AIR EMISSION TEST REPORT

Title:	AIR EMISSION TEST REPORT FOR THE VERIFICATION OF AIR POLLUTANT EMISSIONS FROM NATURAL GAS FUELED RICE – GENERATOR SETS
Report Date:	October 30, 2020
Test Date:	October 9, 2020

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City, County:	Ann Arbor, Washtenaw
Facility SRN:	N2915

Emission Unit and Permit Information	
ROP No.:	MI-ROP-N2915-2017c
Emission Unit ID Nos.:	EU-GENSET1 and EU-GENSET2

Testing Contractor	
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FOR THE
VERIFICATION OF AIR POLLUTANT EMISSIONS
FROM
NATURAL GAS FUELED RICE – GENERATOR SETS

TOYOTA MOTOR NORTH AMERICA R&D
ANN ARBOR, WASHTENAW COUNTY

1.0 INTRODUCTION

Toyota Motor North America R&D of Ann Arbor (TMNA R&D) operates two (2) Jenbacher (GE®) Model No. JMC 416 GS-N.LC gas fueled reciprocating internal combustion engine and electricity generator sets (RICE gensets) at the TMNA R&D facility in Ann Arbor, Washtenaw County, Michigan. The two (2) natural gas fueled RICE gensets are identified as emission units EU-GENSET1 and EU-GENSET2 (collectively flexible emission group FG-GENSETS) in Michigan Renewable Operating Permit (ROP) No. MI-ROP-N2915-2017c issued by the State of Michigan Department of Environment, Great Lakes, and Energy – Air Quality Division (EGLE-AQD).

The conditions of MI-ROP-N2915-2017c:

1. Allow for the installation and operation of two (2) natural gas fueled spark ignition, lean burn reciprocating internal combustion (SI RICE) engine and electricity generation sets (GE® Model JMC 416 GS-N.LC).

2. Require the permittee to conduct performance testing according to 40 CFR 60.4244 for each engine in FG-GENSETS initially and every 8,760 hours of operation or three years, whichever occurs first, to demonstrate compliance.

Air emission compliance testing was performed pursuant to conditions of ROP No. MI-ROP-N2915-2017c and the federal Standards of Performance for Stationary Spark Ignition Internal Combustion Engines (the SI-RICE NSPS; 40 CFR Part 60 Subpart JJJJ).

The compliance testing presented in this report was performed by Impact Compliance & Testing, Inc. (ICT), a Michigan-based environmental consulting and testing company. ICT representatives Blake Beddow and Andrew Eisenberg performed the field sampling and measurements on October 9, 2020. An initial (and the most recent) test event for FG-GENSETS was performed on October 11, 2018.

The exhaust gas sampling and analysis was performed using procedures specified in the Stack Test Protocol dated June 1, 2020, that was reviewed and approved by EGLE-AQD in the July 8, 2020 Test Plan Approval Letter. EGLE-AQD representative Ms. Diane Kavanaugh-Vetort observed portions of the testing project.

The engine emission performance tests consisted of triplicate, one-hour sampling periods for nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOC, as non-methane hydrocarbons (NMHC)). Exhaust gas velocity, moisture content, oxygen (O_2) content, and carbon dioxide (CO_2) content were determined for each test period to calculate pollutant mass emission rates.

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Report Certification

This test report was prepared by ICT based on field sampling data collected by ICT. Facility process data were collected and provided to TMNA R&D employees or representatives. This test report has been reviewed by TMNA R&D representatives and approved for submittal to EGLE-AQD.

I certify that the testing was conducted in accordance with the specified test methods and submitted test plan unless otherwise specified in this report. I believe the information provided in this report and its attachments are true, accurate, and complete.

Report Prepared By:

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Reviewed By:

Tyler J. Wilson
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A Renewable Operating Permit Report Certification form signed by the source responsible official accompanies this report.

2.0 SUMMARY OF TEST RESULTS AND OPERATING CONDITIONS

2.1 Purpose and Objective of the Tests

The conditions of MI-ROP-N2915-2017c and 40 CFR Part 60 Subpart JJJJ require TMNA R&D to test engines EU-GENSET1 and EU-GENSET2 for CO, NOx, and VOC emissions every 8,760 hours of operation or three (3) years, whichever comes first.

2.2 Operating Conditions During the Compliance Tests

The testing was performed while the TMNA R&D engine/generator sets were operated at maximum operating conditions (within 10% of rated capacity). The rated capacity for the GE® Model JMC 416 GS-N.LC engine generator sets are 1,141 kilowatts (kW) electricity output. TMNA R&D or Clarke Energy representatives provided kW output in 15-minute increments for each test period. The RICE gensets generator electricity output ranged between 1,082 and 1,146 kW for each test period.

Fuel flowrate (standard cubic feet per minute) was also recorded by TMNA R&D or Clarke Energy representatives in 15-minute increments for each test period. The RICE gensets fuel consumption rate ranged between 130 and 138 scfm.

Appendix 1 provides operating records provided by TMNA R&D representatives for the test periods.

Engine output (bhp) cannot be measured directly and was calculated based on the recorded electricity output, the calculated CAT® Model G3520C generator efficiency (97%), and the unit conversion factor for kW to horsepower (0.7457 kW/hp).

RICE power (bhp) = Electricity output (kW) / (0.97) / (0.7457 kW/hp)

Table 2.1 presents a summary of the average engine operating conditions during the test periods.

2.3 Summary of Air Pollutant Sampling Results

The gases exhausted from the sampled natural gas fueled RICE (EU-GENSET1 and EU-GENSET2) were sampled for three (3) one-hour test periods during the compliance testing performed October 9, 2020.

Table 2.2 presents the average measured CO, NO_X, and VOC emission rates for each engine (average of the three test periods).

Test results for each one-hour sampling period and comparison to the permitted emission rates are presented in Section 6.0 of this report.

Table 2.1 Average engine operating conditions during the test periods

Engine Parameter	EU-GENSET1	EU-GENSET2
Generator output (kW)	1,142	1,087
Engine LFG fuel use (scfm)	136	131

Table 2.2 Average measured emission rates for each engine (three-test average)

	CO Emission Rates	NOx Emission Rates	VOC Emission Rates
Emission Unit	(g/bhp-hr)	(g/bhp-hr)	(g/bhp-hr)
EU-GENSET1	0.20	0.44	0.18
EU-GENSET2	0.17	0.45	0.18
Permit Limit	*0.9*	*0.5*	*0.35*

3.0 SOURCE AND SAMPLING LOCATION DESCRIPTION

3.1 General Process Description

TMNA R&D operates two (2) GE® JMC 416 GS-N.LC RICE-generator sets at its Ann Arbor facility. The units are fired exclusively with pipeline natural gas.

3.2 Rated Capacities and Air Emission Controls

The GE® JMC 416 GS-N.LC engine generator sets have a rated design capacity of:

- Engine Power; 1,573 horsepower (hp)
- Electricity Generation; 1,141 kW

The GE® JMC 416 GS-N.LC engines are equipped with LEANOX air to fuel controllers (AFC) and an add-on oxidation catalyst for emission reductions. The LEANOX AFC system electronically controls the combustion air and fuel blend to ensures efficient combustion and minimize the NOx emission rate. The oxidation catalyst primarily reduces CO emissions from the engine in an add-on catalyst chamber.

3.3 Sampling Locations

Each RICE exhaust gas is directed through a muffler and is released to the atmosphere through a dedicated vertical exhaust stack with a vertical release point.

The exhaust stack sampling ports for the GE® JMC 416 GS-N.LC engines (EU-GENSET1 and EU-GENSET2) are located after the muffler in a vertical exhaust duct with an inner diameter of 15.0 inches. The duct is equipped with two (2) sample ports, opposed 90°, that provide a sampling location 40 inches (2.67 duct diameters) upstream and 77 inches (5.13 duct diameters) downstream from any flow disturbance.

All sample port locations satisfy the USEPA Method 1 criteria for a representative sample location. Individual traverse points were determined in accordance with USEPA Method 1.

Appendix 2 provides a diagram of the emission test sampling locations.

4.0 SAMPLING AND ANALYTICAL PROCEDURES

A Stack Test Protocol for the air emission testing was reviewed and approved by EGLE-AQD. This section provides a summary of the sampling and analytical procedures that were used during the 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 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 determined using chemiluminescence instrumental analyzers.
USEPA Method 10	Exhaust gas CO concentration was measured using an infrared instrumental analyzer.
USEPA Method 25A / ALT-096	Exhaust gas VOC (as NMHC) concentration was determined using a flame ionization analyzer equipped with methane separation column.

4.2 Exhaust Gas Velocity Determination (USEPA Method 2)

The RICE exhaust stack gas velocities and volumetric flow rates were determined using USEPA Method 2 once for each test period. 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 onsite, prior to the test event, to verify the integrity of the measurement system.

The absence of significant cyclonic flow at the sampling location 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 RICE exhaust gas stream was 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 RICE 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 RICE 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 NO_x and CO Concentration Measurements (USEPA Methods 7E and 10)

NO_X and CO pollutant concentrations in the RICE exhaust gas streams were determined using a Thermo Environmental Instruments, Inc. (TEI) Model 42c High Level chemiluminescence NO_X analyzer and a California Analytics / Fuji Model ZRF NDIR 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 and NO_X calculation sheets. Raw instrument response data are provided in Appendix 5.

4.6 Measurement of Volatile Organic Compounds (USEPA Method 25A/ALT-096)

The VOC emission rate was determined by measuring the nonmethane hydrocarbon (NMHC) concentration in the engine exhaust gas. NMHC pollutant concentration was determined using a TEI Model 55i Methane / Nonmethane hydrocarbon analyzer. The TEI 55i analyzer contains an internal gas chromatograph column that separates methane from non-methane components. The concentration of NMHC in the sampled gas stream, after separation from methane, is determined relative to a propane standard using a flame ionization detector in accordance with USEPA Method 25A.

The USEPA Office of Air Quality Planning and Standards (OAQPS) has issued an alternate test method approving the use of the TEI 55i-series analyzer as an effective instrument for measuring NMOC from gas-fueled RICE (ALT-096).

Samples of the exhaust gas were delivered directly to the instrumental analyzer using the Teflon® heated sample line to prevent condensation. The sample to the NHMC analyzer was not conditioned to remove moisture. Therefore, VOC measurements correspond to standard conditions with no moisture correction (wet basis).

Prior to, and at the conclusion of each test, the instrument was calibrated using mid-range calibration (propane) and zero gas to determine analyzer calibration error and system bias (described in Section 5.0 of this document).

Appendix 4 provides VOC calculation sheets. Raw instrument response data for the NMHC analyzer is provided in Appendix 5.

5.0 QA/QC ACTIVITIES

5.1 Flow Measurement Equipment

Prior to arriving onsite (or while onsite, prior to testing), the instruments used during the source test to measure exhaust gas properties and velocity (barometer, pyrometer, Pitot tube, and scale) were calibrated to specifications in the sampling methods.

The absence of cyclonic flow for each sampling location was verified using an S-type Pitot tube and oil manometer. The Pitot tube was positioned at each of the velocity traverse points 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).

5.2 NO_x Converter Efficiency Test

The NO_2 – NO conversion efficiency of the Model 42c analyzer was verified prior to the testing program. A USEPA Protocol 1 certified concentration of NO_2 was injected directly into the analyzer, following the initial three-point calibration, to verify the analyzer's conversion efficiency. The analyzer's NO_2 – NO converter uses a catalyst at high temperatures to convert the NO_2 to NO for measurement. The conversion efficiency of the analyzer is deemed acceptable if the measured NO_X concentration is greater than or equal to 90% of the expected value.

The NO_2 – NO conversion efficiency test satisfied the USEPA Method 7E criteria (measured NO_X concentration was 95.6% of the expected value, i.e., greater than 90% of the expected value as required by Method 7E).

5.3 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.

5.4 Instrumental Analyzer Interference Check

The instrumental analyzers used to measure NO_X, 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.

5.5 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 NO_x, 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.

At the beginning of each test day, appropriate high-range, mid-range, and low-range span gases followed by a zero gas were introduced to the NMHC analyzer, in series at a tee connection, which is installed between the sample probe and the particulate filter, through a poppet check valve. After each one-hour test period, mid-range and zero gases were re-introduced in series at the tee connection in the sampling system to check against the method's performance specifications for calibration drift and zero drift error.

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

5.6 Determination of Exhaust Gas Stratification

A stratification test was performed for each RICE exhaust stack. 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 concentration data for the RICE exhaust stacks indicated 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 RICE exhaust gas was considered to be unstratified and the compliance test sampling was performed at a single sampling location within each RICE exhaust stack.

5.7 Meter Box Calibrations

The dry gas meter and 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 (NO_2 – NO conversion efficiency test data, instrument calibration and system bias check records, calibration gas and gas divider certifications, interference test results, meter box calibration records, stratification checks, and Pitot tube, barometer, pyrometer, and scale 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 6.2.

The measured air pollutant concentrations and emission rates for EU-GENSET1 and EU-GENSET2 are less than the allowable limits specified in MI-ROP-N2915-2017c:

- 0.9 grams per brake-horsepower hour (g/bhp-hr) for CO;
- 0.5 g/bhp-hr for NOx; and
- 0.35 g/bhp-hr for VOC.

These permit limits are more stringent than those required by the SI RICE NSPS.

6.2 Variations from Normal Sampling Procedures or Operating Conditions

The testing for all pollutants was performed in accordance with USEPA methods and the approved Stack Test Protocol. The engine-generator sets were operated within 10% of maximum output and no variations from normal operating conditions occurred during the engine test periods.

Table 6.1 Measured exhaust gas conditions and NO$_x$, CO, and VOC air pollutant emission rates for Engine No. 1 (EU-GENSET1)

Test No.	1	2	3	
Test date	10/9/2020	10/9/2020	10/9/2020	Three Test Average
Test period (24-hr clock)	0851-0951	1020-1120	1145-1245	
Fuel flowrate (scfm)	135	136	136	136
Generator output (kW)	1,141	1,143	1,142	1,142
Exhaust Gas Composition				
CO$_2$ content (% vol)	6.10	6.10	6.09	6.10
O$_2$ content (% vol)	10.6	10.6	10.7	10.6
Moisture (% vol)	9.06	11.8	10.8	10.6
Exhaust gas temperature (°F)	734	738	737	736
Exhaust gas flowrate (dscfm)	2,924	2,792	2,852	2,856
Exhaust gas flowrate (scfm)	3,216	3,167	3,198	3,193
Nitrogen Oxides				
NO$_X$ conc. (ppmvd)	74.4	73.8	74.7	74.3
NO$_X$ emissions (lb/hr)	1.56	1.48	1.53	1.52
NO$_X$ emissions (g/bhp*hr)	0.45	0.42	0.44	0.44
*Permitted emissions (g/bhp*hr)*	-	-	-	*0.5*
Carbon Monoxide				
CO conc. (ppmvd)	56.5	53.2	57.8	55.9
CO emissions (lb/hr)	0.72	0.65	0.72	0.70
CO emissions (g/bhp*hr)	0.21	0.19	0.21	0.20
*Permitted emissions (g/bhp*hr)*	-	-	-	*0.9*
Volatile Organic Compounds				
VOC conc. (ppmv)	27.5	28.1	27.9	27.8
VOC emissions (lb/hr)	0.61	0.61	0.61	0.61
VOC emissions (g/bhp*hr)	0.17	0.18	0.18	0.18
*Permitted emissions (g/bhp*hr)*	-	-	-	*0.35*

Table 6.2 Measured exhaust gas conditions and NO_X, CO, and VOC air pollutant emission rates for Engine No. 2 (EU-GENSET2)

Test No. Test date Test period (24-hr clock)	1 10/9/2020 1315-1415	2 10/9/2020 1435-1535	3 10/9/2020 1552-1652	Three Test Average
Fuel flowrate (scfm)	131	132	132	131
Generator output (kW)	1,086	1,087	1,089	1,087
Exhaust Gas Composition				
CO_2 content (% vol)	6.02	5.98	6.00	6.00
O_2 content (% vol)	10.7	10.8	10.8	10.8
Moisture (% vol)	10.9	11.6	14.3	12.3
Exhaust gas temperature (°F)	734	734	732	733
Exhaust gas flowrate (dscfm)	2,834	2,690	2,752	2,759
Exhaust gas flowrate (scfm)	3,179	3,044	3,210	3,144
Nitrogen Oxides				
NO_X conc. (ppmvd)	76.4	74.8	75.8	75.7
NO_X emissions (lb/hr)	1.55	1.44	1.49	1.50
NO_X emissions (g/bhp*hr)	0.47	0.44	0.45	0.45
*Permitted emissions (g/bhp*hr)*	-	-	-	*0.5*
Carbon Monoxide				
CO conc. (ppmvd)	45.8	44.5	46.5	45.6
CO emissions (lb/hr)	0.57	0.52	0.56	0.55
CO emissions (g/bhp*hr)	0.17	0.16	0.17	0.17
*Permitted emissions (g/bhp*hr)*	-	-	-	*0.9*
Volatile Organic Compounds				
VOC conc. (ppmv)	28.3	28.3	27.8	28.2
VOC emissions (lb/hr)	0.62	0.59	0.61	0.61
VOC emissions (g/bhp*hr)	0.19	0.18	0.18	0.18
*Permitted emissions (g/bhp*hr)*	-	-	-	*0.35*