



Turbine 2 NOx and O₂ Emissions Test Report

RECEIVED

OCT 20 2017

AIR QUALITY DIVISION

Prepared for:

Wolverine Power Cooperative

Burnips, Michigan

Source Address:

Wolverine Power Cooperative
Vandyke Generating Plant
3150 143th Avenue
Burnips, MI 49314

Project No. 17-5068.00
October 13, 2017

BT Environmental Consulting, Inc.
4949 Fernlee Avenue
Royal Oak, Michigan 48073
(248) 548-8070



EXECUTIVE SUMMARY

BT Environmental Consulting Inc. (BTEC) was retained by Wolverine Power Cooperative, Vandyke Generating Plant (Wolverine) to conduct compliance emissions testing on a simple cycle combustion turbine installed at the Wolverine facility located in Burnips, Michigan. The natural gas-fired turbine identified as Turbine Unit 2 has a rated output capacity of 24.8 Megawatts (MW). The testing was conducted to determine compliance with the emission limits stated in the Michigan Department of Environmental Quality (MDEQ) Permit No. MI-ROP-B5421-2014. Nitrogen oxides (NOx) and oxygen (O₂) concentrations were monitored to establish the concentration and mass emission rate of NOx from the turbine.

The test consisted of triplicate twenty-one minute test runs, conducted at each of two operational loads at approximately 80 and 100 percent of the achievable megawatt capacity. These operating loads represent the normal operating range for this unit, and are consistent with those used for previous stack testing at this site. The test program was conducted on August 24, 2017. A summary of the NOx concentrations and emission rates are presented in Table E-1. Detailed NOx concentration and emission results can be found in Tables 4 and 5 at the end of this report.

**Executive Summary Table E-1
Summary of NOx Emissions**

Load	NOx ppm @ 15% O₂	NOx lb/mmbtu	NOx lb/hr
80%	86.6	0.309	86.5
100%	105.2	0.374	125.3
Limit	132 ppm	0.55 lb/mmbtu	193.1 lb/hr

ppm: Part per million

15% O₂: Concentration corrected to 15% Oxygen, corrected to ISO Standard day conditions

lb/mmBtu: Pound per million British thermal unit

lb/hour: Pound per hour

RECEIVED

OCT 20 2017

AIR QUALITY DIVISION



1. Introduction

BT Environmental Consulting Inc. (BTEC) was retained by Wolverine Power Cooperative, Vandyke Generating Plant (Wolverine) to conduct compliance emissions testing on a simple cycle combustion turbine installed at the Wolverine facility located in Burnips, Michigan. The natural gas fired turbine identified as Turbine Unit 2 has a rated output capacity of 24.8 Megawatts (MW). The testing was conducted to determine compliance with the emission limits stated in the Michigan Department of Environmental Quality (MDEQ) Permit No. MI-ROP-B5421-2014. Nitrogen oxides (NO_x) and oxygen (O₂) concentrations were monitored to establish the concentration and mass emission rate of NO_x from the turbine.

The test consisted of triplicate twenty-one minute test runs conducted at each of two operational loads at 80 and 100 percent of the achievable megawatt capacity. The test program was conducted on August 24, 2017. A summary of the NO_x concentrations and emissions are presented in Table 3. Detailed NO_x concentration and emission results can be found in Tables 4 and 5 at the end of this report.

The Air Quality Division (AQD) of Michigan's Department of Natural Resources and Environment has published a guidance document entitled "Format for Submittal of Source Emission Test Plans and Reports" (December 2013, see Appendix A). The following is a summary of the emissions test program and results in the format outlined by the AQD document.

1.a Identification, Location, and Dates of Test

Field-sampling for this emission test program was conducted on August 24, 2017 at the Wolverine facility located in Burnips, Michigan. The purpose of this report is to document the results of the emissions determined during compliance test program.

The emission test program included the evaluation of NO_x and O₂ concentrations from one 24.8 MW combustion turbine (Turbine 2) at two different operating loads.



1.b Purpose of Testing

Turbine 1 is included in Michigan Renewable Operating Permit MI-ROP-B5421-2014. The emission limits relevant to this emissions test program are summarized by Table 1.

Table 1
Operating Permit MI-ROP-B5421-2009 Emission Limits
Turbine 2

Pollutant	Limit
Nitrogen Oxides (NO _x)	193.1 lb/hr
	0.55 lb.mmbtu
	132 ppm @ 15%O ₂
	35 Tons/yr

1.c Source Description

The Wolverine facility located in Burnips, Michigan operates a simple-cycle Turbine that fires natural gas (NG).

The turbine is nominally rated at an output capacity of 24.8 Megawatts (MW). The turbine uses natural gas as a primary fuel. The turbine generator consists of a compressor, combustion turbine, and generator. Energy is generated at the combustion turbine by drawing in ambient air by means of burning fuel and expanding the hot combustion gases in a three-stage turbine. The emissions of NO_x, CO and SO₂ are minimized by the efficient combustion of low sulfur bearing clean-burning natural gas.

1.d Test Program Contact

Facility Contact:

Mr. Randy Boyles
Wolverine Power Cooperative
Vandyke Generating Plant
3150 143rd Avenue, Route 1
Door, MI 49323
(616) 896-9631

Testing Team Contact:

Mr. Steve Smith
Senior Project Manager
BT Environmental Consulting, Inc.
4949 Fernlee Avenue
Royal Oak, Michigan 48073
Phone (248) 548-8070

1.e Testing Personnel

Names and affiliations for personnel who were present during the testing program are summarized by Table 2.

**Table 2
Test Personnel**

Name and Title	Affiliation	Telephone
Mr. Randy Boyles	Wolverine Power Cooperative Vandyke Generating Plant 3150 143 rd Avenue, Route 1 Door, MI 49323	(616) 896-9631
Mr. David Patterson	MDEQ Air Quality Division	(517) 284-6782
Mr. Steve Smith Project Manager	BTEC 4949 Fernlee Avenue Royal Oak, MI 48073	(248) 548-8070
Mr. Shane Rabideau Field Technician	BTEC 4949 Fernlee Avenue Royal Oak, MI 48073	(248) 548-8070

2. Summary of Results

Sections 2.a through 2.d summarize the results of the emissions compliance test program.

2.a Operating Data

The following information was collected during the performance test:

1. Date, time, MW load
2. Natural gas flow
3. Compressor temperature and pressure

2.b Applicable Permit

The applicable permit for this emissions test program is Michigan Renewable Operating Permit No. MI-ROP-B5421-2014.

2.c Results

The overall results of the emissions compliance test program are summarized by Table 3 (see Section 5.a). Detailed results can be found in Tables 4 and 5.

2.d Emission Regulation Comparison

Emission limitations are summarized by Table 1.

3. Source Description

Sections 3.a through 3.d provide a detailed description of the process.

3.a Process Description

The Vandyke Generating Plant, located in Burnips, Michigan, is owned and operated by Wolverine Power Supply Cooperative, Incorporated (Wolverine). The plant includes Combustion Turbine (CT) #2 that is used to generate electrical power.

3.b Raw and Finished Materials

The raw material supplied to the turbine includes natural gas. The finished material is electricity.

3.c Process Capacity

The turbine is nominally rated at an output capacity of approximately 24.8 Megawatts (MW).

3.d Process Instrumentation

Process data monitored during the emissions test program is provided in Appendix E.

4. Sampling and Analytical Procedures

Sections 4.a through 4.d provide a summary of the sampling and analytical procedures used to verify emission rates.

4.a Sampling Train and Field Procedures

Sampling and analysis procedures utilized the following test methods codified at Title 40, Part 60, Appendix A of the Code of Federal Regulations (40 CFR 60, Appendix A):

- Method 3A - "Determination of Molecular Weight of Dry Stack Gas"

RECEIVED

OCT 20 2017

AIR QUALITY DIVISION

- Method 7E - “Determination of Nitrogen Oxide Emissions from Stationary Sources”

The NO_x content of the exhaust gas was measured using a TECO 42C NO_x gas analyzer, the O₂ content was measured using API Teledyne analyzers. A sample of the gas stream was drawn through an insulated stainless-steel probe with an in-line glass fiber filter to remove any particulate, a heated Teflon[®] sample line, and through a Universal Analyzers 3080PV electronic sample conditioner to remove the moisture from the sample before it entered the analyzer. Data was recorded at 4-second intervals on a PC equipped with data acquisition software.

In accordance with Method 7E, a 3-point (zero, mid and high) bias check and calibration check was performed on the each analyzer prior to initiating the test program. Following each test run, a 2-point (zero and high) calibration drift check was performed. The NO_x analyzer was operated at the 0-100 ppm range and the oxygen analyzer was operated in the 0-25% range. A USEPA Method 7E NO₂ to NO conversion efficiency test was performed and the results are included in Appendix D.

4.b Recovery and Analytical Procedures

Recovery and analytical procedures were described in Section 4.a.

4.c Sampling Ports

Figure 1 documents the exhaust stack dimensions and approximate sampling point locations.

4.d Traverse Points

Three point in the middle port were chosen for sampling for each run. The turbine exhaust stack is approximately 80 feet in height. The turbine exhaust gas flows through a rectangular exhaust duct with dimensions of 122 inches by 134 inches. Figure 1 documents the exhaust stack dimensions and approximate sampling point locations.

5. Test Results and Discussion

Sections 5.a through 5.k provide a summary of the test results.

5.a Results Tabulation

The results of the emissions test program are summarized by Table 3.

**Table 3
Emission Rates Summary
Turbine 2**

Load	NOx ppm @ 15% O₂	NOx lb/mmBtu	NOx lb/hr
80%	86.6	0.309	86.5
100%	105.2	0.374	125.3
Limit	132 ppm	0.55 lb/mmBtu	193.1 lb/hr

ppm: Part per million

15% O₂: Concentration corrected to 15% Oxygen, corrected to ISO Standard day conditions

lb/mmBtu: Pound per million British thermal unit

lb/hour: Pound per hour

Detailed data for each test run can be found in Tables 4 and 5.

5.b Discussion of Results

Emission limitations for Michigan Renewable Operating Permit MI-ROP-B5421-2009 are summarized by Table 1 (see section 1.b) and Table 3 (see section 5.c). The results of the emissions test program are summarized by Table 3 (see section 5.a). Detailed data for each test run can be found in Table 4 and Table 5.

5.c Sampling Procedure Variations

There were no sampling procedure variations during the emission compliance test program.

5.d Process or Control Device Upsets

No upset conditions occurred during testing.

5.e Control Device Maintenance

No control device maintenance was performed during the testing.

5.f Audit Sample Analyses

No audit samples were collected as part of the test program.

Table 4
Turbine 2 (80%) NOx Emission Rates
Wolverine Power
BTEC Project No. 17-5068.00
Sampling Date: August 24, 2017

Parameter	Run 1	Run 2	Run 3	Average
Test Run Date	8/24/2017	8/24/2017	8/24/2017	
Test Run Time	10:20-10:40	10:49-11:09	12:05-12:25	
Ambient Temperature (°F)	55.9	55.9	57.9	
Ambient Pressure (in Hg)	30.14	30.14	30.15	
Relative Humidity (%)	84	84	81	
Ambient Humidity (g H2O/g air)	0.0078	0.0078	0.0081	
Oxides of Nitrogen Concentration (ppmv)	57.5	57.7	59.1	58.1
Oxygen concentration (%)	16.6	16.6	16.6	16.6
Oxygen concentration (%) (corrected as per USEPA 7E)	16.8	16.8	16.8	16.8
Natural Gas Flowrate (kscf/hr)	268.4	267.8	272.0	269.4
Natural Gas Heating Value (Btu/scf)	1040	1040	1040	1040
NOx Concentration (ppmv, corrected as per USEPA 7E)	57.98	58.6	58.4	58.3
NOx Emission Factor (lb/MMBtu, corrected as per USEPA 7E)	0.308	0.309	0.309	0.309
NOx Emission Rate (lb/hr) (corrected as per USEPA 7E)	86.0	86.1	87.3	86.5
NOx Concentration (ppmv@15% O2 and ISO Standard Day Conditions)	86.5	86.8	86.6	86.6
NOx Concentration (ppmv@15% O2)	83.6	83.9	83.8	83.8

Calculated using USEPA Method 19 equation 19-1

dscf = dry standard cubic feet

ppmv = parts per million on a volume-to-volume basis

lb/hr = pounds per hour

MW = molecular weight (NOx = 46.01)

24.14 = molar volume of air at standard conditions (70°F, 29.92" Hg)

35.31 = ft³ per m³

453600 = mg per lb

10⁶ = Btu per MMBtu

3785.4 = mL per gallon

Ambient pressure and relative humidity obtained from www.wunderground.com

Ambient humidity in g H2O/g air obtained from psychrometric chart

Co = Average of initial and final zero gases

Cma = Actual concentration of the calibration gas

Cm = Average of initial and final calibration gases

Equations

lb/dscf = ppmv * MW/24.14 * 1/35.31 * 1/453,600

eq 19-1: $E = C_d F_d * 20.9 / (20.9 - \%O_{2d})$

NOx @ 15% O2 = NOx measured (ppm) X (5.9/(20.9-O2% measured))

NOx corrected to ISO standard day conditions = (Nox @15%) x (P_{std}/P_{amb})^{0.5} x 2.718^{(19x(H-0.00633))} x (T_{std}/T_{amb})^{1.53}

Table 5
Turbine 2 (100%) NOx Emission Rates
Wolverine Power
BTEC Project No. 17-5068.00
Sampling Date: August 24, 2017

Parameter	Run 1	Run 2	Run 3	Average
Test Run Date	8/24/2017	8/24/2017	8/24/2017	
Test Run Time	8:37-8:57	9:08-9:28	9:41-10:10	
Ambient Temperature (°F)	55	55	55.9	
Ambient Pressure (in Hg)	30.11	30.11	30.13	
Relative Humidity (%)	86	86	84	
Ambient Humidity (g H2O/g air)	0.0078	0.0078	0.0078	
Oxides of Nitrogen Concentration (ppmv)	82.3	82.5	82.0	82.3
Oxygen concentration (%)	15.9	15.9	15.8	15.9
Oxygen concentration (%) (corrected as per USEPA 7E)	16.1	16.0	16.0	16.1
Natural Gas Flowrate (kscf/hr)	324.9	320.2	321.3	322.1
Natural Gas Heating Value (Btu/scf)	1040	1040	1040	1040
NOx Concentration (ppmv, corrected as per USEPA 7E)	83.14	83.5	83.1	83.2
NOx Emission Factor (lb/MMBtu, corrected as per USEPA 7E)	0.378	0.373	0.371	0.374
NOx Emission Rate (lb/hr) (corrected as per USEPA 7E)	127.7	124.1	124.1	125.3
NOx Concentration (ppmv@15% O2 and ISO Standard Day Conditions)	106.4	104.9	104.3	105.2
NOx Concentration (ppmv@15% O2)	102.6	101.2	100.8	101.5

Calculated using USEPA Method 19 equation 19-1

dscf = dry standard cubic feet

ppmv = parts per million on a volume-to-volume basis

lb/hr = pounds per hour

MW = molecular weight (NOx = 46.01)

24.14 = molar volume of air at standard conditions (70°F, 29.92" Hg)

35.31 = ft³ per m³

453600 = mg per lb

10⁶ = Btu per MMBtu

3785.4 = mL per gallon

Ambient pressure and relative humidity obtained from www.wunderground.com

Ambient humidity in g H2O/g air obtained from psychrometric chart

Co = Average of initial and final zero gases

Cma = Actual concentration of the calibration gas

Cm = Average of initial and final calibration gases

Equations

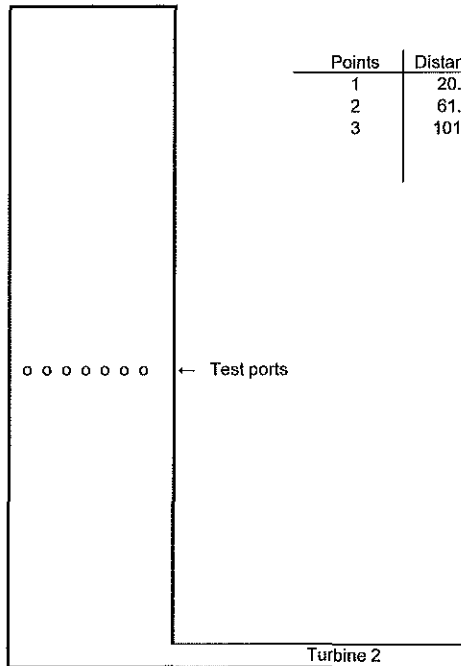
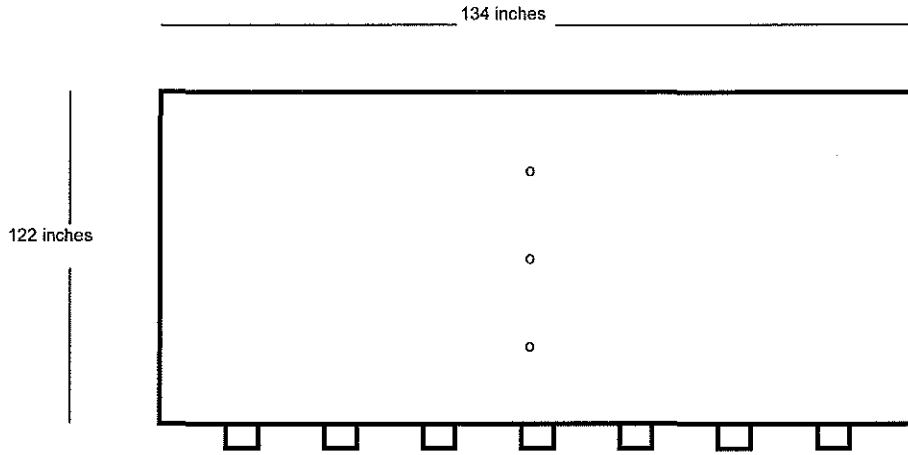
lb/dscf = ppmv * MW/24.14 * 1/35.31 * 1/453,600

eq 19-1: E = C_dF_d * 20.9 / (20.9 - %O_{2,d})

NOx @ 15% O2 = NOx measured (ppm) X (5.9/(20.9-O2% measured))

NOx corrected to ISO standard day conditions = (Nox @15%) x (P_{std}/P_{amb})^{0.5} x 2.718^{(19x(H-0.00633))} x (T_{std}/T_{amb})^{1.53}

RECEIVED
OCT 20 2017
AIR QUALITY DIVISION



Points	Distance "
1	20.4
2	61.0
3	101.6

Figure 1

Site:
Turbine 2 Exhaust Stack
Wolverine Power
Burnips, Michigan

Sampling Date:
August 24, 2017

BT Environmental
Consulting Inc.
4949 Fernlee Ave.
Royal Oak, MI 48073

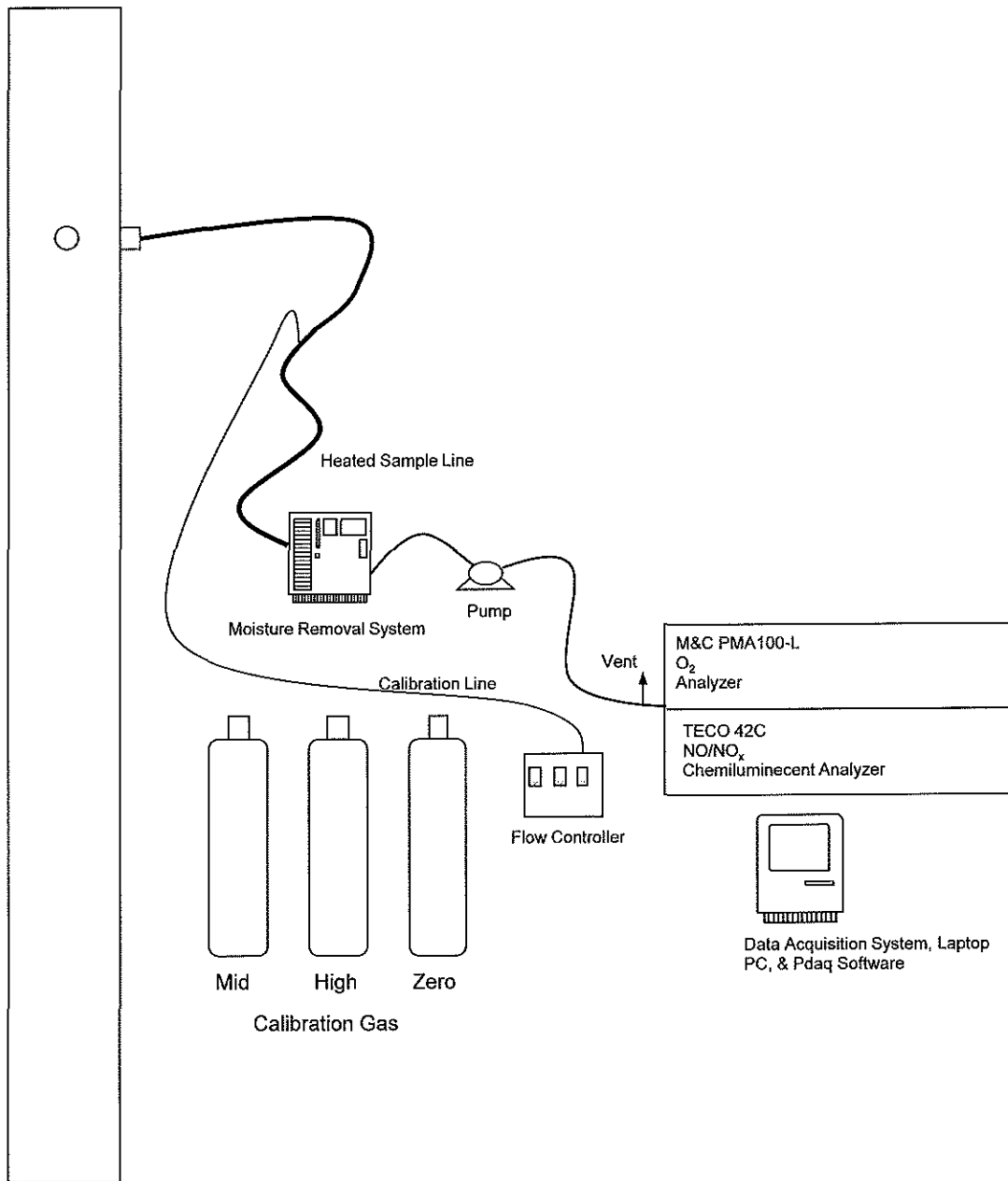


Figure No. 2

Site:
USEPA Method 3A,20 and 7E
Wolverine Power
Burnips, Michigan

Sampling Date:
August 24, 2017

BT Environmental Consulting Inc.
4949 Fernlee Ave.
Royal Oak, MI 48073