AIR EMISSION TEST REPORT FOR THE VERIFICATION OF NOx EMISSIONS FROM A NATURAL GAS FUELED TURBINE

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IMPACT COMPLIANCE & TESTING

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Report Certification

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FOR THE
VERIFICATION OF NOx EMISSIONS
FROM A
NATURAL GAS FUELED TURBINE

Oakland University
at the Central Heating Plant
Rochester, MI

The material and data in this document were prepared under the supervision and direction of the undersigned.

Impact Compliance & Testing, Inc.

Tyler J. Wilson
Senior Project Manager

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1.0 Introduction

Oakland University (OU) operates a natural gas fired turbine equipped with a waste heat recovery unit (WHRU) at its Central Heating Plant (CHP) facility located in Rochester, Oakland County, Michigan.

The State of Michigan Department of Environment, Great Lakes, and Energy – Air Quality Division (EGLE-AQD) has issued to OU Permit to Install (PTI) No. 419-92D for operation of the Central Heating Plant facility. The unit that was tested is a natural gas fired turbine that is equipped with a WHRU that is identified as emission unit EU-TURBINE#1 (also called Turbine No. 1) in PTI No. 419-92D.

Air emission compliance testing was performed pursuant to conditions of PTI No. 419-92D and the New Source Performance Standards for Stationary Combustion Turbines (the NSPS; 40 CFR Part 60, Subpart KKKK), which requires that testing be performed annually to demonstrate compliance with nitrogen oxides (NOx) emissions 1.2 lb/MW-hr, or once every two (2) years if the emission test results (from the previous testing event) are less than or equal to 0.9 lb/MW-hr. The next test event for EU-TURBINE#1 will be scheduled to be performed within two (2) years of this test event.

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 Tyler Wilson and Renee Fromwiller performed the field sampling and measurements on January 16, 2024.

The turbine emission performance tests consisted of triplicate, one-hour sampling periods for nitrogen oxides (NOx). Exhaust gas velocity, moisture, oxygen (O_2) content, and carbon dioxide (CO_2) content were determined for each test period to calculate pollutant mass emission rates.

The exhaust gas sampling and analysis was performed using procedures specified in the Stack Test Protocol dated October 16, 2023, that was reviewed and approved by EGLE-AQD.

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

Tyler J. Wilson
Senior Project Manager
Impact Compliance & Testing, Inc.
37660 Hills Tech Drive
Farmington Hills, MI 48331
(734) 357-8046
Tyler.Wilson@impactCandT.com

Ms. Cora Hanson
Director of Environmental Health and Safety
Oakland University
Office of Environmental Health and Safety
408 Meadow Brook Road, Graham Health Center-Apt
Rochester, MI 48309-4452
chanson@oakland.edu
Ph: (248) 370-4427

2.0 Summary of Test Results and Operating Conditions

2.1 Purpose and Objective of the Tests

Conditions of PTI No. 419-92D and the New Source Performance Standards for Stationary Combustion Turbines (the NSPS; 40 CFR Part 60, Subpart KKKK) require OU to test EU-TURBINE#1 for NOx emissions. EU-TURBINE#1 (Turbine No. 1) was tested during this compliance test event.

2.2 Operating Conditions During the Compliance Tests

Testing was performed while EU-TURBINE#1 was operated at maximum operating conditions (within +/- 25% of rated design capacity). OU representatives provided turbine output (% load) in 15-minute increments for each test period. EU-TURBINE#1 output ranged between 88% and 94% during the test periods.

Additional turbine operating parameters were also recorded by OU representatives in 15-minute increments for each test period.

Appendix 2 provides operating records provided by OU representatives for the test periods.

Tables 2.1 and 6.1 present a summary of the average turbine operating conditions during the test periods.

2.3 Summary of Air Pollutant Sampling Results

The gases exhausted from the sampled natural gas fueled turbine (EU-TURBINE#1; Turbine No. 1) were sampled for three (3) one-hour test periods during the compliance testing performed January 16, 2024.

Table 2.2 presents the average measured NO_X concentrations and emission rates for EU-TURBINE#1 (average of the three test periods).

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

Table 2.1 Average turbine operating conditions during the test periods

Turbine Parameter	EU-TURBINE#1 (Turbine No. 1)
Turbine output (% load)	93
Electricity production (MW)	4.27
Turbine natural gas use (lb/hr)	2,272
WHRU absorbed (MMBTUH)	24.5
Compressor exhaust temperature (°F)	1,243
Compressor exhaust pressure (psi)	136
Hot water flow (KPPH)	387
Hot water temperature (°F)	312

Table 2.2 Average measured NOx concentrations and emission rates (three-test average)

Emission Unit	NOx		
	(ppmvd @ 15% O_2)	(lb/hr)	(lb/MW-hr)
EU-TURBINE#1	10.8	2.51	0.59
Limits	***25***	***8.44***	***1.2***

3.0 Source and Sampling Location Description

3.1 General Process Description

OU is permitted to operate a natural gas fueled turbine (equipped with a WHRU) at its Central Heating Plant facility. The unit is fueled exclusively with natural gas.

3.2 Rated Capacities and Air Emission Controls

The natural gas fueled turbine has a heat release capacity of 51.53 million British Thermal Units per hour (MMBtu/hr). In addition, a natural gas-fired duct burner associated with the WHRU has a rated heat input of 60.0 MMBtu/hr. The WHRU can operate as a standalone boiler for a total of 35.0 MMBtu/hr.

The turbine is equipped with dry low NOx combustors that are designed to pre-mix the fuel and combustion air at a controlled ratio that minimizes combustor temperature and NOx formation. The exhaust gas is used to heat the WHRU and is released to atmosphere without additional add-on emission controls.

3.3 Sampling Locations

The turbine exhaust gas is released to the atmosphere through a vertical exhaust stack with a vertical release point.

The exhaust stack sampling ports are located in the vertical exhaust stack, with an inner diameter of 48.0 inches. The stack is equipped with two (2) sample ports, opposed 90°, that provide a sampling location >200" (>4.17 duct diameters) upstream and >223" (>4.65 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 1 provides a diagram of the emission test sampling locations with actual stack dimension measurements.

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 4	Exhaust gas moisture was determined based on the water weight gain in chilled impingers.
USEPA Method 3A	Exhaust gas O_2 and CO_2 content were determined using paramagnetic and infrared instrumental analyzers, respectively.
USEPA Method 7E	Exhaust gas NOx concentration was determined using a chemiluminescence instrumental analyzer.

4.2 Exhaust Gas Velocity Determination (USEPA Method 2)

The turbine exhaust stack gas velocities and volumetric flow rates were determined using USEPA Method 2 once during 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 periodically throughout the test periods to verify the integrity of the measurement system.

The absence of significant cyclonic flow at the sampling locations 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 turbine 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 1440D 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 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 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 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.

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 turbine exhaust gas was extracted from the stack using the Teflon® heated sample line and gas conditioning system and delivered to the instrumental analyzer. Instrument response for the 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 instrument was 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 Flow Measurement Equipment

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

5.2 NO_x Converter Efficiency Test

The NO_2 – NO conversion efficiency of the 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 at least 90% of the expected value (within 10%).

The NO_2 – NO conversion efficiency test satisfied the USEPA Method 7E criteria (measured NO_x concentration was 101.3% of the expected value).

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, 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 the 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_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 NO_x 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.

5.6 Determination of Exhaust Gas Stratification

A stratification test was performed for the turbine exhaust stack during Test No. 1. The stainless-steel sample probe was positioned at sixteen (16) sample points inside the turbine exhaust stack (eight (8) points per sample port). 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 turbine exhaust stack indicated that the measured NOx concentrations did not satisfy requirements in 40 CFR, Part 60, Subpart KKKK, Section 60.4400 for use of a single sampling location.

Therefore, the turbine exhaust gas compliance test sampling was performed at sixteen (16) sampling locations within the turbine exhaust stack, for each test period.

5.7 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.

5.8 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 Emission Limits

Turbine operating data and NOx concentrations and emission measurement results for each one-hour test period are presented in Table 6.1.

EU-TURBINE#1 has the following allowable NOx concentration limits and emission limits:

- 8.44 pounds per hour (lb/hr); and
- 25 parts per million by volume, dry basis, corrected to 15 percent oxygen (ppmvd @ 15% O_2); or
- 1.2 pounds per megawatt hour (lb/MW-hr).

The measured air pollutant concentrations and emission rates for EU-TURBINE#1 are less than the allowable limits specified in PTI No. 419-92D and the New Source Performance Standards for Stationary Combustion Turbines (the NSPS; 40 CFR Part 60, Subpart KKKK).

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 turbine was operated within +/- 25% of rated design capacity and no variations from normal operating conditions occurred during the turbine test periods.

The EGLE-AQD testing approval letter dated January 8, 2024, requested that "BTU content of the fuel" be recorded during emissions testing. This data was not recorded during emissions testing, but it is a relatively constant value. Historical data is listed below for reference.

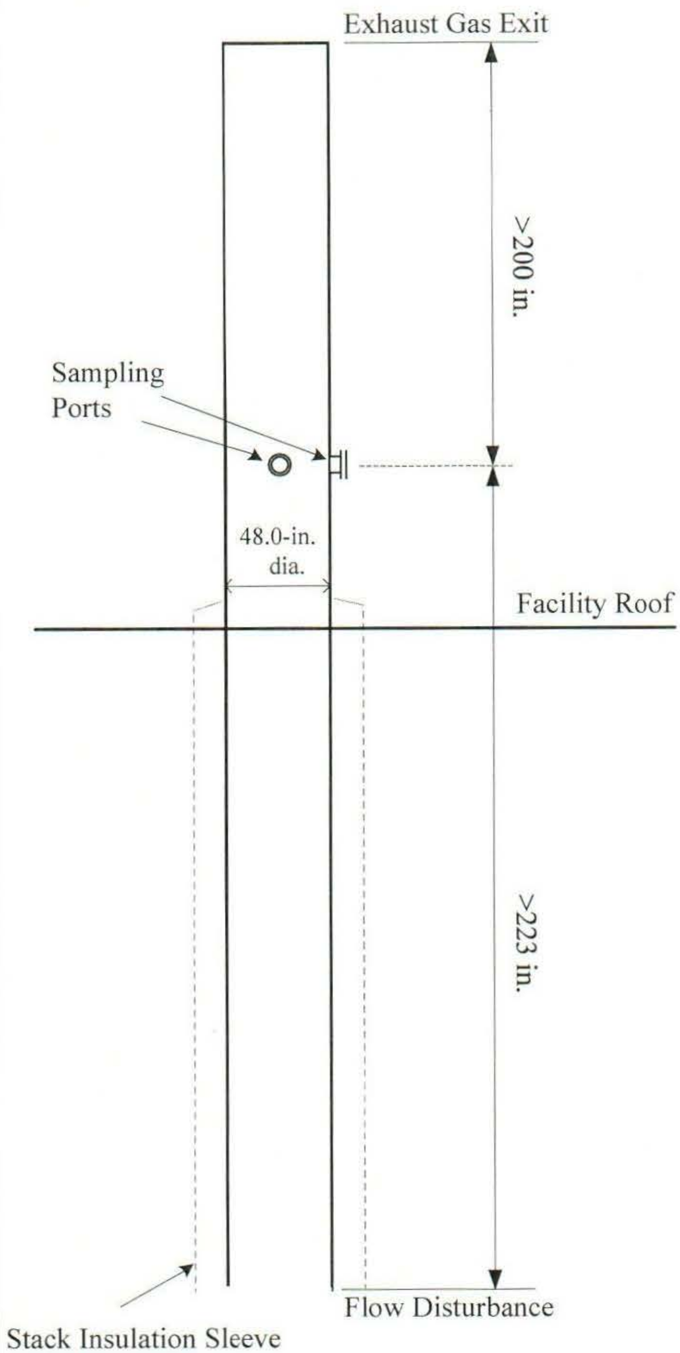
- December 2023 (monthly average): 1.0480 mmbtu/mcf
- Calendar Year 2023 (12-month average): 1.0496 mmbtu/mcf

Table 6.1 Measured exhaust gas conditions and NOx concentrations and emission rates for Turbine No. 1 (EU-TURBINE#1)

Test No. Test date Test period (24-hr clock)	1 1/16/2024 845-945	2 1/16/2024 1000-1100	3 1/16/2024 1115-1215	Three Test Average
Turbine output (% load)	92	94	93	93
Electricity production (MW)	4.21	4.31	4.30	4.27
Turbine natural gas use (lb/hr)	2,263	2,284	2,271	2,272
WHRU absorbed (MMBTUH)	24.7	24.6	24.3	24.5
Compressor exhaust temp. (°F)	1,229	1,250	1,250	1,243
Compressor exhaust pressure (psi)	135	136	136	136
Hot water flow (KPPH)	387	387	388	387
Hot water temp. (°F)	305	316	316	312
Exhaust Gas Composition				
CO_2 content (% vol)	3.42	3.41	3.39	3.41
O_2 content (% vol)	15.4	15.4	15.5	15.4
Moisture (% vol)	2.5	5.9	6.3	4.9
Exhaust gas flowrate (dscfm)	36,161	34,784	34,436	35,127
Exhaust gas flowrate (scfm)	37,076	36,959	36,753	36,929
Exhaust gas temperature (°F)	360	360	358	359
Nitrogen Oxides				
NO_X conc. (ppmvd)	9.64	10.3	10.0	10.0
NO_X conc. (ppmvd @ 15% O_2)	10.3	11.1	10.9	10.8
Limit (ppmvd @ 15% O_2)	-	-	-	*25*
NO_X emissions (lb/hr)	2.50	2.56	2.48	2.51
Limit (lb/hr)	-	-	-	*8.44*
NO_X emissions (lb/MW-hr)	0.59	0.59	0.58	0.59
Limit (lb/MW-hr)	-	-	-	*1.2*

APPENDIX 1

- Turbine Sample Port Diagram



Oakland University - Central Heating Plant
EU-TURBINE#1 Stack Diagram

Scale	Sheet
None	1 of 1

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