BTEC Inc.

Washington Compressor Station
Turbines 100 & 200
Emissions Test Report

Prepared for:

Vector Pipeline L.P.

Washington Compressor Station
12708 30 Mile Road
Macomb, Michigan 48095

Project No. 15-4726.00
August 31, 2015

BT Environmental Consulting, Inc.
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Royal Oak, Michigan 48073
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EXECUTIVE SUMMARY

BT Environmental Consulting, Inc. (BTEC) was retained by Vector Pipeline L.P. (Vector) to evaluate nitrogen oxides (NOx) and carbon monoxide (CO) emission rates from two turbines while operating at two load conditions at the Vector facility located in Washington Township, Michigan. The emissions test program was conducted on July 28, 2015.

Testing of Turbines 100 and 200 consisted of triplicate 20-minute (or longer) test runs while the units were operating at 93% and at 103% NGP (for a total of twelve emissions test runs). The emissions test program was required by MDEQ Air Quality Division Renewable Operating Permit (ROP) No. MI-ROP-N7624-2014. The results of the emission test program are summarized by Table I.

Table I
Turbine Overall Emission Summary
Test Date: July 28, 2015

Turbine 100 (EUTURBINE1)			
Load	**Pollutant**	**Average Emission Rate**	**Emission Limit**
93%	NOx	6.4 ppmv[1]	25 ppmv[1]
93%	CO	0.4 lb/hr	9.4 lb/hr
103%	NOx	5.6 ppmv[1]	25 ppmv[1]
103%	CO	0.5 lb/hr	9.4 lb/hr
Turbine 200 (EUTURBINE2)			
Load	**Pollutant**	**Average Emission Rate**	**Emission Limit**
93%	NOx	1.8 ppmv[1]	25 ppmv[1]
93%	CO	0.2 lb/hr	9.4 lb/hr
103%	NOx	5.5 ppmv[1]	25 ppmv[1]
103%	CO	0.4 lb/hr	9.4 lb/hr

1: Corrected to 15% O_2

BTEC Inc.

1. Introduction

BT Environmental Consulting, Inc. (BTEC) was retained by Vector Pipeline L.P. (Vector) to evaluate oxides of nitrogen (NOx) and carbon monoxide (CO) emission rates from two turbines operating at two load conditions at the Vector facility located in Washington Township, Michigan. The emissions test program was conducted on July 28, 2015. The purpose of this report is to document the results of the test program.

AQD has published a guidance document entitled "Format for Submittal of Source Emission Test Plans and Reports" (December 2013). This document is provided as Appendix A. The following is a summary of the emissions test program and results in the format suggested by the aforementioned document.

1.a Identification, Location, and Dates of Test

Sampling and analysis for the emission test program was conducted on July 28, 2015 at the Vector facility located in Washington Township, Michigan. The test program included evaluation of NOx and CO emissions from Turbines 100 and 200.

1.b Purpose of Testing

AQD issued Renewable Operating Permit No. MI-ROP-N7624-2014 to Vector on August 13, 2014. This permit limits emissions from each turbine as summarized by Table 1.

1.c Source Description

Vector's Washington Compressor Station is used to compress natural gas for transmission through the Vector pipeline.

1.d Test Program Contacts

The contact for the source and test report is:

Mr. Terry McMillin
Senior EHS Coordinator
Vector Pipeline
1100 Louisiana, Suite 3300
Houston, Texas 77002
(753) 353-5670

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

2. Summary of Results

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

2.a Operating Data

Process data monitored during the emissions test program included percent natural gas producer speed (%), turbine natural gas firing rate (kscfd), and natural gas gross heating value (Btu/scf). The turbine was operated in "SoLoNOx" mode throughout the test program.

2.b Applicable Permit

The applicable permit for this emissions test program is Renewable Operating Permit (ROP) No. MI-ROP-N7624-2014.

2.c Results

The overall results of the emission test program are summarized by Table 3 (see Section 5.a). NOx emissions from each turbine were below the corresponding limit of 25 ppmv, corrected to 15% O_2. CO emissions were also below the limit of 9.4 lb/hr.

3. Source Description

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

3.a Process Description

Two natural gas compressor turbines (Turbines 100 and 200) were evaluated for NOx and CO emission rates in terms of parts per million (ppm) corrected to 15% O_2 and lb/hr, respectively. The Solar Mars 100 turbines fire only natural gas and are rated at 15,000 horsepower at a heat input rate of 120 MMBtu/hr. Each turbine exhausts to a single, independent exhaust stack and is equipped with dry low-NOx emission controls.

3.b Process Flow Diagram

Due to the simplicity of the natural gas compressor turbine, a process flow diagram is not necessary.

3.c Raw and Finished Materials

The raw material used by the process is natural gas. Turbine natural gas firing rates recorded during the emissions test program are summarized by the process field data sheets included in Appendix B.

3.d Process Capacity

The turbines are rated at 15,000 horsepower and 120 MMBtu/hr. However, maximum turbine power output and heat input capacity at any given time is variable depending on ambient air temperature and pressure as well as pipeline gas pressure.

3.e Process Instrumentation

Process data monitored during the emissions test program included percent natural gas producer speed (%), turbine natural gas firing rate (kscfd), and natural gas heating value (Btu/scf). The turbine was operated in "SoLoNOx" mode throughout the test program.

4. Sampling and Analytical Procedures

Sections 4.a through 4.d provide a summary of the sampling and analytical procedures used.

4.a Sampling Train and Field Procedures

Turbine exhaust NOx content was measured using a TECO Model 42i NOx gas analyzer, the CO content was measured using a Teledyne Model 300EM CO gas analyzer, and the O_2 content was measured using a M&C Products PMA 100-L O_2 gas analyzer. 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 an electronic sample conditioner to remove the moisture from the sample before it enters the analyzer. Data was recorded at 4-second intervals on a PC equipped with data acquisition software.

For analyzer calibrations, calibration gases were mixed to desired concentrations using an Environics Series 4040 Computerized Gas Dilution System. The Series 4040 consists of a single chassis with four mass flow controllers. The mass flow controllers are factory-calibrated using a primary flow standard traceable to the United State's National Institute of Standards and Technology (NIST). Each flow controller utilizes an 11-point calibration table with linear interpolation, to increase accuracy and reduce flow controller nonlinearity. A schematic of the sampling train is provided as Figure 1.

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 Oxygen and Carbon Dioxide Concentrations in Emissions from Stationary Sources*", was used to measure the O_2 concentration of the exhaust gas.

- Method 7E, "*Determination of Nitrogen Oxide Emissions from Stationary Sources*", was used to measure the NOx concentration of the exhaust gas.

- Method 10, *"Determination of Carbon Monoxide Emissions from Stationary Sources"*, was used to measure the CO concentration of the exhaust gas.

- Method 19, *"Determination of Sulfur Dioxide Removal Efficiency and Particulate Matter, Sulfur Dioxide, and Nitrogen Oxide Emission Rates"*, was used to calculate the exhaust gas flowrates.

- Method 20, *"Determination of Nitrogen Oxides, Sulfur Dioxide, and Diluent Emissions form Stationary Gas Turbines"*, was used for gas turbine testing methodologies.

4.b Recovery and Analytical Procedures

This test program did not include laboratory samples, consequently, sample recovery and analysis is not applicable to this test program.

4.c Sampling Ports

Figure 2 shows relevant sampling port and traverse point locations.

4.d Traverse Points

The sampling locations met the minimum criteria specified by Method 1. Prior to initiating the first test run on each turbine, a fifteen point stratification check was performed. No individual point differed by more than 0.3% O_2 for each turbine. The results of this check (see Appendix B) allowed for the utilization of a single-point sampling location.

5. Test Results and Discussion

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

5.a Results Tabulation

The overall results of the emissions test program are summarized by Table 3. Detailed results for the emissions test program are summarized by Tables 4 through 7.

5.b Discussion of Results

NOx emissions from the turbines were less than the corresponding emission limit of 25 ppmv, corrected to 15% O_2. CO emissions from both turbines were also below the emission limit of 9.4 lb/hr.

5.c Sampling Procedure Variations

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

5.d Process or Control Device Upsets

No upset conditions occurred during testing.

5.e Control Device Maintenance

There was no control equipment maintenance performed during the emissions test program.

5.f Re-Test

The emissions test program was not a re-test.

5.g Audit Sample Analyses

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

5.h Calibration Sheets

Relevant equipment calibration documents are provided in Appendix C.

5.i Sample Calculations

Sample calculations are provided in Appendix D.

5.j Field Data Sheets

Field documents relevant to the emissions test program are presented in Appendix B

5.k Laboratory Data

There are no laboratory results for this test program. Raw CEM data is provided electronically in Appendix E.

TABLES

Table 1
CO and NOx Emission Limitations
Washington Compressor Station

Facility	Permit No.	NOx Emission Limit	CO Emission Limits
Washington	MI-ROP-N7624-2014	25 ppmv @ 15% O_2	400 lbs/hr*
			9.4 lbs/hr**

*Limit applies when the natural gas producer speed is between 87 and 92% of the power turbine speed
** Limit applies when the natural gas producer speed is above 92% of the power turbine speed

Table 2
Test Personnel

Name and Title	Affiliation	Telephone
Mr. Zachery Szeplakay Electrical Technician	Vector Pipeline L.P. Washington Compressor Station 12708 30 Mile Road Macomb, Michigan 48905	(586)-336-5086
Mr. Steven Ellis Electrical Technician	Vector Pipeline L.P. Washington Compressor Station 12708 30 Mile Road Macomb, Michigan 48905	(586)-336-5086
Mr. Randal Tysar Senior Environmental Engineer	BTEC 4949 Fernlee Royal Oak, Michigan 48073	(248) 548-8070
Mr. Terry McMillin Sr EHS Coordinator	Vector Pipeline L.P.	(713) 353-5670
Mr. Matthew Young Sr. Project Manager	BTEC 4949 Fernlee Royal Oak, Michigan 48073	(248) 548-8070
Mr. Paul Diven Environmental Technician	BTEC 4949 Fernlee Royal Oak, Michigan 48073	(248) 548-8070
Mr. Sebastian Kallumkal Environmental Engineer	MDEQ - Air Quality Division 27700 Donald Court Warren, Michigan 48092	(313) 753-3738

Table 3
Turbine Overall Emission Summary
Test Date: July 28, 2015

Turbine 100 (EUTURBINE1)			
Load	**Pollutant**	**Average Emission Rate**	**Emission Limit**
93%	NOx	6.4 ppmv[1]	25 ppmv[1]
93%	CO	0.4 lb/hr	9.4 lb/hr
103%	NOx	5.6 ppmv[1]	25 ppmv[1]
103%	CO	0.5 lb/hr	9.4 lb/hr
Turbine 200 (EUTURBINE2)			
Load	**Pollutant**	**Average Emission Rate**	**Emission Limit**
93%	NOx	1.8 ppmv[1]	25 ppmv[1]
93%	CO	0.2 lb/hr	9.4 lb/hr
103%	NOx	5.5 ppmv[1]	25 ppmv[1]
103%	CO	0.4 lb/hr	9.4 lb/hr

1: Corrected to 15% O_2

Table 4
Turbine 100 (93%) Detailed Emission Test Results Summary
Vector Pipeline
BTEC Project No. 15-4726.00
Sampling Date: July 28, 2015

	Parameter	Run 1	Run 2	Run 3	Average
	Test Run Date	7/28/2015	7/28/2015	7/28/2015	
93% Load	Carbon Monoxide Concentration (ppmv)	0.9	0.9	0.9	0.9
	Oxides of Nitrogen Concentration (ppmv)	5.4	5.2	5.2	5.3
	Oxygen concentration (%)	16.1	16.2	16.2	16.2
	Oxygen concentration (%) (corrected as per USEPA 7E)	16.1	16.3	16.3	16.2
	Natural Gas Flowrate (kscf/hr)	73.8	73.4	74.3	73.8
	Natural Gas Heating Value (Btu/scf)	1072	1072	1072	1072
	NOx Concentration (ppmv, corrected as per USEPA 7E)	5.3	5.0	5.0	5.1
	NOx Concentration (lb/dscf, corrected as per USEPA 7E)	6.3E-07	6.0E-07	6.0E-07	6.1E-07
	NOx Emission Factor (lb/MMBtu, corrected as per USEPA 7E)	0.024	0.023	0.024	0.024
	CO Concentration (ppmv, corrected as per USEPA 7E)	1.6	1.7	1.8	1.7
	CO Concentration (lb/dscf, corrected as per USEPA 7E)	0.000	0.000	0.000	0.000
	CO Emission Factor (lb/MMBtu, corrected as per USEPA 7E)	0.004	0.005	0.005	0.005
	CO Emission Rate (lb/hr) (corrected as per USEPA 7E)	**0.338**	**0.375**	**0.410**	**0.374**
	NOx Emission Rate (lb/hr) (corrected as per USEPA 7E)	**1.9**	**1.8**	**1.9**	**1.9**
	Nox Concentration (ppmv@15% O2)	**6.4**	**6.4**	**6.4**	**6.4**

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 = ft^3 per m^3
453600 = mg per lb
10^6 = Btu per MMBtu
3785.4 = mL per gallon

Ambient pressure and relative humidty 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 100 (103%) Detailed Emission Test Results Summary
Vector Pipeline
BTEC Project No. 15-4726.00
Sampling Date: July 28, 2015

	Parameter	Run 1	Run 2	Run 3	Average
103% Load	Test Run Date	7/28/2015	7/28/2015	7/28/2015	
	Carbon Monoxide Concentration (ppmv)	0.9	0.8	0.8	0.9
	Oxides of Nitrogen Concentration (ppmv)	5.3	5.3	5.3	5.3
	Oxygen concentration (%)	15.6	15.5	15.5	15.5
	Oxygen concentration (%) (corrected as per USEPA 7E)	15.6	15.6	15.6	15.6
	Natural Gas Flowrate (kscf/hr)	101.2	101.4	100.3	100.9
	Natural Gas Heating Value (Btu/scf)	1072	1072	1072	1072
	NOx Concentration (ppmv, corrected as per USEPA 7E)	5.08	5.1	5.1	5.1
	NOx Concentration (lb/dscf, corrected as per USEPA 7E)	6.1E-07	6.1E-07	6.1E-07	6.1E-07
	NOx Emission Factor (lb/MMBtu, corrected as per USEPA 7E)	0.021	0.021	0.021	0.021
	CO Concentration (ppmv, corrected as per USEPA 7E)	1.9	1.8	1.8	1.8
	CO Concentration (lb/dscf, corrected as per USEPA 7E)	0.000	0.000	0.000	0.000
	CO Emission Factor (lb/MMBtu, corrected as per USEPA 7E)	0.005	0.005	0.004	0.005
	CO Emission Rate (lb/hr) (corrected as per USEPA 7E)	**0.519**	**0.498**	**0.476**	**0.498**
	NOx Emission Rate (lb/hr) (corrected as per USEPA 7E)	**2.3**	**2.3**	**2.2**	**2.3**
	Nox Concentration (ppmv@15% O2)	**5.7**	**5.7**	**5.6**	**5.6**

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 = ft^3 per m^3
453600 = mg per lb
10^6 = Btu per MMBtu
3785.4 = mL per gallon

Ambient pressure and relative humidty 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 6
Turbine 200 (93%) Detailed Emission Test Results Summary
Vector Pipeline
BTEC Project No. 15-4726.00
Sampling Date: July 28, 2015

	Parameter	Run 1	Run 2	Run 3	Average
	Test Run Date	7/28/2015	7/28/2015	7/28/2015	
93% Load	Carbon Monoxide Concentration (ppmv)	0.3	0.3	0.2	0.2
	Oxides of Nitrogen Concentration (ppmv)	1.8	1.8	1.8	1.8
	Oxygen concentration (%)	15.7	15.7	15.7	15.7
	Oxygen concentration (%) (corrected as per USEPA 7E)	15.7	15.7	15.7	15.7
	Natural Gas Flowrate (kscf/hr)	75.3	75.5	75.8	75.5
	Natural Gas Heating Value (Btu/scf)	1072	1072	1072	1072
	NOx Concentration (ppmv, corrected as per USEPA 7E)	1.6	1.6	1.7	1.6
	NOx Concentration (lb/dscf, corrected as per USEPA 7E)	1.9E-07	1.9E-07	2.0E-07	1.9E-07
	NOx Emission Factor (lb/MMBtu, corrected as per USEPA 7E)	0.007	0.007	0.007	0.007
	CO Concentration (ppmv, corrected as per USEPA 7E)	0.9	0.9	0.9	0.9
	CO Concentration (lb/dscf, corrected as per USEPA 7E)	0.000	0.000	0.000	0.000
	CO Emission Factor (lb/MMBtu, corrected as per USEPA 7E)	0.002	0.002	0.002	0.002
	CO Emission Rate (lb/hr) (corrected as per USEPA 7E)	**0.187**	**0.178**	**0.177**	**0.180**
	NOx Emission Rate (lb/hr) (corrected as per USEPA 7E)	**0.5**	**0.5**	**0.6**	**0.5**
	Nox Concentration (ppmv@15% O2)	**1.8**	**1.8**	**1.9**	**1.8**

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 = ft^3 per m^3
453600 = mg per lb
10^6 = Btu per MMBtu
3785.4 = mL per gallon

Ambient pressure and relative humidty 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 7
Turbine 200 (103%) Detailed Emission Test Results Summary
Vector Pipeline
BTEC Project No. 15-4726.00
Sampling Date: July 28, 2015

	Parameter	Run 1	Run 2	Run 3	Average
	Test Run Date	7/28/2015	7/28/2015	7/28/2015	
103% Load	Carbon Monoxide Concentration (ppmv)	2.3	0.7	0.4	1.1
	Oxides of Nitrogen Concentration (ppmv)	5.1	5.3	5.4	5.3
	Oxygen concentration (%)	15.5	15.5	15.5	15.5
	Oxygen concentration (%) (corrected as per USEPA 7E)	15.5	15.5	15.5	15.5
	Natural Gas Flowrate (kscf/hr)	102.9	100.9	101.7	101.8
	Natural Gas Heating Value (Btu/scf)	1072	1072	1072	1072
	NOx Concentration (ppmv, corrected as per USEPA 7E)	4.99	5.1	5.2	5.1
	NOx Concentration (lb/dscf, corrected as per USEPA 7E)	6.0E-07	6.1E-07	6.2E-07	6.1E-07
	NOx Emission Factor (lb/MMBtu, corrected as per USEPA 7E)	0.020	0.020	0.021	0.020
	CO Concentration (ppmv, corrected as per USEPA 7E)	2.8	1.1	1.0	1.7
	CO Concentration (lb/dscf, corrected as per USEPA 7E)	0.000	0.000	0.000	0.000
	CO Emission Factor (lb/MMBtu, corrected as per USEPA 7E)	0.007	0.003	0.002	0.004
	CO Emission Rate (lb/hr) (corrected as per USEPA 7E)	**0.758**	**0.295**	**0.268**	**0.440**
	NOx Emission Rate (lb/hr) (corrected as per USEPA 7E)	**2.2**	**2.2**	**2.3**	**2.2**
	Nox Concentration (ppmv@15% O2)	**5.4**	**5.5**	**5.7**	**5.5**

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 = ft^3 per m^3
453600 = mg per lb
10^6 = Btu per MMBtu
3785.4 = mL per gallon

Ambient pressure and relative humidty 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 = $(Nox\ @15\%) \times (P_{std}/P_{amb})^{0.5} \times 2.718^{(19 \times (H-0.00633))} \times (T_{std}/T_{amb})^{1.53}$