J:

- 4.977 lb CO/gal for FGTestCells.

The data presented in Table 6.2 provides a breakdown of each operating condition (i.e. step) in the E4 emissions test cycle. The measured data for the final operating condition, engine at idle conditions (i.e., low engine speed, low load and low fuel use) result in a CO emission factor that is greater than the allowable limit. However, the emission limit specifies the test protocol as the averaging time for compliance determination. The test protocol was the entire E4 emissions test cycle, therefore, the average CO emission factor for the entire test cycle was used to demonstrate compliance.

6.2 Variations from Normal Sampling Procedures or Operating Conditions

The testing for all pollutants was performed in accordance with the approved test protocols. No variations from the normal operating conditions of the engine operated in the test cell occurred during the test periods.

The first two test periods were aborted prior to completion of the test cycle because the engine dynamometer datalogging software locked up and became unresponsive (i.e., stopped logging performance data). To correct the problem Ilmor representatives manually manipulated the engine operating conditions for the remaining three test runs. During the first manual test period the engine was shut down prior to achieving a 60 minute run (i.e., the engine was operated at each operating scenario for 10 minutes instead of 12 minutes). This was discussed with the MDEQ representative and determined that additional time could be added to the following runs (i.e., Run No. 1 results were acceptable).

Table 6.1 Measured exhaust gas conditions and CO air pollutant emission rates for Ilmor facility (EUTestCellA)

Test No. Test date Test period (24-hr clock)	1 8/12/2015 1045 - 1147	2 8/12/2015 1244 - 1348	3 8/12/2015 1406 - 1507	Three Test Average
Fuel flowrate (gal/hr)	15.1	15.7	15.4	15.4
Engine Speed (rpm)	3,182	3,267	3,181	3,210
Air to Fuel Ratio	14.2	14.1	14.1	14.1
Exhaust Gas Composition				
CO_2 content (% vol)	11.6	11.6	11.6	11.6
O_2 content (% vol)	2.36	2.34	2.25	2.32
Exhaust gas flowrate (dscfm)	313	324	316	317
Carbon Monoxide				
CO conc. (%)	2.44	2.39	2.40	2.41
CO emissions (lb/hr)	33.3	33.7	33.1	33.4
CO emissions (lb/gal)	2.14	2.09	2.09	2.10

Table 6.2 Summary of individual E4 emissions test steps during the August 12, 2015 Ilmor Engineering performance test

		Step No. 1	Step No. 2	Step No. 3	Step No. 4	Step No. 5	**Total**
Test No. 1	Measured CO Concentration (%)	3.63	0.77	0.82	2.38	4.37	**2.44**
	Exhaust Gas Flowrate (dscfm)	822	347	170	69.4	54.6	**313**
	CO Emission Rate (lb/hr)	130	11.7	6.07	7.21	10.4	**33.3**
	CO Emission Factor (lb/gal)	2.89	0.63	0.69	2.07	5.07	**2.14**
	Fuel Use Rate (gal/hr)	45.0	18.5	8.85	3.48	2.05	**15.6**
	Engine Speed (rpm)	5400	4320	3240	2157	801	**3182**
	Air to Fuel Ratio	13.3	14.8	15.1	14.2	13.4	**14.2**

		Step No. 1	Step No. 2	Step No. 3	Step No. 4	Step No. 5	**Total**
Test No. 2	Measured CO Concentration (%)	3.43	0.88	0.89	1.98	4.36	**2.39**
	Exhaust Gas Flowrate (dscfm)	820	351	174	71.6	53.5	**324**
	CO Emission Rate (lb/hr)	123	13.4	6.80	6.20	10.2	**33.7**
	CO Emission Factor (lb/gal)	2.74	0.72	0.75	1.70	5.04	**2.09**
	Fuel Use Rate (gal/hr)	44.8	18.8	9.12	3.64	2.02	**16.2**
	Engine Speed (rpm)	5400	4320	3240	2159	800	**3267**
	Air to Fuel Ratio	13.4	14.7	15.0	14.2	13.2	**14.1**

		Step No. 1	Step No. 2	Step No. 3	Step No. 4	Step No. 5	**Total**
Test No. 3	Measured CO Concentration (%)	3.51	0.89	0.97	1.90	4.47	**2.40**
	Exhaust Gas Flowrate (dscfm)	819	350	187	72.1	52.8	**316**
	CO Emission Rate (lb/hr)	126	13.6	7.86	5.98	10.3	**33.1**
	CO Emission Factor (lb/gal)	2.80	0.73	0.81	1.63	5.07	**2.09**
	Fuel Use Rate (gal/hr)	44.9	18.7	9.76	3.68	2.03	**15.8**
	Engine Speed (rpm)	5400	4320	3224	2159	801	**3181**
	Air to Fuel Ratio	13.3	14.7	14.9	14.3	13.4	**14.1**

		Step No. 1	Step No. 2	Step No. 3	Step No. 4	Step No. 5	**Total**
Three-Test Average	Measured CO Concentration (%)	3.52	0.85	0.89	2.09	4.40	**2.41**
	Exhaust Gas Flowrate (dscfm)	820	349	177	71	54	**317**
	CO Emission Rate (lb/hr)	126	12.9	6.91	6.46	10.3	**33.4**
	CO Emission Factor (lb/gal)	2.81	0.69	0.75	1.80	5.06	**2.10**
	Fuel Use Rate (gal/hr)	44.9	18.7	9.24	3.60	2.03	**15.9**
	Engine Speed (rpm)	5400	4320	3235	2158	800	**3210**
	Air to Fuel Ratio	13.3	14.7	15.0	14.3	13.3	**14.1**