BTEC Inc.

Boiler Nos. 2 and 6 Emissions Test Summary Report

Prepared for:

The University of Michigan

Ann Arbor, Michigan

Central Power Plant
1120 East Huron Street
Ann Arbor, Michigan

Project No. 049AS-239748
May 9, 2018

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EXECUTIVE SUMMARY

BT Environmental Consulting, Inc. (BTEC) was retained by The University of Michigan (U-M) Central Power Plant (CPP) to evaluate oxides of nitrogen (NOx) emissions from CPP Boiler No. 2 and to evaluate carbon monoxide (CO) and volatile organic compound (VOC) emission rates from Boiler No. 6. The purpose of this document is to present the test results for the required emission rate test program.

The purpose of the emissions test program was to evaluate (1) NOx emission rates (in terms of pounds per million Btu heat input) from Boiler No. 2 while firing natural gas and while firing distillate fuel oil, (2) CO and VOC emission rates (in terms of pounds per million Btu heat input and pounds per hour) from Boiler No. 6 while firing natural gas and while firing fuel oil, and (3) compare the emission test results to corresponding emission limitations included in Michigan Department of Environmental Quality, Air Quality Division, Renewable Operating Permit No. MI-ROP-M0675-2014a. Testing of CPP Boiler No. 1 was not conducted because Boiler No. 1 is not currently operational and is being decommissioned in the future. Table I summarizes the results of the emissions test program. As summarized by Table I, NOx emission rates from Boiler No. 2 and CO and VOC emission rates from Boiler No. 6 boiler were less than the corresponding emission limitations.

Table I
Emissions Test Program Results Summary

Boiler	Pollutant	Test Date	Fuel	Test Result	Emission Limit	Result/Limit Units
2	NOx	3/12/18	Gas	0.09	0.20	lbs/MMBtu
		3/22/18	Oil	0.11	0.30	lbs/MMBtu
6	CO	3/20/18	Gas	0.00	0.10	lbs/MMBtu
				0.2	37.6	lbs/hr
	VOC	3/20/18	Gas	0.000	0.025	lbs/MMBtu
				0.0	9.4	lbs/hr
	CO	3/21/18	Oil	0.00	0.15	lbs/MMBtu
				0.032	54.0	lbs/hr
	VOC	3/21/18	Oil	0.000	0.025	lbs/MMBtu
				0.0	9.4	lbs/hr

1. Introduction

BT Environmental Consulting, Inc. (BTEC) was retained by The University of Michigan (U-M) Central Power Plant (CPP) to evaluate oxides of nitrogen (NOx) emissions from CPP Boiler No. 2 and to evaluate carbon monoxide (CO) and volatile organic compound (VOC) emission rates from Boiler No. 6. Testing of CPP Boiler No. 1 was not conducted because Boiler No. 1 is not currently operational and is being decommissioned in the future. The purpose of this document is to present the results of the emissions test program.

The Air Quality Division (AQD) of Michigan's Department of Environmental Quality 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

Boiler No. 2 was evaluated for exhaust gas NOx and oxygen (O_2) concentrations and Boiler No. 6 was evaluated for exhaust gas VOC, CO, and O_2 concentrations. Emission rates from each boiler were evaluated with the boiler firing natural gas and again with the boiler firing distillate fuel oil. Each boiler is located at CPP (1120 East Huron Street, Ann Arbor, Michigan). Table 1 summarizes the emissions test program.

Table 1
Emissions Test Program Summary

Boiler	Fuel	Parameters Evaluated	Test Result Units	Test Dates
2	Gas	NOx & O_2 Conc.	lbs/MMBtu	3/12/18
2	Oil	NOx & O_2 Conc.	lbs/MMBtu	3/22/18
6	Gas	VOC, CO, & O_2 Conc.; Flowrate	lbs/MMBtu & lbs/hr	3/20/18
6	Oil	VOC, CO, & O_2 Conc.; Flowrate	lbs/MMBtu & lbs/hr	3/21/18

*Exhaust gas flowrates for Boiler No. 6 are as recorded by the continuous emission monitoring system serving Boiler No. 6.

1.b Purpose of Testing

The purpose of the testing was to evaluate oxides of nitrogen (NOx) emissions from CPP Boiler No. 2 and to evaluate carbon monoxide (CO) and volatile organic compound (VOC) emission rates from Boiler No. 6. Emissions testing of both boilers is required once within the five-year term of Michigan Department of Environmental Quality, Air Quality Division, Renewable Operating Permit No. MI-ROP-M0675-2014a.

1.c Source Description

CPP Boiler Nos. 2 and 6 generate steam and electricity for use by various U of M campus buildings in essentially the same manner. Natural gas or distillate fuel oil is supplied to the firebox section of the boiler and combusted. The hot exhaust gases then travel through the water tubes banks in the heat exchanger section of the boiler where the heat of the exhaust gases is absorbed by water (without actually contacting the water) to create high-pressure steam. The exhaust gases then exit the boiler and are exhausted to the ambient air via one of two masonry exhaust stacks. A portion of the steam generated by the boilers is routed to one of three steam turbines connected to an associated electrical generator. The steam is routed to U of M's underground steam delivery system and finally to various campus buildings to provide thermal energy to heat the buildings during winter and air conditioning in the summer. The remainder of the steam drives the steam turbine which, in turn, drives the electrical generator.

1.d Test Program Contact

The contact for the source and report is:

Mr. Stephen O'Rielly
Manager
The University of Michigan
Environmental, Health, and Safety (EHS)
Campus Safety Services Building
1239 Kipke Drive
Ann Arbor, Michigan 48109
(734) 763-4642

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	Affiliation
Brandi Campbell	U-M–EHS
Jim O'Brien	U-M–CPP
Randal Tysar	BTEC
Steve Smith	BTEC
Mason Sakshaug	BTEC
Dave Trahan	BTEC
Jake Zott	BTEC
Mark Dziadosz	MDEQ-AQD
Gina Hines	MDEQ-AQD

2. Summary of Results

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

2.a Operating Data

Boiler steam load (lbs/hr) and other data was monitored throughout the emissions test program and is summarized by the summary sheets presented in Appendix B.

2.b Applicable Permit

Emission limitations for Boiler Nos. 2 and 6 are summarized by AQD Renewable Operating Permit No. MI-ROP-M0675-2014a.

2.c Results

The results of the emissions test program are summarized by Tables 3 through 6.

2.d Emission Regulation Comparison

Boiler Nos. 2 and 6 emission limitations and corresponding emission test results are summarized by Table 7.

Table 7
Emission Regulation Comparison

Boiler	Fuel	Pollutant	Emission Limitation	Test Result	Limitation/Result Units
6	Gas	CO	0.10	0.00	lbs/MMBtu
6	Gas	CO	37.6	0.2	lbs/hr
6	Oil	CO	0.15	0.00	lbs/MMBtu
6	Oil	CO	54.0	0.032	lbs/hr
6	Gas	VOC	0.025	0.000	lbs/MMBtu
6	Gas	VOC	9.4	0.0	lbs/hr
6	Oil	VOC	0.025	0.000	lbs/MMBtu
6	Oil	VOC	9.4	0.0	lbs/hr
2	Gas	NOx	0.20	0.09	lbs/MMBtu
2	Oil	NOx	0.30	0.11	lbs/MMBtu

3. Source Description

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

3.a Process Description

Boiler Nos. 2 and 6 are each capable of firing natural gas or distillate fuel oil. The maximum rated steam load for Boiler No. 2 is 110,000 pounds per hour and the maximum rated steam load for Boiler No. 6 is 250,000 pounds per hour. The rated capacity of each boiler is the same firing either fuel.

3.b Process Flow Diagram

Due to the simplicity of the boiler process, a process flow diagram is not necessary.

3.c Raw and Finished Materials

The raw materials used by the boilers include natural gas, distillate fuel oil, and water and the products are steam and electricity. The steam flowrate for each test run is summarized by the summary sheets presented in Appendix B.

3.d Process Capacity

The capacity of each boiler is summarized in Section 3.a.

3.e Process Instrumentation

Process instrumentation relevant to the emissions test program includes the measurement of boiler steam generation rate, exhaust gas O_2 concentration, exhaust gas NOx concentration, fuel flowrate, and Boiler No. 6 exhaust gas opacity.

4. Sampling and Analytical Procedures

Sections 4.a through 4.d provide a summary of the sampling and analytical procedures used to test the emissions from Boiler Nos. 2 and 6.

4.a Sampling Train and Field Procedures

The CO content of the Boiler No. 6 exhaust gas was measured using a Teledyne T300M CO gas analyzer and the Boiler No. 6 O_2 content was measured using a Servomex 4100 gas analyzer. The NO_x content of the Boiler No. 2 exhaust gas was measured using a Teledyne T200H NO_x gas analyzer and the O_2 content was measured using a Servomex 1400 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 a Universal Analyzers Model 3080PV 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.

BTEC used a J.U.M. Model 109A methane/non-methane hydrocarbon analyzer to determine Boiler No. 6 exhaust gas total hydrocarbon (THC) concentrations as propane. The J.U.M. Model 109A utilizes two flame ionization detectors (FID) to determine the average concentration (ppm) for THC (as propane) and the average concentration for methane. Upon entry, the gas stream is split by the analyzer. One FID ionizes all of the hydrocarbons in the gas stream sample into carbon, which is then detected as a concentration of total hydrocarbons. Using an analog signal, specifically voltage, the concentration of THC is then sent to a data acquisition system (DAS), where 4-second interval data points were recorded to produce an average based on the overall duration of the test. This average was then used to determine the average concentration for THC reported as the calibration gas, propane, in equivalent units.

The second FID reports methane only. The sample enters a chamber containing a catalyst that destroys all of the hydrocarbons present in the gas stream other than methane. As with the THC sample, the methane gas concentration was recorded by the DAS. The methane concentration, reported as methane, can then be converted to methane, reported as propane, by dividing the measured methane concentration by the analyzer's response factor. The analyzer's response factor is obtained by introducing a methane calibration gas to the calibrated J.U.M. 109A. The response of the analyzer's THC FID to the methane calibration gas, in ppm as propane, is divided by the Methane analyzer's response to the methane calibration gas, in ppm as methane. Because the total hydrocarbon concentration in the Boiler No. 6 exhaust gas was negligible, methane concentrations were not quality-assured during the emissions test program and, consequently, were not subtracted from the total hydrocarbon concentrations.

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. Method 205 dilution system verification results are provided in Appendix C. A schematic drawing of the continuous emission systems is provided as Figure 1.

4.b Recovery and Analytical Procedures

Because all measurements were conducted using on-line analyzers, no samples were recovered during the test program.

4.c Sampling Ports

The CEM system sampling probe for each boiler is installed in a rectangular section of ductwork following the boiler but before the exhaust gas enters the common CPP exhaust stacks. Each of these rectangular sections of ductwork are equipped with five sampling ports, each equidistant from the other as well as from the outer walls of the rectangular section of ductwork. For each boiler, an exhaust gas stratification test was performed to verify that exhaust gas concentrations are not stratified. Because each exhaust location satisfied the stratification criteria of Method 7E, BTEC sampled three points for each test run.

4.d Traverse Points

Boiler exhaust gas stratification tests were conducted using traverse points as determined by Method 1.

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 Tables 3 through 6. Relevant raw test data for emissions test runs and for analyzer calibrations are provided electronically in Appendix C.

5.b Discussion of Results

As summarized by Table 7, emission rates from each boiler were well below corresponding emission limitations.

5.c Sampling Procedure Variations

Because the total hydrocarbon concentration in the Boiler No. 6 exhaust gas was negligible, methane concentrations were not quality-assured during the emissions test program and, consequently, were not subtracted from the total hydrocarbon concentrations or used in calculating emission test results. All testing was conducted as specified in the MDEQ test plan approval letter included in Appendix E.

5.d Process or Control Device Upsets

No upset conditions occurred during testing.

5.e Control Device Maintenance

There is no add-on control device for Boiler Nos. 2 and 6.

5.f Re-Test Changes

The emission testing program was not a re-test.

5.g Audit Sample Analyses

No audit samples were requested by AQD.

5.h Calibration Sheets

Certificates of analysis for the calibration gases used during testing are provided as Appendix C.

5.i Sample Calculations

Sample calculations are provided as Appendix D.

5.j Field Data Sheets

Copies of field data sheets and relevant field notes are provided as Appendix C.

5.k Laboratory Data

No laboratory analysis was included in this test program.

Table 3
Boiler 2 Gas NOx Emission Rates
University of Michigan
Ann Arbor, Michigan
BTEC Project No. 049AS-239748
Sampling Date: 3/12/2018

Parameter	Run 1	Run 2	Run 3	Average
Test Run Date	3/12/2018	3/12/2018	3/12/2018	
Test Run Time	8:16-9:32	9:50-10:50	11:07-12:07	
Oxygen Concentration (%)	4.97	5.10	4.76	**4.94**
Oxygen Concentration (%, drift corrected as per USEPA 7E)	4.86	5.00	4.65	**4.84**
Outlet Oxides of Nitrogen Concentration (ppmv)	66.6	65.3	66.4	**66.1**
Outlet NOx Concentration (ppmv, corrected as per USEPA 7E)	67.3	66.6	67.9	**67.3**
NOx Emission Rate (lbs/Mmbtu)	0.09	0.09	0.09	**0.09**

O_2 Correction			
Co	0.16	0.19	0.17
Cma	10.06	10.06	10.06
Cm	10.12	10.08	10.10

NOx Correction			
Co	0.37	0.40	0.40
Cma	90.49	90.49	90.49
Cm	89.43	88.63	88.29

Definitions:
kscfh: thousand standard cubic feet per hour
ppmv: parts per million on a volume to volume basis (v/v)
%: percent
lbs/MMBtu: pounds per million British thermal units
lbs/hr: pounds per hour
Co= Average of initial and final zero gases
Cma=Actual concentration of the calibration gas
Cm= Average of initial and final calibration gases

Equations:
lbs/MMBtu = ppmv*7.268*10*10^-8*dscf/MMBtu*8710*(20.9/(20.9-O2%))

Table 4
Boiler 2 Oil NOx Emission Rates
University of Michigan
Ann Arbor, Michigan
BTEC Project No. 049AS-239748
Sampling Date: 3/22/2018

Parameter	Run 1	Run 2	Run 3	Average
Test Run Date	3/22/2018	3/22/2018	3/22/2018	
Test Run Time	10:49-11:49	11:59-12:59	13:10-14:10	
Oxygen Concentration (%)	7.44	7.33	7.30	**7.36**
Oxygen Concentration (%, drift corrected as per USEPA 7E)	7.53	7.47	7.42	**7.47**
Outlet Oxides of Nitrogen Concentration (ppmv)	63.6	64.1	64.1	**63.9**
Outlet NOx Concentration (ppmv, corrected as per USEPA 7E)	64.7	65.2	65.3	**65.1**
NOx Emission Rate (lbs/Mmbtu)	0.11	0.11	0.11	**0.11**

O_2 Correction			
Co	0.03	0.02	0.06
Cma	10.06	10.06	10.06
Cm	9.94	9.86	9.88

NOx Correction			
Co	0.66	0.67	0.65
Cma	90.49	90.49	90.49
Cm	88.71	88.58	88.67

Definitions:
kscfh: thousand standard cubic feet per hour
ppmv: parts per million on a volume to volume basis (v/v)
%: percent
lbs/MMBtu: pounds per million British thermal units
lbs/hr: pounds per hour
Co= Average of initial and final zero gases
Cma=Actual concentration of the calibration gas
Cm= Average of initial and final calibration gases

Equations:
lbs/MMBtu = ppmv*7.268*10*10^-8*dscf/MMBtu*9190*(20.9/(20.9-O2%))

Table 5
Boiler 6 Gas VOC and CO Emission Rates
University of Michigan
Ann Arbor, Michigan
BTEC Project No. 049AS-239748
Sampling Date: 3/20/2018

Parameter	Run 1	Run 2	Run 3	Average
Test Run Date	3/20/2018	3/20/2018	3/20/2018	
Test Run Time	10:33-11:47	12:10-13:10	13:27-14:27	
Oxygen Concentration (%)	4.28	4.22	4.30	**4.27**
Oxygen Concentration (%, drift corrected as per USEPA 7E)	4.23	4.18	4.26	**4.23**
Boiler Natural Gas Flowrate (kscfh, as recorded by Boiler 6 CEMS)	272.0	272.0	272.0	**272.0**
Fuel Gross Heating Value (Btu/scf)	1066	1066	1066	**1066.0**
Boiler Heat Input Rate (MMBtu/hr)	290	290	290	**289.9**
Outlet Carbon Monoxide Concentration (ppmv)	0.5	0.8	0.8	**0.7**
Outlet CO Concentration (ppmv, corrected as per USEPA 7E)	0.9	1.2	1.2	**1.1**
CO Emission Rate (lb/MMBtu) (corrected as per USEPA 7E)	0.00	0.00	0.00	**0.00**
CO Emission Rate (lb/hr) (corrected as per USEPA 7E)	0.2	0.3	0.3	**0.2**
Outlet VOC Concentration (ppmv as propane)	0.0	0.0	0.0	**0.0**
Outlet VOC Concentration (ppmv as propane, corrected using USEPA 7E calculations)	-0.2	0.0	-0.2	**-0.1**
VOC Emission Rate (lb/MMBtu) (corrected as per USEPA 7E)	0.000	0.000	0.000	**0.000**
VOC Emission Rate as Propane (lb/hr) (corrected as per USEPA 7E)	-0.1	0.0	-0.1	**0.0**

O_2 Correction			
Co	0.08	0.09	0.10
Cma	10.06	10.06	10.06
Cm	10.06	10.02	10.01

CO Correction			
Co	-0.33	-0.36	-0.37
Cma	24.9	24.9	24.9
Cm	24.31	24.33	24.17

VOC Correction			
Co	0.21	0.05	0.22
Cma	14.9	14.9	14.9
Cm	14.92	14.91	14.90

Definitions:
kscfh: thousand standard cubic feet per hour
ppmv: parts per million on a volume to volume basis (v/v)
%: percent
lbs/MMBtu: pounds per million British thermal units
lbs/hr: pounds per hour
Co= Average of initial and final zero gases
Cma=Actual concentration of the calibration gas
Cm= Average of initial and final calibration gases

Equations:
CO lbs/MMBtu = ppmv*7.268*10*10^-8*dscf/MMBtu*8710*(20.9/(20.9-O2%))
VOC lbs/MMBtu = ppmv*1.142*10*10^-7*dscf/MMBtu*8710*(20.9/(20.9-O2%))
lbs/hr =kscfh*1000*1066*(lbs/MMBtu)*(1/1,000,000)

Table 6
Boiler 6 Oil VOC and CO Emission Rates
University of Michigan
Ann Arbor, Michigan
BTEC Project No. 049AS-239748
Sampling Date: 3/21/2018

Parameter	Run 1	Run 2	Run 3	Average
Test Run Date	3/21/2018	3/21/2018	3/21/2018	
Test Run Time	12:20-13:30	13:50-14:50	15:08-16:08	
Oxygen Concentration (%)	4.06	3.99	4.02	**4.02**
Oxygen Concentration (%, drift corrected as per USEPA 7E)	4.01	3.95	3.99	**3.98**
Boiler Fuel Oil Flowrate (gph, as recorded by Boiler 6 CEMS)	1950.0	1955.4	1953.8	**1953.1**
Fuel Oil Heating Value (Btu/gal)	138,480	138,480	138,480	**138,480**
Boiler Heat Input Rate (MMBtu/hr)	270.0	270.8	270.6	**270.5**
Outlet Carbon Monoxide Concentration (ppmv)	0.8	0.8	0.8	**0.8**
Outlet CO Concentration (ppmv, corrected as per USEPA 7E)	0.3	0.2	0.0	**0.1**
CO Emission Rate (lb/MMBtu) (corrected as per USEPA 7E)	0.000	0.000	0.000	**0.000**
CO Emission Rate (lb/hr) (corrected as per USEPA 7E)	0.06	0.04	0.00	**0.032**
Outlet VOC Concentration (ppmv as propane)	0.1	0.0	0.3	**0.1**
Outlet VOC Concentration (ppmv as propane, corrected using USEPA 7E calculations)	-0.1	-0.2	0.1	**-0.1**
VOC Emission Rate (lb/MMBtu) (corrected as per USEPA 7E)	0.000	0.000	0.000	**0.000**
VOC Emission Rate as Propane (lb/hr) (corrected as per USEPA 7E)	-0.05	-0.07	0.02	**-0.03**

O_2 Correction			
Co	0.08	0.08	0.08
Cma	10.06	10.06	10.06
Cm	10.07	10.04	10.03

CO Correction			
Co	0.57	0.65	0.82
Cma	24.9	24.9	24.9
Cm	24.59	24.57	24.63

VOC Correction			
Co	0.22	0.23	0.22
Cma	14.9	14.9	14.9
Cm	14.97	14.92	14.58

Definitions:
kscfh: thousand standard cubic feet per hour
ppmv: parts per millino on a volume to volume basis (v/v)
%: percent
lbs/MMBtu: pounds per million British thermal units
lbs/hr: pounds per hour
Co= Average of initial and final zero gases
Cma=Actual concentration of the calibration gas
Cm= Average of initial and final calibration gases

Equations:
CO lbs/MMBtu = ppmv*7.268*10*10^-8*dscf/MMBtu*9190*(20.9/(20.9-O2%))
VOC lbs/MMBtu = ppmv*1.142*10*10^-7*dscf/MMBtu*9190*(20.9/(20.9-O2%))
lbs/hr =gph*138,480*(lbs/MMBtu)*(1/1,000,000)

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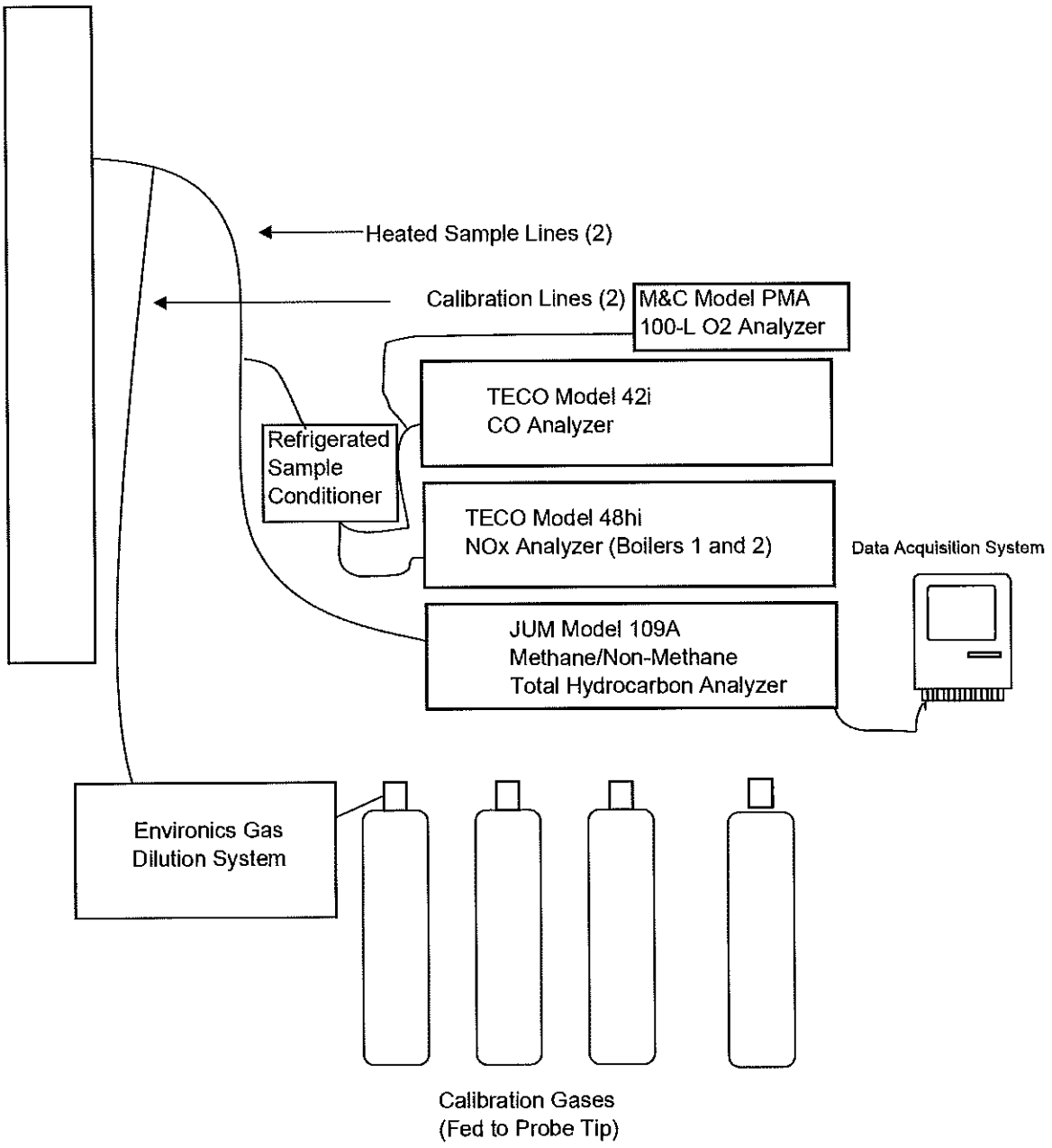

Figure 1

Site: **The University of Michigan** **Central Power Plant - Boilers 2 & 6** **Methods 3A, 7E, 10, & 25A CEM System Sampling Train**	**Sampling Dates:** **March 12, 20, 21, and 22, 2018**
BT Environmental Consulting, Inc. **4949 Fernlee Ave** **Royal Oak, Michigan**	