Derenzo and Associates, Inc.
Environmental Consultants

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AIR QUALITY DIV.

AIR EMISSION TEST REPORT

Title	AIR EMISSION TEST REPORT FOR THE VERIFICATION OF CARBON MONOXIDE EMISSION FACTORS FROM ENGINE AND TRANSMISSION DYNAMOMETER TEST CELLS
Report Date	March 19, 2015
Test Dates	January 20 – 22, 2015

Facility Information	
Name:	Toyota Motor Engineering and Manufacturing, NA, Inc.
Street Address:	1555 Woodridge, RR#7
City, County:	Ann Arbor, Washtenaw County

Facility Permit Information			
State Registration Number:	N2915	Permit to Install No.: ROP No:	186-13 MI-ROP-N2915-2012

Testing Contractor	
Company	Derenzo and Associates, Inc.
Mailing Address	39395 Schoolcraft Road Livonia, MI 48150
Phone	(734) 464-3880
Project No.	1407003

DEQ

MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY
AIR QUALITY DIVISION

RENEWABLE OPERATING PERMIT
REPORT CERTIFICATION

Authorized by 1994 P.A. 451, as amended. Failure to provide this information may result in civil and/or criminal penalties.

Reports submitted pursuant to R 336.1213 (Rule 213), subrules (3)(c) and/or (4)(c), of Michigan's Renewable Operating Permit (ROP) program must be certified by a responsible official. Additional information regarding the reports and documentation listed below must be kept on file for at least 5 years, as specified in Rule 213(3)(b)(ii), and be made available to the Department of Environmental Quality, Air Quality Division upon request.

Source Name: Toyota Motor Engineering & Manufacturing N.A.-TEMA County: Washtenaw

Source Address: 1555 & 1588 Woodridge Ave. City: Ann Arbor

AQD Source ID (SRN): N2915 ROP No.: MI-ROP-N2915-2012 ROP Section No.: NA

Please check the appropriate box(es):

☐ **Annual Compliance Certification (Pursuant to Rule 213(4)(c))**

Reporting period (provide inclusive dates): From ________ To ________

☐ 1. During the entire reporting period, this source was in compliance with **ALL** terms and conditions contained in the ROP, each term and condition of which is identified and included by this reference. The method(s) used to determine compliance is/are the method(s) specified in the ROP.

☐ 2. During the entire reporting period this source was in compliance with all terms and conditions contained in the ROP, each term and condition of which is identified and included by this reference, **EXCEPT** for the deviations identified on the enclosed deviation report(s). The method used to determine compliance for each term and condition is the method specified in the ROP, unless otherwise indicated and described on the enclosed deviation report(s).

☐ **Semi-Annual (or More Frequent) Report Certification (Pursuant to Rule 213(3)(c))**

Reporting period (provide inclusive dates): From ________ To ________

☐ 1. During the entire reporting period, **ALL** monitoring and associated recordkeeping requirements in the ROP were met and no deviations from these requirements or any other terms or conditions occurred.

☐ 2. During the entire reporting period, all monitoring and associated recordkeeping requirements in the ROP were met and no deviations from these requirements or any other terms or conditions occurred, **EXCEPT** for the deviations identified on the enclosed deviation report(s).

☒ **Other Report Certification**

Reporting period (provide inclusive dates): From 01/20/2015 To 01/22/2015

Additional monitoring reports or other applicable documents required by the ROP are attached as described:

Air Emission Test Report for verification of CO EF from engine & transmission dynamometer test cells

I certify that, based on information and belief formed after reasonable inquiry, the statements and information in this report and the supporting enclosures are true, accurate and complete

Name of Responsible Official (print or type)	Title	Phone Number
Melissa Baylis	General Manager	(734)995-5780

Signature of Responsible Official: Melissa Baylis   Date: 3/19/2015

* Photocopy this form as needed.

EQP 5736 (Rev 11-04)

AIR EMISSION TEST REPORT
FOR THE VERIFICATION OF
CARBON MONOXIDE EMISSION FACTORS
FROM
ENGINE AND TRANSMISSION
DYNAMOMETER TEST CELLS

1.0 INTRODUCTION

Toyota Motor Engineering and Manufacturing, NA, Inc. (TEMA), State Registration No. N2915, operates a vehicle research and testing facility in Ann Arbor, Michigan. Engine and vehicle performance testing is conducted within dynamometers located in the Evaluation Building (located at 1555 Woodridge) and at the Powertrain Building (located at 1588 Woodridge) on the TEMA Ann Arbor campus.

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-N2915-2012, issued TEMA on May 31, 2012 and Permit to Install (PTI) No. 186-13, issued TEMA on March 27, 2014. Special Condition No. V.1. of FG-EG125 and FG-TM145 and Special Condition No. V.4. of FG-EG34 of PTI No. 186-13 requires TEMA to verify CO emission factors from a representative engine during representative operation for these flexible groups within 180 days of the completion of installation.

The compliance testing was performed by Derenzo and Associates, Inc. (Derenzo and Associates), a Michigan-based environmental consulting and testing company. Derenzo and Associates representatives Jeff Schlaff and Andrew Rusnak performed the field sampling and measurements January 20 – 22, 2015.

The exhaust gas sampling and analysis was performed using procedures specified in the Test Plan dated December 19, 2014 that was reviewed and approved by the Michigan Department of Environmental Quality (MDEQ). MDEQ representatives Mr. Tom Maza and Mr. Scott Miller observed portions of the testing project.

Questions regarding this emission test report should be directed to:

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2.0 SOURCE AND SAMPLING LOCATION DESCRIPTION

2.1 General Process Description

Flexible Group No. FG-EG125 consists of three (3) individual test cells, EU-EG1, EU-EG2 and EU-EG5. Compliance testing was performed on test cell EU-EG5. EU-EG5 was equipped with an inline four (4) cylinder (L4) gasoline fueled engine for the compliance demonstration.

Flexible Group No. FG-TM145 consists of three (3) individual test cells, EU-TM1, EU-TM4 and EU-TM5. Compliance testing was performed on test cell EU-TM5. EU-TM5 was equipped with a six (6) cylinder (V6) gasoline fueled engine for the compliance demonstration.

Flexible Group No. FG-EG34 consists of two (2) individual test cells, EU-EG3 and EU-EG4. Compliance testing was performed on test cell EU-EG4. EU-EG4 was equipped with an eight (8) cylinder (V8) gasoline fueled engine for the compliance demonstration.

2.2 Rated Capacities and Air Emission Controls

The L4 engine that was tested in EU-EG5 had the following capacities:

- Engine Size: 2.5 liters
- Engine Power Output: 178 horsepower
- Number of Cylinders: 4

The V6 engine that was tested in EU-TM5 had the following capacities:

- Engine Size: 3.6 liters
- Engine Power Output: 270 horsepower
- Number of Cylinders: 6

The V8 engine that was tested in EU-EG4 had the following capacities:

- Engine Size: 5.7 liters
- Engine Power Output: 385 horsepower
- Number of Cylinders: 8

The engines in EU-EG5 and EU-TM5 are permitted to operate with dedicated catalytic oxidizers. The control device reduces the exhaust gas CO concentration by catalytic oxidation when the exhaust gas passes through the catalyst matrix in the presence of oxygen. Heat supplied by the combustion of fuel in the engine provides the activation energy required for the reaction. The catalytic oxidizers have a specified maximum CO reduction efficiency of 95%.

The engines operated in EU-EG4 are permitted to operate with and without production catalytic converters. The testing condition for EU-EG4 specified that emissions testing shall be conducted during high speed 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 individual EU-EG5 and EU-TM5 exhaust stacks are identical.

The exhaust stack sampling ports for EU-EG5 and EU-TM5 are located in individual exhaust stacks with an inner diameter of 12.0 inches. Each stack is equipped with two (2) sample ports, opposed 90°, that provide a sampling location greater than 120 inches (>10.0 duct diameters) upstream and 60.0 inches (5.0 duct diameters) downstream from any flow disturbance and satisfies the USEPA Method 1 criteria for a representative sample location.

The exhaust stack sampling ports for EU-EG4 are located an exhaust stack with an inner diameter of 18.0 inches. The stack is equipped with two (2) sample ports, opposed 90°, that provide a sampling location 12.0 inches (0.67 duct diameters) upstream and greater than 120.0 inches (>6.67 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 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. 186-13 requires TEMA to verify the CO emission factors of FG-EG125, FG-TM145 and FG-EG34 from a representative engines during representative operations for these flexible groups within 180 days of the completion of installation.

3.2 Operating Conditions During the Compliance Tests

Special Condition No. V.1. of FG-EG125 and FG-TM145 requires testing to be performed *...during representative operation...* TEMA performs numerous test patterns on engines installed in each test cell. The MDEQ-AQD requested that one (1) one-hour emissions test be performed for three (3) different test patterns in order to determine a greater number of CO emission factors.

TEMA performed one (1) one-hour emissions test on the following three (3) test patterns in EU-EG5:

- TOGO test pattern;
- High-speed test pattern; and
- Composite test pattern.

TEMA performed one (1) one-hour emissions test on the following three (3) test patterns in EU-TM5:

- Shift test pattern;
- Differential test pattern; and
- Launch test pattern.

Special Condition No. V.4. of FG-EG34 requires compliance testing to be performed on a representative engine during uncontrolled high speed operation. TEMA performed three (3) one hour emissions tests while the engine operated the uncontrolled high speed pattern.

Gasoline usage for each individual test period is presented in Table Nos. 6-1 through 6-3.

3.3 Summary of Air Pollutant Sampling Results

The gases exhausted from the sampled test cells were each sampled for three (3) one-hour test periods during the compliance testing performed January 20 through January 22, 2015.

Table 3.1 presents the measured CO emission factor for each test pattern.

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

Table 3.1 Measured CO emission factor for each tested cycle

	CO Emission Rates	
Emission Unit / Test Cycle	(lb/hr)	(lb/gal)
EU-EG5 / Controlled High Speed Test	1.57E-02	9.69E-04
EU-EG5 / Controlled TOGO Test	9.86E-03	1.25E-03
EU-EG5 / Controlled Composite Test	6.52E-03	8.73E-04
EU-TM5 / Controlled Shift Test	4.20	0.71
EU-TM5 / Controlled Differential Test	4.08	1.09
EU-TM5 / Controlled Launch Test	1.50	1.34
EU-EG4 / Uncontrolled High Speed Test[1]	233	6.93

<u>Notes for table 3.1:</u>

1. Presented emission factors are average of three (3) test runs.

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 TEMA testing periods.

4.1 Summary of Sampling Methods

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 10	Exhaust gas CO concentration was measured using NDIR 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 2 or USEPA Method 19)

The EU-EG4 and EU-EG5 (high speed test only) exhaust stack gas velocities and volumetric flow rates were determined using USEPA Method 2 prior to and after 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 each traverse 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 2 provides exhaust gas flowrate calculations and field data sheets.

The EU-EG5 (TOGO and composite tests) and EU-TM5 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:

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

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 Fuji ZRF nondispersive infrared (NDIR) gas analyzer. The O_2 content of the exhaust was monitored using a Fuji ZFK3 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 (for test runs that utilized USEPA Method 2) 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 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 ZRF NDIR 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 CO, 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 Fuji ZFK3 analyzer exhibited the longest system response time at 86 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.

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 and CO_2 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 Tables 6.1 through 6.3.

The measured air pollutant emission factors (lb/gal) will be used for future recordkeeping purposes. The air pollutant concentrations and mass emission rates (lb/hr) for each emission unit are less than the allowable limits specified in Permit to Install No. 186-13:

- 79.4 lb CO/hr for FG-EG125;
- 30.54 lb CO/hr for FG-TM145; and
- 428 lb CO/hr for FG-EG34.

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 test cells occurred during the engine test periods.

During the EU-EG5 composite testing the engine was shut down 1-minute prior to the end of the test period (i.e., after 59 minutes of sampling). This was discussed with the MDEQ representative and determined that the run did not need to be repeated (i.e., results were acceptable).

Table 6.1 Measured exhaust gas conditions and CO air pollutant emission rates for TEMA Ann Arbor facility (EU-EG5)

Test No.	High Speed	TOGO	Composite
Test date	1/20/15	1/20/15	1/20/15
Test period (24-hr clock)	1030 - 1130	1233 - 1333	1357 - 1456
Fuel flowrate (gal/hr)	16.2	7.86	7.47
Heat Input (MMBtu/hr)	2.01	0.97	0.93
Exhaust Gas Composition			
CO_2 content (% vol)	4.27	3.02	5.63
O_2 content (% vol)	14.8	16.5	13.2
Moisture (% vol)	6.89	-	-
Exhaust gas temperature (°F)	722	-	-
Exhaust gas flowrate (dscfm)	1,028	707	380
Carbon Monoxide			
CO conc. (ppmvd)	3.49	3.20	3.93
CO emissions (lb/hr)	1.57E-02	9.86E-03	6.52E-03
CO emissions (lb/gal)	9.69E-04	1.25E-03	8.73E-04

Table 6.2 Measured exhaust gas conditions and CO air pollutant emission rates for TEMA Ann Arbor facility (EU-EG4)

Test No. Test date Test period (24-hr clock)	1 1/21/15 1134 - 1234	2 1/21/15 1259 - 1400	3 1/21/15 1422 - 1522	 Three Test Average
Fuel flowrate (gal/hr)	33.9	33.6	33.5	33.7
Heat Input (MMBtu/hr)	4.20	4.16	4.15	4.17
Exhaust Gas Composition				
CO_2 content (% vol)	1.02	1.05	1.04	1.04
O_2 content (% vol)	17.1	17.2	17.4	17.2
Moisture (% vol)	1.50	1.78	1.93	1.74
Exhaust gas temperature (°F)	264	264	266	265
Exhaust gas flowrate (dscfm)	4,213	4,315	4,342	4,290
Carbon Monoxide				
CO conc. (ppmvd)	12,593	12,450	12,359	12,468
CO emissions (lb/hr)	232	234	234	233
CO emissions (lb/gal)	6.83	6.99	6.99	6.93

Table 6.3 Measured exhaust gas conditions and CO air pollutant emission rates for TEMA Ann Arbor facility (EU-TM5)

Test No.	Shift	Differential	Launch
Test date	1/22/15	1/22/15	1/22/15
Test period (24-hr clock)	1205 - 1305	1355 - 1455	1526 - 1626
Fuel flowrate (gal/hr)	5.90	3.74	1.12
Heat Input (MMBtu/hr)	0.73	0.46	0.14
Exhaust Gas Composition			
CO_2 content (% vol)	4.20	2.20	2.38
O_2 content (% vol)	14.4	17.3	17.0
Exhaust gas flowrate (dscfm)	355	410	112
Carbon Monoxide			
CO conc. (ppmvd)	2,651	2,262	3,118
CO emissions (lb/hr)	4.20	4.08	1.50
CO emissions (lb/gal)	0.71	1.09	1.34