AIR EMISSION TEST REPORT

Title	AIR EMISSION TEST REPORT FOR THE VERIFICATION OF CARBON MONOXIDE EMISSION FACTORS FROM AN ENGINE DYNAMOMETER TEST CELL
Report Date	May 9, 2018
Test Date	March 20, 2018

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.:	186-13D
		ROP No:	MI-ROP-N2915-2017a

Testing Contractor	
Company	Derenzo Environmental Services
Mailing Address	39395 Schoolcraft Road Livonia, MI 48150
Phone	(734) 464-3880
Project No.	1711021

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

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-N2915-2017a, initially issued TEMA on December 20, 2017 and Permit to Install (PTI) No. 186-13D, issued TEMA on October 30, 2017. PTI No. 186-13D requires that performance testing be completed to verify the emission factor and emission rate of carbon monoxide (CO) from a representative engine installed in engine dynamometer EG6.

Special Condition No. V.1. of Emission Unit (EU)-EG6 requires TEMA to perform a one-time performance test to verify the CO emission factor and emission rate from EU-EG6 within 180 days after the issuance of the PTI.

The compliance testing was performed by Derenzo Environmental Services (DES), a Michigan-based environmental consulting and testing company. DES representatives Tyler Wilson and Blake Beddow performed the field sampling and measurements March 20, 2018.

The exhaust gas sampling and analysis was performed using procedures specified in the Test Plan dated February 8, 2018 that was reviewed and approved by the Michigan Department of Environmental Quality – Air Quality Division (MDEQ-AQD). MDEQ-AQD representatives Mr. Mark Dziadosz, Ms. Regina Hines, and Ms. Diane Kavanaugh-Vetort 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.

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2.0 SOURCE AND SAMPLING LOCATION DESCRIPTION

2.1 General Process Description

EU-EG6 consists of an individual test cell. EU-EG6 is a catalyst aging dynamometer installed in the Powertrain Building. The dynamometer is used to perform accelerated catalyst aging testing on developmental catalysts. EU-EG6 was equipped with an eight (8) cylinder V8 gasoline fueled engine for the compliance demonstration.

2.2 Rated Capacities and Air Emission Controls

The V8 engine that was tested in EU-EG6 testing has the following capacities:

- Engine Size: 5.7 liters
- Engine Maximum Power Output: 385 horsepower (maximum output)
- Number of Cylinders: 8

EU-EG6 is permitted to operate with a catalyst installed. 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 catalyst aging test pattern runs at an engine speed of 2,800 rpm.

During fuel rich, high air intake operation the catalyst installed on EU-EG6 may operate at a reduced efficiency.

2.3 Sampling Locations

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 EU-EG6 are located in an individual 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 greater than 70.0 inches (3.9 duct diameters) upstream and 81.0 inches (4.5 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.

3.0 SUMMARY OF TEST RESULTS AND OPERATING CONDITIONS

3.1 Purpose and Objective of the Tests

The conditions of Permit to Install No. 186-13D require TEMA to verify the CO emission factor and emission rate of EU-EG6 from a representative engine during maximum routine operating conditions within 180 days of issuance of the PTI.

3.2 Operating Conditions During the Compliance Tests

TEMA performed three (1) one-hour emissions tests for EU-EG6 during a 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.

3.3 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 March 20, 2018.

Table 3.1 presents the measured CO emission factor and emission rate for EU-EG6.

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 EU-EG6

Emission Unit	CO Emission Rates (lb/hr)	CO Emission Rates (lb CO/1,000 gal gasoline)
EU-EG6	3.64	185.98
Permitted Limit	*10.1*	*502.67*

Notes for table 3.1:

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

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 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 10	Exhaust gas CO concentration was measured using an NDIR instrumental analyzer.

4.2 Exhaust Gas Velocity Determination (USEPA Method 2)

The EU-EG6 exhaust stack gas velocities and volumetric flow rates were determined using USEPA Method 2 once for 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 1440D single beam single wavelength (SBSW) infrared gas analyzer. The O_2 content of the exhaust was monitored using a Servomex 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 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 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 Thermo Environmental Instruments, Inc. (TEI) Model 48i 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 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 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 TEI Model 48i infrared CO analyzer exhibited the longest system response time at 42 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, 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 emission factor (lb CO/1,000 gal gasoline) and mass emission rates (lb/hr) for EU-EG6 are less than the emission factor and allowable limit specified in Permit to Install No. 186-13D:

- 502.67 lb CO/1,000 gallons fuel; and
- 10.1 lb CO/hr.

6.2 Variations from Normal Sampling Procedures or Operating Conditions

The testing for all pollutants was performed in accordance with the approved test protocol. No 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 air pollutant emission factor and emission rate for EU-EG6 at the TEMA Ann Arbor facility

Test No. Test date Test period (24-hr clock)	1 3/20/18 936 - 1036	2 3/20/18 1058 - 1158	3 3/20/18 1213 - 1313	Three Test Average
Avg. catalyst inlet temp. (°C)	910	933	915	920
Avg. catalyst outlet temp. (°C)	877	893	878	883
Engine speed (rpm)	2,801	2,803	2,803	2,802
Fuel flowrate (gal/hr)	19.7	19.6	19.5	19.6
<u>Exhaust Gas Composition</u>				
CO_2 content (% vol)	1.17	1.19	1.19	1.18
O_2 content (% vol)	19.8	19.8	19.8	19.8
Moisture (% vol)	1.49	1.27	1.28	1.35
Exhaust gas temperature (°F)	179	176	178	178
Exhaust gas flowrate (dscfm)	3,106	3,152	3,243	3,167
<u>Carbon Monoxide</u>				
CO conc. (ppmvd)	259	265	267	264
CO emissions (lb/hr)	3.52	3.64	3.77	3.64
Permitted Emission Rate (lb/hr)	-	-	-	*10.1*
CO emissions (lb/1,000 gal gasoline)	179	186	194	185.98
Permit Emission Factor (lb/1,000 gal)	-	-	-	*502.67*