AIR EMISSION TEST REPORT
FOR THE
VERIFICATION OF AIR POLLUTANT EMISSIONS
FROM A
NATURAL GAS AND FUEL OIL FIRED TURBINE

Prepared for:

University of Michigan
North Campus Research Complex
Powerhouse
SRN M0675
MI-ROP-M0675-2021b

ICT Project No.: 2200199

IMPACT COMPLIANCE & TESTING

Report Certification

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University of Michigan
North Campus Research Complex Powerhouse
Ann Arbor, MI

Report Certification

This test report was prepared by ICT based on field sampling data collected by ICT. Facility process data were collected and provided by Cummins employees or representatives (hired by University of Michigan). This test report has been reviewed by University of Michigan representatives and approved for submittal to the State of Michigan EGLE-AQD.

I certify that the testing was conducted in accordance with the Emission Test Plan and approved test plan approval letter 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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Impact Compliance & Testing, Inc.

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1.0 Introduction

The University of Michigan (University) operates a natural gas-fired turbine (EUTURBINE) with No. 2 fuel oil-firing capability at the North Campus Research Complex (NCRC) Powerhouse located in Ann Arbor, Washtenaw County, Michigan.

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 Andrew Eisenberg, Nick Steinthal, and Blake Beddow performed the field sampling and measurements on December 20, 2022.

The engine performance tests consisted of triplicate, one-hour sampling periods for nitrogen oxides (NOx). Exhaust gas moisture, oxygen (O_2), and carbon dioxide (CO_2) content was determined for each test period to calculate air pollutant concentrations for comparison to applicable permit limits.

The exhaust gas sampling and analysis was performed using procedures specified in the Emission Test Plan (ICT) dated November 15, 2022 that was reviewed and approved by EGLE-AQD. Attached is a copy of the EGLE approval letter presented in Appendix 7.

Questions regarding this air emission test report should be directed to:

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2.0 Summary of Test Results and Operating Conditions

2.1 Purpose and Objective of the Tests

The testing requirements in ROP No. MI-ROP-M0675-2021b and the federal Standards for Stationary Gas Turbines (40 CFR Part 60, Subparts A and GG) require testing to be performed at least every five (5) years from the date of the last test. Measurements were performed for the turbine exhaust to determine NO_X concentrations and diluent gas content (oxygen and carbon dioxide).

2.2 Operating Conditions During the Compliance Tests

The testing was performed while the turbine was operated near maximum routine operating conditions. University of Michigan representatives provided kW output in 15-minute increments for each test period. The turbine kW output was 3,207 kW throughout the natural gas fired test periods, and 3,067 kW throughout the fuel oil fired test periods.

Fuel flowrate (standard cubic feet per hour (SCFH) for natural gas, and gallons per minute (GPM) for fuel oil) was also recorded by University of Michigan representatives in 15-minute increments for each test period. The turbine fuel consumption rate was 42,813 SCFH throughout the natural gas fired test periods, and 32 GPM throughout the fuel oil fired test periods.

Appendix 2 provides operating records provided by University of Michigan representatives for the test periods.

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 turbine were sampled for six (6) one-hour test periods during the compliance testing performed December 20, 2022. Three (3) one-hour test periods were performed while the turbine was fired by natural gas, and three (3) one-hour test periods were performed while the turbine was fired by fuel oil.

Table 2.2 presents the average measured NO_X concentrations, and emission rates for EUTURBINE (average of the three test periods) and applicable limits.

Test results for each one-hour sampling period and comparison to the applicable concentration limits are presented in Section 6.0 of this report.

Table 2.1 Average engine operating conditions during the test periods

Turbine Parameter	EUTURBINE Natural Gas Fired	EUTURBINE Fuel Oil Fired
Generator output (kW)	3,207	3,067
Engine fuel use (SCFH)	42,813	--
Engine fuel use (GPM)	--	32

Table 2.2 Average measured pollutant concentrations for the turbine (3-test average)

Emission Unit	NOx	
	(ppmvd)†	(lb/hr)
EUTURBINE – natural gas	120	13.2
EUTURBINE – fuel oil	157	18.0
Permit Limit	***167***	***36.1***

† Parts per million by volume, dry basis, corrected to 15% oxygen.

The data presented in Table 2.2 indicates that EUTURBINE was tested while the unit operated near its maximum capacity and is in compliance with the emission standards specified in MI-ROP-M0675-2021b and 40 CFR Part 60, Subparts A and GG.

3.0 Source and Sampling Location Description

3.1 General Process Description

The natural gas-fired turbine with fuel oil-firing capability is operated to generate electricity, which is then provided to the NCRC.

3.2 Rated Capacities and Air Emission Controls

The emissions unit is a single gas turbine with a capacity of 40.1 MMBtu/hr. Exhaust from the turbine can either be sent through the waste heat boiler (EU-DUCTBURNER) or exhaust through a by-pass stack (SV-BYPASS). EU-DUCTBURNER provides supplemental heat to Boiler 4. This burner only fires natural gas and is rated at 32 MMBtu/hr heat input. The duct burner heat combines with the exhaust heat from the turbine. The emission test program was conducted with EU-DUCTBURNER off.

EUTURBINE is not equipped with add-on emission control equipment. Exhaust gas is exhausted directly to the atmosphere through an exhaust stack.

3.3 Sampling Locations

The turbine exhaust gas is released to the atmosphere through a vertical exhaust stack with vertical release points. The stack inner diameter is 41 inches.

The stack is equipped with two (2) sample ports, opposed 90°, that provide a sampling location greater than 240 inches (>5.85 duct diameters) upstream and greater than 120 inches (>2.93 duct diameters) downstream from any flow disturbance and satisfies the USEPA Method 1 criteria for a representative sample location.

Sample port locations were determined in accordance with USEPA Method 1.

Appendix 1 provides a diagram of the test sampling location.

4.0 Sampling and Analytical Procedures

An Emission Test Plan, dated November 15, 2022, for the air compliance 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	Selections of sample and velocity traverse locations by physical stack measurements.
USEPA Method 2	Measurement of velocity head using a Type-S Pitot tube with an inclined manometer
USEPA Method 3A	Exhaust gas O_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.

4.2 Velocity Traverse Locations & Stack Gas Velocity Measurements (USEPA Method 1 & 2)

Prior to commencing the emission performance test field measurements, turbine gas sampling locations (i.e., pollutant concentration and velocity pressure measurement locations) were determined in accordance with USEPA Method 1. Sample ports were located more than two (2) duct diameters (greater than 120 inches) downstream from the nearest flow disturbance. Stack measurements were verified in the field.

To determine hourly pollutant emission rates, the stack gas velocity and volumetric flowrate was measured using USEPA Method 2 once during each sampling period. Gas velocity (pressure) measurements will be conducted at each traverse point of the stack with an S-type Pitot tube and red-oil manometer. Temperature measurements will be conducted at each traverse point using a K-type thermocouple and a calibrated digital thermometer. Once the molecular weight and moisture content of the engine exhaust gas is obtained, the stack exhaust volumetric flowrate will be determined.

The absence of cyclonic flow will be verified for each sampling location to ensure the validity of the measured data.

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

O_2 content in the turbine exhaust gas stream was measured continuously throughout each test period in accordance with USEPA Method 3A. 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 turbine 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 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 calculation sheets. Raw instrument response data are provided in Appendix 5.

4.4 Exhaust Gas Moisture Content (USEPA Method 4)

Moisture content of the turbine exhaust gas was determined in accordance with USEPA Method 4 using a chilled impinger sampling train. Exhaust gas moisture content measurements were performed concurrently with the instrumental analyzer sampling periods. 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.

Appendix 3 provides moisture calculations and field data sheets.

4.5 NO_x Concentration Measurements (USEPA Method 7E)

NO_X pollutant concentrations in the turbine exhaust gas stream was determined using a Thermo Environmental Instruments, Inc. (TEI) Model 42i High Level chemiluminescence NO_X 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 NO_X calculation sheets. Raw instrument response data are provided in Appendix 5.

5.0 QA/QC Activities

5.1 NO_x Converter Efficiency Test

The NO_2 – NO conversion efficiency of the TEI Model 42i 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 within 90% of the expected value.

The NO_2 – NO conversion efficiency test satisfied the USEPA Method 7E criteria (measured NO_2 concentration was 99.8% of the expected value).

5.2 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.

5.3 Instrumental Analyzer Interference Check

The instrumental analyzers used to measure NO_X, CO_2, and O_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.

5.4 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_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 reintroduced 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 O_2, NO_x, and CO_2 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.

5.5 Determination of Exhaust Gas Stratification

A stratification test was performed for the turbine exhaust stack. The stainless-steel sample probe was positioned at sample points according to USEPA Method 1. Pollutant concentration data were recorded at each sample point for a minimum of twice the maximum system response time for the turbine exhaust stack.

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

5.6 System Response Time

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.

Sampling periods did not commence until the sampling probe had been in place for at least twice the greatest system response time.

5.7 Meter Box Calibrations

The dry gas meter sampling console used for moisture testing 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 metering console was 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 certifications, interference test results, meter box calibration records, and field equipment calibration records).

6.0 Results

6.1 Test Results and Allowable Concentration Limits

Engine operating data and air pollutant concentration measurement results for each one-hour test period are presented in Table 6.1 and 6.2.

EUTURBINE has the following allowable concentration limits specified in ROP No. MI-ROP-M0675-2021b and the federal Standards for Stationary Gas Turbines (40 CFR Part 60, Subparts A and GG).

- 36.1 pounds per hour (lb/hr) NO_x, and
- 167 ppmvd @ 15% O_2 NO_x.

The measured air pollutant concentrations for EUTURBINE are less than the allowable limits specified in ROP No. MI-ROP-M0675-2021b and the federal Standards for Stationary Gas Turbines (40 CFR Part 60, Subparts A and GG).

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 Emission Test Plan. The turbine was operated near maximum capacity and no variations from normal operating conditions occurred during the engine test periods.

Table 6.1 Measured exhaust gas conditions and pollutant concentrations for EUTURBINE (Natural Gas Fired)

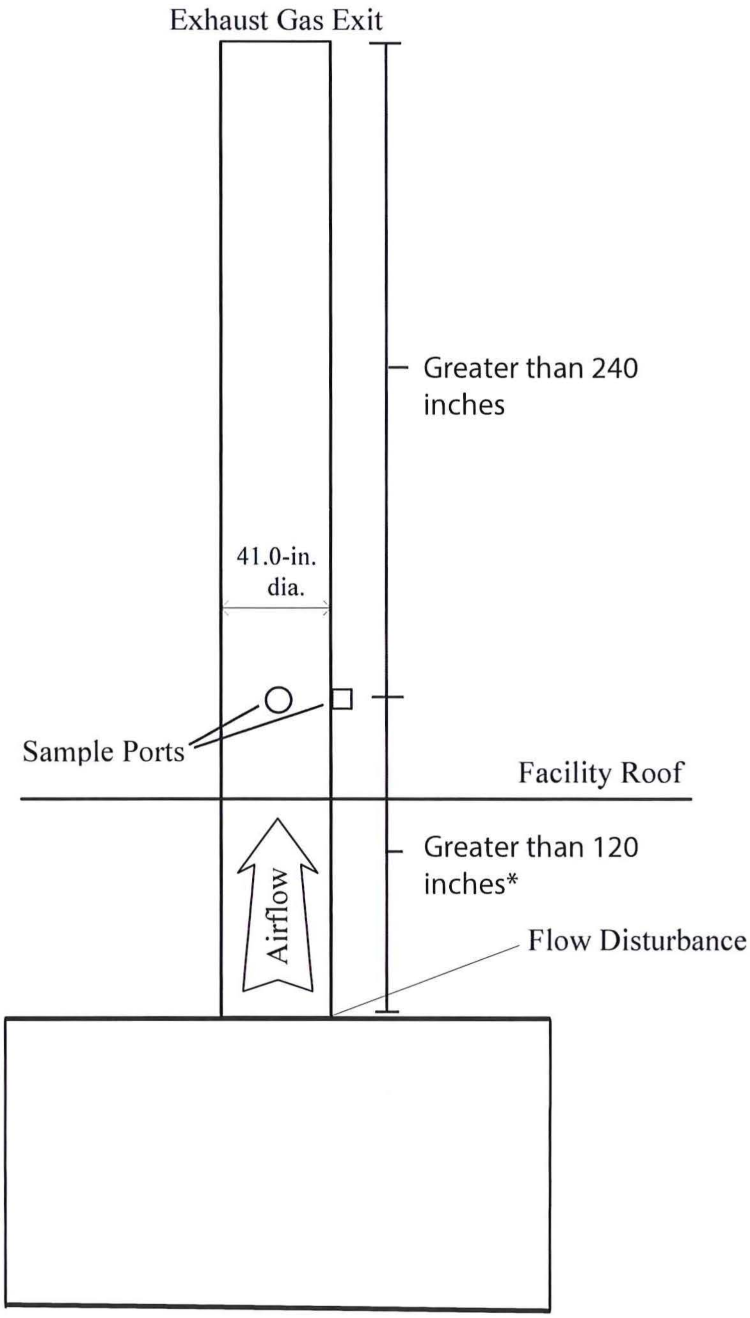
Test No. Test date Test period (24-hr clock)	1 12/20/2022 0745-0815, 0820-0850	2 12/20/2022 0908-1008	3 12/20/2022 1025-1125	Three Test Average
Fuel flowrate (SCFH)	42,850	42,820	42,770	42,813
Generator output (kW)	3,200	3,217	3,205	3,207
Exhaust Gas Composition				
O_2 content (% vol)	17.4	17.8	17.6	17.6
CO_2 content (% vol)	2.33	2.21	2.20	2.25
Moisture (% vol)	3.72	4.82	5.62	4.72
Nitrogen Oxides				
NO_X conc. (ppmvd)	69.1	65.9	67.3	67.4
NO_X conc. corrected to 15% O_2	116	124	120	120
Permit limit @ 15% O_2 (ppmvd)	-	-	-	*167*

Table 6.2 Measured exhaust gas conditions and pollutant concentrations for EUTURBINE (Fuel Oil Fired)

Test No. Test date Test period (24-hr clock)	1 12/20/2022 1155-1255	2 12/20/2022 1310-1410	3 12/20/2022 1430-1530	Three Test Average
Fuel flowrate (GPM)	32	31	34	32
Generator output (kW)	3,100	3,050	3,052	3,067
Exhaust Gas Composition				
O_2 content (% vol)	17.4	17.3	17.3	17.4
CO_2 content (% vol)	2.91	2.91	2.99	2.94
Moisture (% vol)	4.13	2.46	3.71	3.43
Nitrogen Oxides				
NO_X conc. (ppmvd)	93.9	93.0	97.0	94.6
NO_X conc. corrected to 15% O_2	159	153	160	157
Permit limit @ 15% O_2 (ppmvd)	-	-	-	*167*

APPENDIX 1

- Turbine Sample Port Diagram



University of Michigan - NCRC Powerhouse
EUTURBINE Stack Diagram

Scale	Sheet
None	1 of 1

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