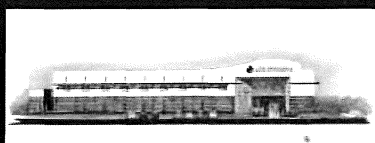RECEIVED

DEC 16 2019

AIR QUALITY DIVISION

STACK EMISSIONS STUDY
EPA 40 CFR PART 63 SUBPART LLL
FOR
KILNS 22 AND 23
PREPARED FOR
HOLCIM (US) INC. D/B/A LAFARGE, SRN B1477
AT THE
ALPENA PLANT
ALPENA, MICHIGAN
OCTOBER 24-25 AND DECEMBER 4, 2019

Permit No: MI-ROP-B1477-2012

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EPA 40 CFR PART 63 SUBPART LLL
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HOLCIM (US) INC. D/B/A LAFARGE, SRN B1477
AT THE
ALPENA PLANT
ALPENA, MICHIGAN
OCTOBER 24-25 AND DECEMBER 4, 2019

Prepared and Reviewed by:

Logan K. Tsotsoros

Logan Tsotsoros
AHU Support Staff

Thomas K. Graham

Thomas K. Graham, PE, QSTI
Director of AHU

M. Sharief

I, _____

Mars A. Sharief, QSTI
Sr. Regional Manager-Chicago, IL
certify that this testing was conducted and
this report was created in conformance
with the requirements of ASTM D7036

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APPENDICES

Stack Emissions Study
Kilns 22 and 23
Holcim (US) Inc. d/b/a Lafarge, SRN B1477
Alpena Plant
Alpena, Michigan
October 24-25 and December 4, 2019

1.0 INTRODUCTION

Air Hygiene International, Inc. (Air Hygiene) has completed the Stack Emissions Study for Dioxins and Furans (PCDD/Fs) from the exhaust of Kilns 22 and 23 for Holcim (US) Inc. d/b/a Lafarge, SRN B1477 at the Alpena Plant in Alpena, Michigan. This report details the background, results, process description, and the sampling/analysis methodology of the stack sampling survey conducted on October 24-25 and December 4, 2019.

1.1 TEST PURPOSE AND OBJECTIVES

The purpose of the test was to conduct a periodic compliance emission test to document levels of selected pollutants. The information will be used to confirm compliance with 40 Code of Federal Regulations (CFR) 60, Subpart LLL and the operating permit issued by the Michigan Department of Environment, Great Lakes, and Energy (EGLE). The specific objective was to determine the emission concentration of PCDD/Fs from the exhaust of Holcim (US) Inc. d/b/a Lafarge, SRN B1477's Kilns 22 and 23. EGLE has asked that Lafarge conduct additional testing to confirm the absence of cyclonic flow at the Kiln 22 and 23 breach ducts, since these locations do not meet the conventional Method 1 upstream/downstream disturbance distance criteria.

1.2 SUMMARY OF TEST PROGRAM

The following list details pertinent information related to this specific project:

- 1.2.1 Participating Organizations
  - Michigan Department of Environment, Great Lakes, and Energy (EGLE)
  - Holcim (US) Inc. d/b/a Lafarge, SRN B1477
  - Air Hygiene
- 1.2.2 Industry
  - Cement
- 1.2.3 Air Permit and Federal Requirements
  - Permit Number: MI-ROP-B1477-2012
  - 40 CFR 63, Subpar LLL
- 1.2.4 Plant Location
  - Alpena Plant in Alpena, Michigan
    - GPS Coordinates [Latitude 45.07095, Longitude -83.41489]
    - 1435 Ford Avenue, Alpena, Michigan 49707
    - Federal Registry System / Facility Registry Service (FRS) No. – 110015742605
    - Source Classification Codes (SCC) – 30501120, 30500699, and 30500613
- 1.2.5 Equipment Tested
  - Kilns 22 and 23
- 1.2.6 Emission Points
  - Exhaust from Kilns 22 and 23
  - For all molecular weight gases, a single sample point in the exhaust stack from each unit

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- For all wet chemistry testing, 24 sampling points in the exhaust stack from each unit
- For all cyclonic flow verification test, 40 sampling points in the exhaust stack from each unit

1.2.7 Emission Parameters Measured
- Dioxins and Furans (PCDD/Fs)

1.2.8 Dates of Emission Test
- October 24-25 and December 4, 2019

1.2.9 Federal Certifications
- Stack Testing Accreditation Council AETB Certificate No. 3796.02
- International Standard ISO/IEC 17025:2005 Certificate No. 3796.01

1.3 KEY PERSONNEL

Holcim (US) Inc. d/b/a Lafarge, SRN B1477:	Travis Weide (travis.weide@lafargeholcim.com)	989-358-3321
EGLE:	Jeremy Howe	231-878-6687
EGLE:	Kurt Childs	231-878-2045
Air Hygiene:	Mars Sharief (msharief@airhygiene.com)	918-307-8865
Air Hygiene:	James Reynolds	918-307-8865
Air Hygiene:	Atlas Melchert	918-307-8865
Air Hygiene:	Jeff Reese	918-307-8865

2.0 SUMMARY OF TEST RESULTS

Results from the sampling conducted on Holcim (US) Inc. d/b/a Lafarge, SRN B1477's Kilns 22 and 23 located at the Alpena Plant on October 24-25 and December 4, 2019 are summarized in the following tables and relate only to the items tested.

The results of all measured pollutant emissions and flow verifications were below the required limits. All testing was performed without any real or apparent errors. All testing was conducted according to the approved testing protocols.

TABLE 2.1
KILN 22 EMISSIONS DATA SUMMARY

Emission Rate Data	K22_23-1	K22_23-2	K22_23-3	Average	Units	Limits
PCDD/Fs (TEF: NATO) Mass	9.65E-09	4.35E-09	5.35E-09	6.45E-09	mg	--
PCDD/Fs (TEF: NATO) Concentration	6.05E-14	2.90E-14	3.55E-14	4.17E-14	g/dscf	--
	9.33E-13	4.48E-13	5.48E-13	6.43E-13	gr/dscf	--
PCDD/Fs (TEF: NATO) Emission Rate	2.75E-03	1.28E-03	1.54E-03	1.86E-03	ngTEQ/dscm@7%O_2	0.20
	1.14E-09	5.18E-10	6.37E-10	7.66E-10	lb/hr	--
PCDD/Fs (total mass) Mass	4.99E-07	5.96E-07	5.06E-07	5.34E-07	mg	--
PCDD/Fs (total mass) Concentration	3.12E-12	3.98E-12	3.36E-12	3.49E-12	g/dscf	--
	1.10E-01	1.40E-01	1.19E-01	1.23E-01	ng/dscm	--
PCDD/Fs (total mass) Emission Rate	1.42E-01	1.76E-01	1.46E-01	1.55E-01	ng/dscm@7%O_2	--
	5.91E-08	7.09E-08	6.03E-08	6.34E-08	lb/hr	--

laf-19-alpena.mi-comp#6-Kiln22&23PCDDF-rpt

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TABLE 2.2

KILN 23 EMISSIONS DATA SUMMARY

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Emission Rate Data	K23_23-1	K23_23-2	K23_23-3	Average	Units	Limits
PCDD/Fs (TEF: NATO) Mass	1.52E-08	1.20E-08	9.45E-09	1.22E-08	mg	--
PCDD/Fs (TEF: NATO) Concentration	1.04E-13	8.19E-14	6.28E-14	8.30E-14	g/dscf	--
	1.61E-12	1.26E-12	9.68E-13	1.28E-12	gr/dscf	--
PCDD/Fs (TEF: NATO) Emission Rate	3.90E-03	3.11E-03	2.30E-03	3.11E-03	ngTEQ/dscm@7%O_2	0.20
	1.77E-09	1.42E-09	1.11E-09	1.43E-09	lb/hr	--
PCDD/Fs (total mass) Mass	1.22E-06	8.98E-07	8.00E-07	9.72E-07	mg	--
PCDD/Fs (total mass) Concentration	8.39E-12	6.16E-12	5.31E-12	6.62E-12	g/dscf	--
	2.96E-01	2.17E-01	1.88E-01	2.34E-01	ng/dscm	--
PCDD/Fs (total mass) Emission Rate	3.14E-01	2.34E-01	1.95E-01	2.48E-01	ng/dscm@7%O_2	--
	1.42E-07	1.06E-07	9.44E-08	1.14E-07	lb/hr	--

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TABLE 2.3

KILN 22 AND 23 FLOW VERIFICATION

</div>

Parameter	Kiln 22	Kiln 23	Limits
Date (mm/dd/yy)	12/04/19	12/04/19	--
$R_{i(avg)}$ (degrees)	10.96	15.90	20
S_d (degrees)	7.52	6.01	10

3.0 SOURCE OPERATION

3.1 PROCESS DESCRIPTION

The Alpena Plant is located in Alpena, Michigan. The Raw Mill System mixes and grinds the raw materials (limestone, sand, bauxite, Bell shale, gypsum) and alternate raw materials (slag, iron ore, fly ash, and CKD) then sends the materials to the kilns.

Holcim (US) Inc. d/b/a Lafarge, SRN B1477 operates five rotary kilns, which manufacture Portland cement clinker using the dry process. A mixture of pulverized bituminous coal and petroleum coke, with a heating value of approximately 11,750 Btu per pound, serves as the primary fuel fed to the kilns. Coal and coke are fed to a Raymond bowl mill and ground to a fineness of approximately 95% passing a 200-mesh sieve.

Kiln Group 5:

Kiln Group 5 at the Alpena Plant consists of three rotary kilns (#19, #20, and #21). Specific components of Kiln Group 5 are:

laf-19-alpena.mi-comp#6-Kiln22&23PCDDF-rpt

- Coal/petroleum coke and combustion air delivery;
- Raw mix preparation and delivery;
- Three rotary kilns;
- Kiln burners; and
- Air pollution control system, consisting of the following components:
  - Boiler;
  - Multiclone dust collectors;
  - Baghouses;
  - SNCR;
  - Induced draft (ID) fans; and
  - Exhaust stacks.

Allis Chalmers manufactured all kilns identified as #19, #20, and #21. Each kiln is 460.5 feet long. Each kiln shell has an inside diameter of 15 feet at the feed end and 13 feet at the firing end. The kilns in Kiln Group 5 rotate at speeds of greater than 40 revolutions per hour and are driven by an electric motor.

Dracco manufactured the baghouse for Kiln 19. The baghouse has two parallel sets of six chambers with a designed airflow of 175,000 cubic feet per minute (cfm) at 400°F. The maximum operating temperature is 550°F. The baghouses for kilns 20 and 21, manufactured by Wheelbrator-Frye are identical in design and construction, with two parallel sets of six chambers. Each baghouse has a designed air flow of 166,000 cfm at 400°F. The maximum operating temperature is 550°F.

3.2 SAMPLING LOCATION

The baghouse breeching ducts have been demonstrated as acceptable locations to conduct EPA reference method testing on all kilns. For each location the stack sampling occurs at the breaching duct between each kiln's baghouse and discharge stack. Ductwork geometry is adequate for collecting a representative sample of gaseous constituents at this point. Further descriptions of all sampling locations for this test program are provided in Appendix B.

4.0 SAMPLING AND ANALYTICAL PROCEDURES

4.1 TEST METHODS

The emission test on Kilns 22 and 23 at the Alpena Plant was performed following United States Environmental Protection Agency (EPA) methods described by the Code of Federal Regulations (CFR). Table 4.1 outlines the specific methods performed on October 24-25 and December 4, 2019.

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TABLE 4.1
SUMMARY OF SAMPLING METHODS

Pollutant or Parameter	Sampling Method	Analysis Method
Sample Point Location	EPA Method 1	Equal Area Method
Flow Verification	EPA Method 1	Section 12.3.4
Stack Flow Rate	EPA Method 2	S-Type Pitot Tube
Flow Verification	EPA Method 2F	DAT type Prism head
Oxygen	EPA Method 3A	Paramagnetic Cell
Carbon Dioxide	EPA Method 3A	Nondispersive Infrared Analyzer
Stack Moisture Content	EPA Method 4	Gravimetric Analysis
Dioxins and Furans (PCDD/Fs)	EPA Method 23	Digestion

4.2 INSTRUMENT CONFIGURATION AND OPERATIONS FOR GAS ANALYSIS

The sampling and analysis procedures used during these tests conform with the methods outlined in the Code of Federal Regulations (CFR), Title 40, Part 60, Appendix A, Methods 1, 2, 2F, 3A, 4, and 23.

Figure 4.1 depicts the sample system used for the real-time gas analyzer tests. The gas sample was continuously pulled through the probe and transported, via heat-traced Teflon® tubing, to a stainless-steel minimum-contact condenser designed to dry the sample. Transportation of the sample, through Teflon® tubing, continued into the sample manifold within the mobile laboratory via a stainless steel/Teflon® diaphragm pump. From the manifold, the sample was partitioned to the real-time analyzers through rotameters that controlled the flow rate of the sample.

Figure 4.1 shows that the sample system was also equipped with a separate path through which a calibration gas could be delivered to the probe and back through the entire sampling system. This allowed for convenient performance of system bias checks as required by the testing methods.

All instruments were housed in a climate controlled, trailer-mounted mobile laboratory. Gaseous calibration standards were provided in aluminum cylinders with the concentrations certified by the vendor. EPA Protocol No. 1 was used to determine the cylinder concentrations where applicable (i.e. NOx calibration gases).

Table 4.2 provides a description of the analyzers used for the instrument portion of the tests. All data from the continuous monitoring instruments were recorded on a Logic Beach Portable Data Logging System which retrieves calibrated electronic data from each instrument every one second and reports an average of the collected data every 30 seconds.

Figure 4.2 represents the sample system used for the wet chemistry tests (PCDD/Fs). A heated stainless-steel probe with a glass liner and nozzle was inserted into the sample ports of the stack to extract gas measurements from the emission stream through a filter and glass impinger train. Flow rates are monitored with oil filled manometers and total sample volumes are measured with a dry gas meter.

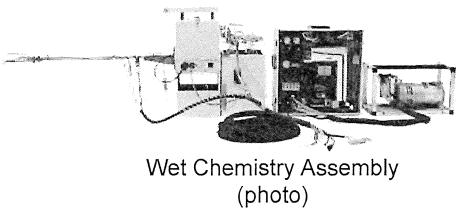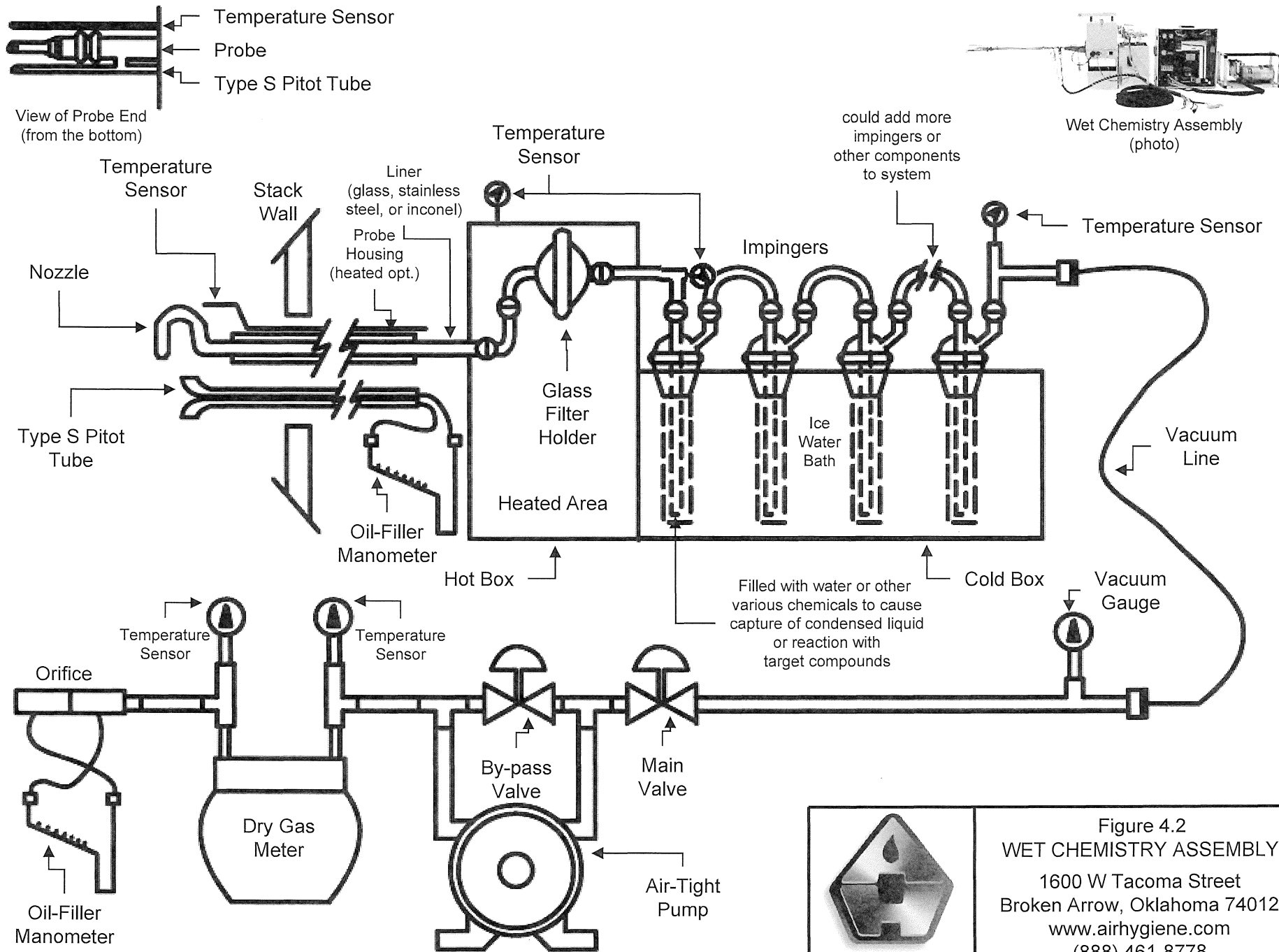laf-19-alpena.mi-comp#6-Kiln22&23PCDDF-rpt

Figure 4.3 represents the sample system used for the 3D Flow tests. A DAT type Prism stainless steel head probe was inserted into the sample ports of the stack to extract gas measurements from the emission stream and read with either analog or digital manometers.

The stack gas analysis for O_2 and CO_2 concentrations was performed in accordance with procedures set forth in EPA Method 3A. The O_2 analyzer uses a paramagnetic cell detector and the CO_2 analyzer uses a continuous nondispersive infrared analyzer.

TABLE 4.2
ANALYTICAL INSTRUMENTATION

Parameter	Manufacturer and Model	Range	Sensitivity	Detection Principle
CO_2	SERVOMEX 1440	0-20%	0.1%	Nondispersive infrared
O_2	SERVOMEX 1440	0-25%	0.1%	Paramagnetic cell, inherently linear.

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HEATED PROBE FILTER

PROBE

LEGEND

Heated Teflon Tubing (pre-conditioned sample)

Unheated Teflon Tubing (conditioned sample)

Diluted Calibration Gas

Calibration Gas

Electronic Input/Output

HEATED PROBE FILTER

PROBE

STACK EXHAUST

PROBE

PROCESS INLET OR 2ND STACK

dual line heated sample umbilical

dual line heated sample umbilical

TEST TRAILER EXTERIOR
TEST TRAILER INTERIOR

DATA RECORDER

COMPUTER

GAS CONDITIONER

MOBILE SECONDARY ANALYZERS

MANIFOLD

O_2, CO_2, NOx, CO, SO_2

COLD/DRY ANALYZERS HOT/WET

THC, VOC

CONDITIONER

VENT

CALIBRATION/BIAS GAS BOTTLES

GAS DILUTER

THC, VOC

HOT/WET ANALYZERS
COLD/DRY ANALYZERS

O_2, CO_2, NOx, CO, SO_2

FIXED PRIMARY ANALYZERS

VENT

FLOW CONTROL MANIFOLD

FTIR

Figure 4.1
EMISSIONS TESTING LAB

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Shown fully equipped. Some labs may not contain these features and others may contain additional features specific to certain scopes.

Temperature Sensor
Probe
Type S Pitot Tube

View of Probe End
(from the bottom)

Wet Chemistry Assembly
(photo)

Temperature
Sensor

Stack
Wall

Liner
(glass, stainless
steel, or inconel)

Probe
Housing
(heated opt.)

Temperature
Sensor

could add more
impingers or
other components
to system

Temperature Sensor

Nozzle

Impingers

Type S Pitot
Tube

Glass
Filter
Holder

Ice
Water
Bath

Vacuum
Line

Heated Area

Oil-Filler
Manometer

Hot Box

Filled with water or other
various chemicals to cause
capture of condensed liquid
or reaction with
target compounds

Cold Box

Vacuum
Gauge

Temperature
Sensor

Temperature
Sensor

Orifice

By-pass
Valve

Main
Valve

Dry Gas
Meter

Air-Tight
Pump

Oil-Filler
Manometer

Figure 4.2
WET CHEMISTRY ASSEMBLY

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3-D Probe Assembly
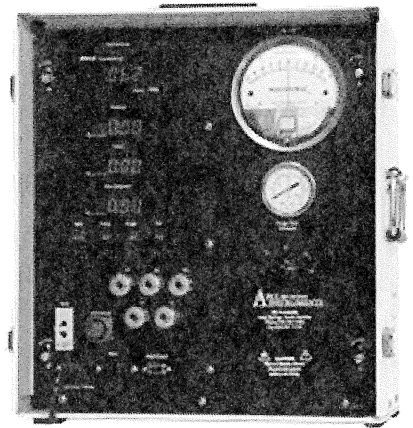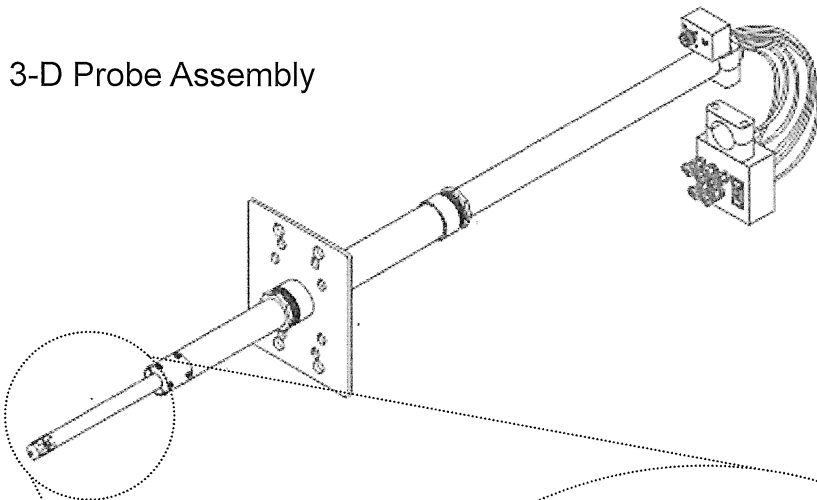
3-D Console
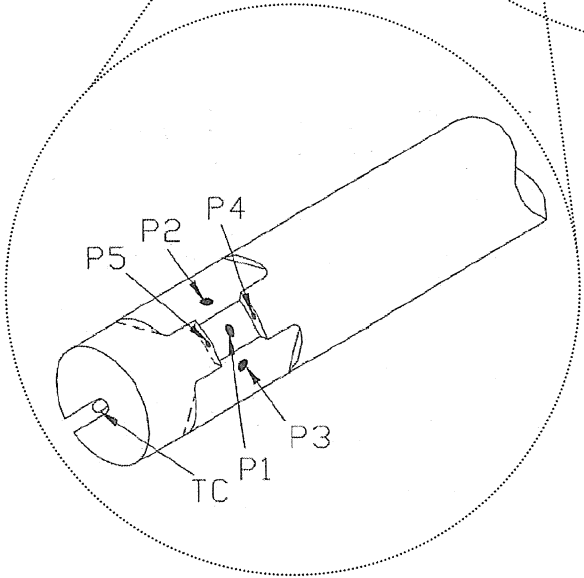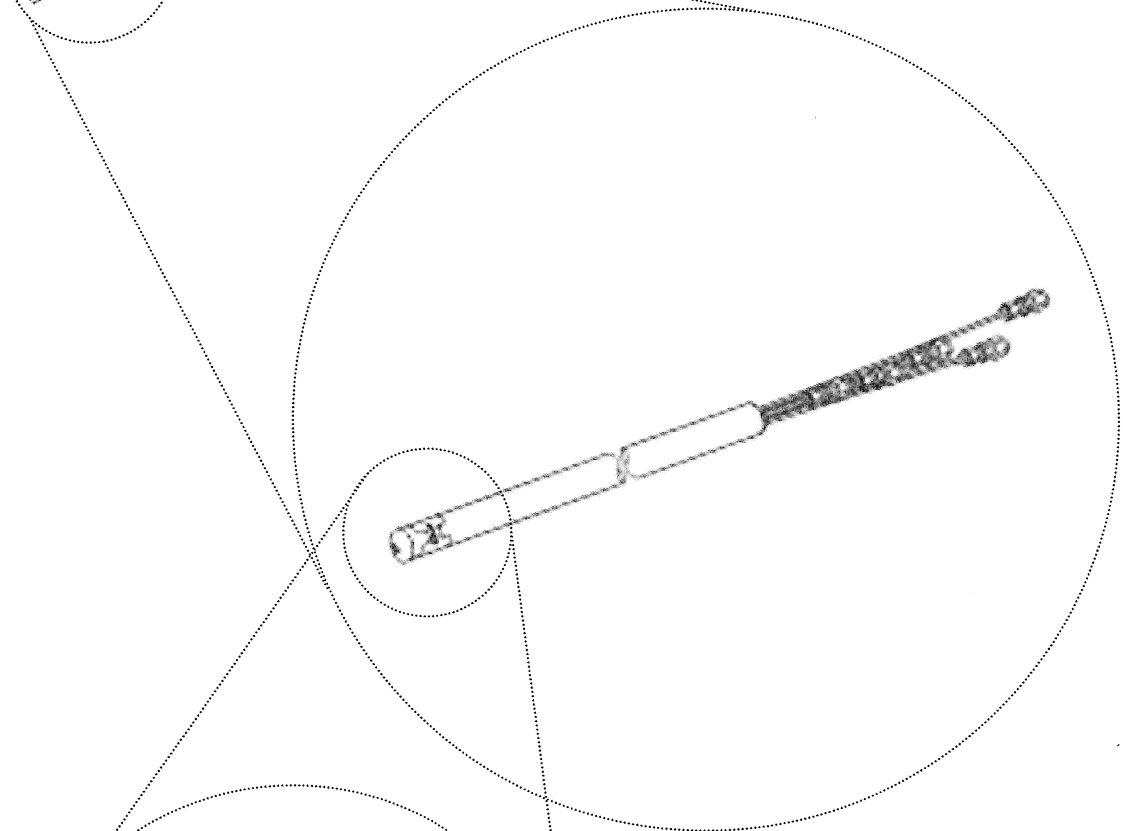
Prism Shaped 3D Pitot Head

P4

P2

P5

P3

TC

P1

Figure 4.3
3D FLOW EQUIPMENT

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APPENDIX A

TEST RESULTS AND CALCULATIONS

TEST RESULTS AND CALCULATIONS

Kiln 22 Emissions Data

TABLE A.1: EMISSIONS TESTING SCHEDULE

Unit	Component	Run	Date	Start	Stop	Time Sync
K22	Preliminaries	K22_23-V1	10/24/19	16:52:00	17:20:00	DAHS
K22	Dioxins/Furans	K22_23-1	10/26/19	7:45:00	11:03:00	DAHS
K22	Dioxins/Furans	K22_23-2	10/26/19	11:38:00	14:51:00	DAHS
K22	Dioxins/Furans	K22_23-3	10/26/19	15:20:00	18:45:00	DAHS
K22	Flow Verification	1	12/04/19	15:23:00	16:00:00	DAHS

Note: DAHS Time (EDT)

METHOD 23 (DIOXINS) - RESULTS

Plant Name	Alpena Plant
Sampling Location	Kiln 22
Project #	laf-19-alpena.mi-comp#5

Historical Data	K22_23-1	K22_23-2	K22_23-3	Average	Units
Run Start Time	07:45	11:38	15:20		hh:mm
Run Stop Time	11:03	14:51	18:45		hh:mm
Test Date	10/26/19	10/26/19	10/26/19		mm/dd/yy
Production Rate	77.00	73.00	72.00	74.00	ton/hr
Meter Calibration Factor	1.016	1.016	1.016		
Pitot Tube Coefficient	0.8225	0.8225	0.8225		
Average Nozzle Diameter	0.298	0.298	0.298		in
Stack Test Data	**K22_23-1**	**K22_23-2**	**K22_23-3**	**Average**	**Units**
Initial Meter Volume	0.000	0.000	0.000		ft³
Final Meter Volume	157.349	148.060	148.820		ft³
Total Meter Volume	157.349	148.060	148.820	151.410	ft³
Total Sampling Time	180.00	180.00	180.00	180.00	min
Average Meter Temperature	64.13	64.33	62.71	63.72	°F
Average Stack Temperature	412.04	416.17	424.50	417.57	°F
Barometric Pressure	29.44	29.43	29.33	29.40	in Hg
Stack Static Pressure	-1.10	-1.10	-1.10	-1.10	in H_2O
Absolute Stack Pressure	29.36	29.35	29.25	29.32	in Hg
Average Orifice Pressure Drop	2.83	2.53	2.55	2.64	in H_2O
Absolute Meter Pressure	29.58	29.57	29.47	29.54	in Hg
Avg Square Root Pitot Pressure	0.76	0.72	0.73	0.74	$\sqrt{(in\ H_2O)}$
Moisture Content Data	**K22_23-1**	**K22_23-2**	**K22_23-3**	**Average**	**Units**
Impinger Water Weight Gain	93.00	94.30	99.90	95.73	g
Silica Gel Weight Gain	33.90	36.30	31.40	33.87	g
Total Water Volume Collected	127.13	130.84	131.54	129.83	ml
Standard Water Vapor Volume	5.98	6.16	6.19	6.11	scf
Standard Meter Volume	159.6	149.9	150.7	153.4	dscf
Standard Metric Meter Volume	4.5	4.2	4.3	4.3	dscm
Calculated Stack Moisture	3.61	3.94	3.95	3.84	%
Saturated Stack Moisture	100.00	100.00	100.00	100.00	%
Reported Stack Moisture Content	3.61	3.94	3.95	3.84	%

METHOD 23 (DIOXINS) - RESULTS

Plant Name	Alpena Plant
Sampling Location	Kiln 22
Project #	laf-19-alpena.mi-comp#5

Gas Analysis Data	K22_23-1	K22_23-2	K22_23-3	Average	Units
Carbon Dioxide Content	16.0	16.0	16.0	16.0	%
Oxygen Content	10.1	9.8	9.6	9.8	%
Carbon Monoxide Content	0.0	0.0	0.0	0.0	ppm
Nitrogen Content	73.9	74.2	74.4	74.2	%
Stack Dry Molecular Weight	30.96	30.95	30.95	30.95	lb/lb-mole
Stack Wet Molecular Weight	30.49	30.44	30.43	30.46	lb/lb-mole
Volumetric Flow Rate Data	**K22_23-1**	**K22_23-2**	**K22_23-3**	**Average**	**Units**
Average Stack Gas Velocity	52.99	50.40	51.32	51.57	ft/sec
Stack Cross-Sectional Area	78.54	78.54	78.54	78.54	ft²
Actual Stack Flow Rate	249,720	237,501	241,822	243,015	acfm
Wet Standard Stack Flow Rate	8,902	8,424	8,467	8,598	wkscfh
Dry Standard Stack Flow Rate	8,580,194	8,091,318	8,132,947	8,268,153	dscfh
Percent of Isokinetic Rate	101.1	100.6	100.6	100.7	%
Emission Rate Data	**K22_23-1**	**K22_23-2**	**K22_23-3**	**Average**	**Units**
PCDD/Fs (TEF: NATO) Mass	9.65E-09	4.35E-09	5.35E-09	6.45E-09	mg
PCDD/Fs (TEF: NATO) Concentration	6.05E-14	2.90E-14	3.55E-14	4.17E-14	g/dscf
	9.33E-13	4.48E-13	5.48E-13	6.43E-13	gr/dscf
PCDD/Fs (TEF: NATO) Emission Rate	2.75E-03	1.28E-03	1.54E-03	1.86E-03	ngTEQ/dscm@7%O₂
	1.14E-09	5.18E-10	6.37E-10	7.66E-10	lb/hr
PCDD/Fs (total mass) Mass	4.99E-07	5.96E-07	5.06E-07	5.34E-07	mg
PCDD/Fs (total mass) Concentration	3.12E-12	3.98E-12	3.36E-12	3.49E-12	g/dscf
	1.10E-01	1.40E-01	1.19E-01	1.23E-01	ng/dscm
PCDD/Fs (total mass) Emission Rate	1.42E-01	1.76E-01	1.46E-01	1.55E-01	ng/dscm@7%O₂
	5.91E-08	7.09E-08	6.03E-08	6.34E-08	lb/hr

Nomenclature

- %CO = carbon monoxide concentration (%)
- $\%CO_2$ = carbon dioxide concentration (%)
- $\%N_2$ = nitrogen concentration (%)
- $\%O_2$ = oxygen concentration (%)
- $\%O_{2,wet}$ = Oxygen content of gas stream, % by volume of wet gas. (Note: The oxygen percentage used in Method 201A, Equation 3 is on a wet gas basis. That means that since oxygen is typically measured on a dry gas basis, the measured percent O2 must be multiplied by the quantity (1 - B_{ws}) to convert to the actual volume fraction. Therefore, $\%O_{2,wet} = (1 - B_{ws}) * \%O_{2,\,dry}$)

- $(\%EA)_{avg}$ = average excess air (%)
- $(F_o)_{avg}$ = average calculated fuel factor
- $[(\Delta p)^{0.5}]_{avg}$ = Average of square roots of the velocity pressures measured during the preliminary traverse, inches W.C.
- μ = Gas viscosity, micropoise
- 12.0 = Constant calculated as 60 percent of 20.5 square inch cross-sectional area of combined cyclone head, square inches

- 17.03 = mg/milliequivalents for ammonium ion
- 22.4 = liters of ideal gas per lb-mol of substance at 0^oC and 1 atm (ref. Civil Engineering Reference Manual, 7th ed. - Michael R. Lindeburg)
- 24.04 = liters of ideal gas per lb-mol of substance at 20^oC and 1 atm (ref. Civil Engineering Reference Manual, 7th ed. - Michael R. Lindeburg)
- 5.02×10^4 = constant derived from the molecular weight and correcting standard temperature and pressure (ref. Bay Area Air Quality Management District, Source Test Procedure ST-1B, Ammonia Integrated Sampling, Adopted January 20, 1982, Regulation 7-303)

- A = distance upstream (in.)
- A_D = stack diameters upstream (dia.)
- An = Area of nozzle, square feet
- A_s = area of stack (ft^2)
- B = distance downstream (in.)
- B_D = stack diameters downstream (dia.)
- b_f = Average blockage factor calculated in Equation 26, dimensionless
- B_{wm} = meter moisture content (%)
- B_{ws} = stack moisture content (%)
- C = Cunningham correction factor for particle diameter, Dp, and calculated using the actual stack gas temperature, dimensionless

- C_1 = -150.3162 (micropoise)
- C_2 = 18.0614 (micropoise/$K^{0.5}$) = 13.4622 (micropoise/$R^{0.5}$)
- C_3 = 1.19183 × 10^6 (micropoise/K^2) = 3.86153 × 10^6 (micropoise/R^2)
- C_4 = 0.591123 (micropoise)
- C_5 = 91.9723 (micropoise)
- C_6 = 4.91705 × 10^{-5} (micropoise/K^2) = 1.51761 × 10^{-5} (micropoise/R^2)
- C_a = Acetone blank concentration, mg/mg
- C_b = Concentration of NH3 ion in the back half of train (breakthrough)
- C_f = Concentration of NH3 ion in the front half of train (main catch)
- C_{fPM10} = Conc. of filterable PM_{10}, gr/dscf
- $C_{fPM2.5}$ = Conc. of filterable $PM_{2.5}$, gr/dscf
- C_k = K Factor Constant, 849.8
- C_n = nozzle diameter constant, 0.03575
- C_p' = Coefficient for the pitot used in the preliminary traverse, dimensionless
- C_p = Pitot coefficient for the combined cyclone pitot, dimensionless

Nomenclature

- C_{cpm} = Concentration of the condensable PM in the stack gas, dry basis, corrected to standard conditions, milligrams/dry standard cubic foot.
- C_r = Re-estimated Cunningham correction factor for particle diameter equivalent to the actual cut size diameter and calculated using the actual stack gas temperature, dimensionless
- D_{50} = Particle cut diameter, micrometers
- $D_{50(N+1)}$ = D_{50} value for cyclone IV calculated during the N+1 iterative step, micrometers
- D_{50-1} = Re-calculated particle cut diameters based on re-estimated C_r, micrometers
- D_{50LL} = Cut diameter for cyclone I corresponding to the 2.25 micrometer cut diameter for cyclone IV, micrometer
- D_{50N} = D_{50} value for cyclone IV calculated during the Nth iterative step, micrometers
- D_{50T} = Cyclone I cut diameter corresponding to the middle of the overlap zone shown in Method 201A, Figure 10 of Section 17, micrometers
- D_e = equivalent stack diameter (in.)
- $\Delta H@$ = ΔH @ 0.75 scfm (in. H2O)
- ΔH_{avg} = average orifice pressure (in. H_2O)
- D_n = Inner diameter of sampling nozzle mounted on Cyclone I, inches
- D_{na} = actual nozzle diameter (in.)
- D_p = Physical particle size, micrometers
- Δp = velocity head (in. H_2O)
- Δp_1 = velocity head at first current traverse point (in. H_2O)
- $\Delta p'_1$ = velocity head at first preliminary traverse point (in. H_2O)
- Δp_{avg} = average pitot tube differential pressure (in. H_2O)
- Δp_n = velocity head at subsequent current traverse point (in. H_2O)
- Δp_{RM2} = method 2 velocity head (in. H_2O)
- D_s = diameter of stack (in.)
- F_d = fuel f-factor (dscf/MMBtu)
- f_{O2} = stack gas fraction of O_2, by volume, dry basis
- I = Percent isokinetic sampling, dimensionless
- K_1 = standard volume correction, 17.65°R/in. Hg
- K_4 = isokinetic conversion constant, 0.0945 min•in.Hg/sec•°R
- K_5 = water mass to std water vapor, 0.04715 ft^3/g
- K_p = 85.49, ((ft/sec)/(pounds/mole -°R))
- L = length of stack (in.)
- L_{fw} = distance to far wall of stack (in.)
- L_{nw} = distance to near wall of stack (in.) [reference]
- $m_{\#x}$ = weight measurements (g)
- M_1 = Milligrams of PM collected on the filter, less than or equal to 2.5 micrometers
- M_2 = Milligrams of PM recovered from Container #2 (acetone blank corrected), greater than 10 micrometers
- M_3 = Milligrams of PM recovered from Container #3 (acetone blank corrected), less than or equal to 10 and greater than 2.5 micrometers
- M_4 = Milligrams of PM recovered from Container #4 (acetone blank corrected), less than or equal to 2.5 micrometers
- m_a = Mass of residue of acetone after evaporation, mg
- m_c = Mass of the NH4+ added to sample to form ammonium sulfate, mg
- m_{cpm} = Mass of the total condensable PM, mg
- M_d = Molecular weight of dry gas, pounds/pound mole
- m_{fb} = Mass of total CPM in field train recovery blank, mg
- m_{fx} = final weight, avg of last two measurements (g)

Nomenclature

- mg = Milligram
- mg/L = Milligram per liter
- m_i = Mass of inorganic CPM, mg
- m_{ib} = Mass of inorganic CPM in field train recovery blank, mg
- M_n = total particulates (mg)
- m_o = Mass of organic CPM, mg
- m_{ob} = Mass of organic CPM in field train blank, mg
- m_r = Mass of dried sample from inorganic fraction, mg
- m_{tx} = tare weight (g)
- MW = molecular weight (lb/lb-mole)
- M_w = Molecular weight of wet gas, pounds/pound mole
- N = Normality of ammonium hydroxide titrant
- N_a = null angle (deg.)
- N_{re} = Reynolds number, dimensionless
- N_{tp} = Number of iterative steps or total traverse points
- $P_b = P_{bar}$ = barometric pressure (in. Hg)
- P_{bar} = barometric pressure (in. Hg)
- ppmCO = carbon monoxide concentration (ppm)
- ppmv = Parts per million by volume
- ppmw = Parts per million by weight
- P_s = absolute stack pressure (in. Hg)
- P_{static} = static pressure (in. H_2O)
- P_{std} = standard pressure, 29.92 in. Hg
- Θ = total sampling time (min)
- Q_{aw} = average stack wet flow rate (ascf/min)
- Q_I = Sampling rate for cyclone I to achieve specified D_{50}
- Q_m = estimated orifice flow rate, 0.750 acfm, else Vm/Q from previous run
- Q_s = Sampling rate for cyclone I to achieve specified D_{50}
- $Q_{s(std)}$ = total cyclone flow rate at standard conditions (dscf/min)
- Q_{sd} = dry standard stack flow rate (dscfm)
- Q_{sST} = Dry gas sampling rate through the sampling assembly, dscfm
- Q_{sw} = wet standard stack flow rate (ascfm)
- R_{max} = Nozzle/stack velocity ratio parameter, dimensionless
- R_{min} = Nozzle/stack velocity ratio parameter, dimensionless
- t_1 = Sampling time at point 1, min
- t_m = average gas meter temperature (^{o}F)
- t_m = average meter temperature (^{o}F)
- T_m = Meter box and orifice gas temperature, ^{o}R
- t_n = Sampling time at point n, min
- t_r = Total projected run time, min
- T_s = Absolute stack gas temperature, ^{o}R
- T_{std} = standard temperature, 68°F, 528°R
- T_u = absolute temperature offset, 460°R
- V_a = Volume of acetone blank, ml
- V_{aw} = Volume of acetone used in sample recovery wash, ml
- V_b = Volume of aliquot taken for IC analysis, ml
- V_c = Quantity of water captured in impingers and silica gel, ml
- V_f = final impinger volume (ml)
- V_i = initial impinger volume (ml)

Nomenclature

- V_{ic} = Volume of impinger contents sample, ml
- V_m = Dry gas meter volume sampled, acf
- $V_{m(std)}$ = standard meter volume (dscf)
- v_{max} = Maximum gas velocity calculated from Equations 18 or 19, ft/sec
- v_{max} = maximum nozzle velocity (ft/sec)
- V_{mf} = final dry gas meter reading (dcf)
- V_{mi} = initial dry gas meter reading (dcf)
- v_{min} = Minimum gas velocity calculated from Method 201A, Equations 16 or 17, ft/sec
- V_{ms} = Dry gas meter volume sampled, corrected to standard conditions, dscf
- v_n = Sample gas velocity in the nozzle, ft/sec
- v_{org} = organics wash volume (ml)
- V_p = Volume of water added during train purge
- v_s = average stack gas velocity (ft/sec)
- v_{sl} = local velocity (ft/sec)
- V_t = total impinger volume (ml) = ;$(V_f\text{-}V_i)$
- V_t = Volume of NH4OH titrant, ml
- $V_{w(std)}$ = volume of water vapor in gas sample at standard conditions (scf)
- v_x = blank volume (ml)
- W = width of stack (in.)
- $W_{2,3,4}$ = Weight of PM recovered from Containers #2, #3, and #4, mg
- W_a = Weight of blank residue in acetone used to recover samples, mg
- W_f = final impinger weight (g)
- W_i = initial impinger weight (g)
- W_t = total impinger weight (g) = ;$(W_f\text{-}W_i)$
- w_x = blank weight of solids (g)
- Y = meter calibration factor (a.k.a gamma)
- Z = Ratio between estimated cyclone IV D_{50} values, dimensionless
- γ = Dry gas meter gamma value, dimensionless
- ΔH = Meter box orifice pressure drop, inches W.C.
- $\Delta H@$ = Pressure drop across orifice at flow rate of 0.75 scfm at standard conditions, inches W.C. (Note: Specific to each orifice and meter box.)
- Δp_1 = Velocity pressure measured at point 1, inches W.C.
- Δp_{avg} = Average velocity pressure, inches W.C.
- Δp_m = Observed velocity pressure using S-type pitot tube in preliminary traverse, inches W.C.
- Δp_{max} = Maximum velocity pressure, inches W.C.
- Δp_{min} = Minimum velocity pressure, inches W.C.
- Δp_n = Velocity pressure measured at point n during the test run, inches W.C.
- Δp_s = Velocity pressure calculated in Method 201a, Equation 25, inches W.C.
- Δp_{s1} = Velocity pressure adjusted for combined cyclone pitot tube, inches W.C.
- Δp_{s2} = Velocity pressure corrected for blockage, inches W.C.
- θ = Total run time, min
- ρ_a = Density of acetone, mg/ml (see label on bottle)
- Σ_n = total number of sampling points

EXAMPLE CALCULATIONS (Reference Method 1 - Circular Stack)

Diameter of Stack (in.)

$$D(in.) = L_{fw} - L_{nw}$$

D (in.) = 128.00 in. - 8.00 in. = 120.00 in.

Area of Stack (ft^2)

$$A_s(ft^2) = \pi \times \left(\frac{D}{2 \times 12}\right)^2$$

$$A_s (ft^2) = \quad 3.14 \times \left(\frac{120.00 \text{ in.}}{2 \times 12 \text{in./ft}}\right)^2 = \qquad 78.54 \text{ ft}^2$$

Stack Diameters Downstream

$$B_D(dia.) = \frac{B}{D}$$

$$B_D \text{ (dia.)} = \frac{175.00 \text{ in.}}{120.00 \text{ in.}} = \quad 1.46 \quad \text{diameters}$$

Stack Diameters Upstream

$$A_D(dia.) = \frac{A}{D}$$

$$A_D \text{ (dia.)} = \frac{23.00 \text{ in.}}{120.00 \text{ in.}} = \quad 0.19 \quad \text{diameters}$$

Note: Lack of significant figures may cause rounding errors between actual calculations and example calculations.

EXAMPLE CALCULATIONS (Reference Method 3a) [Values from Run 1 test]

Carbon Monoxide Concentration (%)

$$\%CO = \frac{ppmCO}{10,000}$$

%CO (%) = $\dfrac{0.00 \quad ppm}{10,000 \ ppm/\%}$ = 0.0000 %

Nitrogen Concentration (%)

$$\%N_2 = 100 - \%CO_2 - \%O_2 - \%CO$$

%N$_2$ (%) = 100 - 15.98 % - 10.12 % - 0.00 / 10,000 % = 73.9 %

Stack Dry Molecular Weight (lb/lb-mole)

$$M_d(lb/lb-mol) = \sum\left(\frac{MW_{comp}}{100} \times \%component\right)$$

M$_d$ (lb/lb-mol) = ($\dfrac{44 \ lb/lb-mol}{100}$ x 15.98 %) +

($\dfrac{32 \ lb/lb-mol}{100}$ x 10.12 %) + ($\dfrac{28 \ lb/lb-mol}{100}$ x [$\dfrac{0.00}{10,000}$ + 73.90]) = $\dfrac{30.96 \ lb}{lb-mol}$

Stack Wet Molecular Weight (lb/lb-mole)

$$M_S(lb/lb-mol) = \left[M_d \times \left(1 - \frac{B_{WS}}{100}\right)\right] + \left[MW_{H_2O} \times \frac{B_{WS}}{100}\right]$$

M$_S$ (lb/lb-mol) = { $\dfrac{30.96 \ lb}{lb-mol}$ x (1 - $\dfrac{3.61 \ \%}{100}$) } + { $\dfrac{18 \ lb}{lb-mol}$ x $\dfrac{3.61 \ \%}{100}$ } = $\dfrac{30.49 \ lb}{lb-mol}$

Average Calculated Fuel Factor (F$_o$)

$$F_{o(avg)} = \frac{\left[20.9 - (\%O_2)_{avg} - (0.5 \times (\%CO)_{avg})\right]}{(\%CO_2)_{avg} + (\%CO)_{avg}}$$

F$_{o(avg)}$ = $\dfrac{20.9\% - 10.12 \% - (0.5 \ x \ 0.000 \ \%)}{15.98 \ \% \ + \ 0.000 \ \%}$ = 0.674

Average Excess Air (%)

$$\%EA_{avg}(\%) = \frac{100 \times \left[(\%O_2)_{avg} - (0.5 \times (\%CO)_{avg})\right]}{(0.264 \times (N_2)_{avg}) - \left[(\%O_2)_{avg} - (0.5 \times (\%CO)_{avg})\right]}$$

(%EA)$_{AVG}$ = $\dfrac{100 \ x \ \{ \ 10.12 \ \% - (0.5 \ x \ 0.000 \ \% \ ) \}}{(\ 0.264 \ x \ 73.90 \ \%) - \{ \ 10.12 \ \% - (0.5 \ x \ 0.000 \ \%)\}}$ = 107.81 %

Note: Lack of significant figures may cause rounding errors between actual calculations and example calculations.

EXAMPLE CALCULATIONS (Reference Method 2) [Values from Run 1 test]

Absolute Stack Pressure (in. Hg)

$$P_s\,(in.Hg) = P_b + \frac{P_{static}}{13.6}$$

P_s (in. Hg) = 29.44 in. Hg + $\dfrac{-1.10 \quad \text{in. } H_2O}{13.6 \text{ in. } H_2O/\text{in. Hg}}$ = 29.36 in. Hg

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Average Stack Gas Velocity (ft/sec)

$$v_s\,(ft/sec) = K_p \times C_p \times \left(\sqrt{\Delta p}\right)_{avg} \times \sqrt{\frac{(t_s)_{avg} + T_u}{P_s \times M_s}}$$

v_{sl} (ft/sec) =

$\left(\dfrac{85.49 \text{ ft} \quad (lb/lb\text{-}mol)(in. Hg)}{sec \quad (^oR)(in. H_2O)}\right)^{1/2}$ x 0.82 x 0.76 in.$H_2O^{1/2}$ x $\sqrt{\dfrac{412.04 \quad + 460\ ^oR}{29.36 \quad \text{in. Hg x} \quad 30.49 \quad lb/lb\text{-}mol}}$ = $\dfrac{52.9 \quad \text{ft}}{sec}$

Average Stack Dry Standard Flow Rate (dscfh)

$$Q_{sd}\,(dscfh) = \frac{60 \times 60 \times \left(1 - \dfrac{B_{ws}}{100}\right) \times v_s \times A_s \times T_{std} \times P_s}{(t_s + T_u) \times P_{std}}$$

Q_{sd} (dscf/hr) = $\dfrac{3600 \text{ sec}}{hr}$ x (1 - $\dfrac{3.61 \quad \%}{100}$) x $\dfrac{52.99 \quad \text{ft}}{sec}$ x 78.54 ft^2 x

$\dfrac{68.00 \quad + 460\ ^oR}{412.04 \quad + 460\ ^oR}$ x $\dfrac{29.36 \text{ in. Hg}}{29.92 \text{ in. Hg}}$ = $\dfrac{8,580,194.07 \quad dscf}{hr}$

Average Stack Wet Flow Rate (acfm)

$$Q_{aw}\,(acfm) = 60 \times v_s \times A_s$$

Q_{aw} (acf/min) = $\dfrac{60 \text{ sec}}{min}$ x $\dfrac{52.99 \quad \text{ft}}{sec}$ x 78.54 ft^2 = $\dfrac{249,719.82 \quad acf}{min}$

Average Stack Wet Standard Flow Rate (ascfh)

$$Q_{sw}\,(ascfh) = \frac{60 \times Q_{aw} \times T_{std} \times P_s}{(t_s + T_u) \times P_{std}}$$

Q_{sw} (ascf/hr) = $\dfrac{60 \text{ min}}{hr}$ x $\dfrac{249,719.82 \quad acf}{min}$ x

$\dfrac{68.00 \quad + 460\ ^oR}{412.04 \quad + 460\ ^oR}$ x $\dfrac{29.36 \text{ in. Hg}}{29.92 \text{ in. Hg}}$ = $\dfrac{8,901,892.90 \quad ascf}{hr}$

Note: Lack of significant figures may cause rounding errors between actual calculations and example calculations.

EXAMPLE CALCULATIONS (Reference Method 4) [Values from Run 1 test]

Water Volume Weighed (scf)

$$V_{wsg\,(std)}(scf) = W_t \times K_5$$

$V_{wsg(std)}$ = 126.90 g x 0.04715 ft³/g = 5.983 scf

Standard Meter Volume (dscf)

$$V_{m(std)}(dscf) = \frac{K_1 \times Y \times V_m \times \left(P_b + \dfrac{\Delta H_{avg}}{13.6}\right)}{(t_m)_{avg} + T_u}$$

$V_{m(std)}$ = $\dfrac{17.65 \text{ °R}}{\text{in. Hg}}$ x 1.02 x 157.35 dcf x (29.44 in. Hg + $\dfrac{2.83 \text{ in. } H_2O}{13.6 \text{ in. } H_2O \text{ / in. Hg}}$) = 159.58 dscf

over: 64.13 °F + 460 °R

Calculated Moisture Content (%)

$$B_{ws(calc)}(\%) = 100 \times \frac{V_{wsg\,(std)}}{V_{wsg\,(std)} + V_{m(std)}}$$

$B_{ws(calc)}$ = 100 x $\dfrac{5.98 \text{ dscf}}{5.98 \text{ dscf} + 159.58 \text{ dscf}}$ = 3.61 %

Saturated Moisture Content (%)

$$B_{ws(svp)}(\%) = 100 \times \frac{10^{\,6.691 - \frac{3144}{t_{s(avg)} + 390.86}}}{P_b + \dfrac{P_{static}}{13.6}} \leq 100$$

$B_{ws(svp)}$ = 100 x $\dfrac{10^{\left(6.691 - \frac{3144}{412.04 \text{ °F} + 390.86}\right)}}{29.44 \text{ in. Hg} + \dfrac{-1.10 \text{ in. } H_2O}{13.6 \text{ in. } H_2O \text{ / in. Hg}}}$ ≤ 100 = 100.00 %

Note: Lack of significant figures may cause rounding errors between actual calculations and example calculations.

EXAMPLE CALCULATIONS (Isokinetic Sampling) [Values from Run 1 test]

Desired Orifice (in. H_2O) (first point)

$$\Delta H_d (in.H_2O) = K \times \Delta p$$

ΔH_d (in. H_2O) = 4.85 x

0.61 in. H_2O = 2.96 in. H_2O

Absolute Meter Pressure (in. Hg)

$$P_m(in.Hg) = P_b + \frac{\Delta H @}{13.6}$$

P_m (in. Hg) = 29.44 in. Hg + $\dfrac{1.91 \quad in.\ H_2O}{13.6\ in.\ H_2O/in.\ Hg}$ = 29.58 in. Hg

Recommended Nozzle Diameter (in.)

$$D_{ni}(in.) = \sqrt{\frac{C_n \times Q_m \times P_m}{(t_m + T_n) \times C_p} \times \left(\frac{1 - \frac{B_{wm}}{100}}{1 - \frac{B_{ws}}{100}}\right)} \times \sqrt{(t_s + T_n) \times \left[\frac{M_d \times \left(1 - \frac{B_{ws}}{100}\right) + \left(18 \times \frac{B_{ws}}{100}\right)}{P_s \times \Delta p_{avg}}\right]}$$

D_{ni} (in.) =

$\sqrt{\dfrac{\dfrac{0.03575\ (lb\text{-}mole \cdot °R \cdot in.\ H_2O)^{1/2} \cdot min \cdot in.^2}{acf \cdot in.\ Hg^{3/4} \cdot lb^{1/2}} \times 0.75\ acf \times 29.58\ in.\ Hg}{\left[64.13\ °F + 460°R\right] \times 0.82} \times \left(\dfrac{1 - \dfrac{0.00\ \%}{100}}{1 - \dfrac{3.61\ \%}{100}}\right) \times}$

$\overline{(412.04\ °F + 460°R) \times \dfrac{\dfrac{30.96\ lb}{lb\text{-}mole} \times \left(1 - \dfrac{3.61\ \%}{100}\right) + \left(\dfrac{18\ lb}{lb\text{-}mol} \times \dfrac{3.61\ \%}{100}\right)}{29.36\ in.\ Hg \times 0.76\ in.\ H_2O}}$ = 0.252 in.

ΔP to ΔH Isokinetic Factor

$$K = C_k \times C_p^2 \times \Delta H @ \times D_{na}^4 \times \left[\frac{M_d \times \left(1 - \frac{B_{wm}}{100}\right) + \left(18 \times \frac{B_{wm}}{100}\right)}{M_d \times \left(1 - \frac{B_{ws}}{100}\right) + \left(18 \times \frac{B_{ws}}{100}\right)}\right] \times \left(\frac{1 - \frac{B_{ws}}{100}}{1 - \frac{B_{wm}}{100}}\right)^2 \times \left(\frac{t_m + T_n}{ts + T_n}\right) \times \frac{P_s}{P_m}$$

$K = \dfrac{849.8}{in.\ H_2O \cdot in.^4} \times 0.82^2 \times 1.91\ in.\ H_2O \times 0.30^4 \times \left(\dfrac{1 - \dfrac{3.61\ \%}{100}}{1 - \dfrac{0.00\ \%}{100}}\right)^2 \times \dfrac{64.13\ °F + 460°R}{412.04\ °F + 460°R} \times$

$\left(\dfrac{\dfrac{30.96\ lb}{lb/mole} \times \left(1 - \dfrac{0.00\ \%}{100}\right) + \left(\dfrac{18\ lb}{lb\text{-}mol} \times \dfrac{0.00\ \%}{100}\right)}{\dfrac{30.96\ lb}{lb/mole} \times \left(1 - \dfrac{3.61\ \%}{100}\right) + \left(\dfrac{18\ lb}{lb\text{-}mol} \times \dfrac{3.61\ \%}{100}\right)}\right) \times \dfrac{29.36\ in.\ Hg}{29.58\ in.\ Hg}$ = 4.85

Percent Isokinetic (%) (first point)

$$I(\%) = \frac{K_4 \times \left((t_s)_{avg} + T_n\right) \times V_{m(std)}}{\left(\Theta \times (v_{s(I)})_{avg} \times P_s \times \pi \times \left(\frac{D_{na}}{2} \times \frac{1}{12}\right)^2\right) \times \left(1 - \frac{B_{ws}}{100}\right)}$$

$I(\%) = \dfrac{\dfrac{0.0945\ min \cdot in.\ Hg}{sec \cdot °R} \times (411.00\ °F + 460\ °R) \times 6.72\ dscf}{7.50\ min \times \dfrac{54.17\ ft}{sec} \times 29.36\ in.\ Hg \times 3.14 \times \left(\dfrac{0.30\ in.}{2} \times \dfrac{ft.}{12\ in.}\right)^2 \times \left(1 - \dfrac{3.61\ \%}{100}\right)}$ = 99.60 %

Note: Lack of significant figures may cause rounding errors between actual calculations and example calculations.

EXAMPLE CALCULATIONS (Isokinetic Sampling) [Values from Run 1 test]

Cumulative Percent Isokinetic (%) (weighted average of all points)
Using Method 5, Eq 5-8 to determine intermediate isokinetics at each point, weighted averaging
of the cumulative isokinetics is necessary since all points are not equal, and determined by using
the dry standard meter volume collected at each point to weight the cumulative average. Intermediate isokinetics and dry
standard meter volumes are found at each point. At each point the cumulative sum is found of each value and the quotient of the
two used to determine the cumulative isokinetics for each residual point (n).

$$I(\%) = \sum_{1-n} \frac{\left[I(\%) \times V_{m(std)} \right]_{1-n}}{V_{m(std)_{1-n}}}$$

Pt	In (%)	x	Vm(std)n	=	I (%)n	Σ(I (%)n)	/	Σ(Vm(std)n)	=	I (%)
A-1	99.60	x	6.723	=	669.63	669.63	/	6.72	=	99.6
A-2	101.64	x	7.170	=	728.77	1398.40	/	13.89	=	100.7
A-3	101.63	x	7.111	=	722.73	2121.13	/	21.00	=	101.0
A-4	102.67	x	7.019	=	720.64	2841.77	/	28.02	=	101.4
A-5	101.64	x	6.893	=	700.58	3542.35	/	34.92	=	101.5
A-6	97.88	x	7.236	=	708.24	4250.59	/	42.15	=	100.8
A-7	103.11	x	6.875	=	708.87	4959.46	/	49.03	=	101.2
A-8	101.68	x	6.242	=	634.70	5594.16	/	55.27	=	101.2
A-9	99.45	x	5.307	=	527.78	6121.94	/	60.58	=	101.1
A-10	99.03	x	5.011	=	496.21	6618.15	/	65.59	=	100.9
A-11	95.95	x	5.037	=	483.30	7101.45	/	70.62	=	100.6
A-12	101.24	x	4.946	=	500.73	7602.18	/	75.57	=	100.6
B-1	99.30	x	6.811	=	676.39	8278.57	/	82.38	=	100.5
B-2	100.37	x	6.666	=	669.10	8947.67	/	89.05	=	100.5
B-3	101.91	x	6.971	=	710.43	9658.10	/	96.02	=	100.6
B-4	97.60	x	6.838	=	667.37	10325.47	/	102.86	=	100.4
B-5	111.70	x	8.035	=	897.56	11223.03	/	110.89	=	101.2
B-6	88.53	x	6.301	=	557.86	11780.89	/	117.19	=	100.5
B-7	101.26	x	7.057	=	714.64	12495.53	/	124.25	=	100.6
B-8	102.21	x	7.004	=	715.88	13211.41	/	131.25	=	100.7
B-9	105.82	x	7.129	=	754.35	13965.75	/	138.38	=	100.9
B-10	101.00	x	6.980	=	705.00	14670.76	/	145.36	=	100.9
B-11	106.07	x	6.965	=	738.82	15409.57	/	152.33	=	101.2
B-12	99.25	x	7.252	=	719.77	16129.35	/	159.58	=>	101.1
Last Pt										

Percent Isokinetic (%) (intermediate equation, all points)
[equivalent to taking an average of point-by-point isokinetics
without weighting the average (e.g. all points equal)]

$$I(\%) = \frac{K_4 \times \left(\left(t_s\right)_{avg} + T_u\right) \times V_{m(std)}}{\left(\Theta \times \left(v_{s(l)}\right)_{avg} \times P_s \times \pi \times \left(\frac{D_{na}}{2} \times \frac{1}{12}\right)^2 \right) \times \left(1 - \frac{B_{ws}}{100}\right)}$$

I (%) =
$$\frac{0.0945 \text{ min·in. Hg}}{\text{sec·°R}} \times (\quad 412.04 \quad \text{°F} + 460 \text{ °R}) \times \quad 159.58 \quad \text{dscf}$$

$$180.00 \text{ min} \times \frac{52.99 \text{ ft}}{\text{sec}} \times \quad 29.36 \quad \text{in. Hg} \times 3.14 \times \left(\frac{0.30 \text{ in.}}{2} \times \frac{\text{ft.}}{12 \text{ in.}} \right)^2 \times \left(1 - \frac{3.61 \%}{100} \right) = 100.82 \%$$

Raw Data Percent Isokinetic (%)
[utilizes the raw data equation for isokinetics from Method 5]

$$I(\%) = \frac{100 \left(\left(t_s\right)_{avg} + T_u\right) \left[K_4 V_{1c} + \frac{V_m Y}{\left(t_m\right)_{avg} + T_u} \left(P_{bar} + \frac{\Delta H}{13.6}\right) \right]}{60 \left(\Theta \times \left(v_{s(l)}\right)_{avg} \times P_s \times \pi \times \left(\frac{D_{na}}{2} \times \frac{1}{12}\right)^2 \right)}$$

I (%) =

$$100 \times (\quad 412.04 \quad \text{°F} + 460 \text{ °R}) \times \left[\frac{0.002669 \text{ ft}^3 \text{·in. Hg}}{\text{ml·°R}} \times \quad 127.1 \quad \text{ml} + \frac{157.35 \text{ dcf} \times 1.016}{64.13 \text{ °F} + 460 \text{ °R}} \left(\quad 29.44 \quad \text{in Hg} + \frac{0.763}{13.6} \right) \right]$$

$$60 \times 180.00 \text{ min} \times \frac{52.99 \text{ ft}}{\text{sec}} \times \quad 29.36 \quad \text{in. Hg} \times 3.14 \times \left(\frac{0.30 \text{ in.}}{2} \times \frac{\text{ft.}}{12 \text{ in.}} \right)^2 = 100.26 \%$$

Note: Lack of significant figures may cause rounding errors between actual calculations and example calculations.

EXAMPLE CALCULATIONS (Analysis) [Values from Run 1 test - PCDD/Fs (TEF: NATO) Mass]

Stack PCDD/Fs Concentration (g/dscf)

$$c_s(g/dscf) = 0.001 \times \frac{M_n}{V_{m(std)}}$$

$$c_s\ (g/dscf) = \frac{g}{1000\ mg} \times \frac{0.00\ mg}{159.58\ dscf} = \frac{6.00E\text{-}14\ g}{dscf}$$

Stack PCDD/Fs Concentration (gr/dscf)

$$c_s'(gr/dscf) = 0.001 \times \frac{M_n}{V_{m(std)}} \times \frac{7000}{453.592}$$

$$c_s'\ (gr/dscf) = \frac{g}{1000\ mg} \times \frac{0.00\ mg}{159.58\ dscf} \times \frac{7000\ gr}{lb} \times \frac{lb}{453.592\ g} = \frac{9.33E\text{-}13\ gr}{dscf}$$

PCDD/Fs Emissions Rate (lb/hr)

$$E'(lb/hr) = \frac{M_n \times Q_{sd}}{V_{m(std)}} \times \frac{lb \times g}{453.592g \times 1000mg}$$

$$E'\ (lb/hr) = \frac{g}{1000\ mg} \times \frac{lb}{453.592\ g} \times \frac{0.00\ mg}{159.58\ dscf} \times \frac{8,580,194\ dscf}{hr} = \frac{1.14E\text{-}09\ lb}{hr}$$

Note: Lack of significant figures may cause rounding errors between actual calculations and example calculations.

TEST RESULTS AND CALCULATIONS

Kiln 23 Emissions Data

TABLE A.2: EMISSIONS TESTING SCHEDULE

Unit	Component	Run	Date	Start	Stop	Time Sync
K23	Preliminaries	K23_23-V1	10/24/19	17:31:00	18:00:00	DAHS
K23	Dioxins/Furans	K23_23-1	10/25/19	9:24:00	12:42:00	DAHS
K23	Dioxins/Furans	K23_23-2	10/25/19	13:27:00	16:43:00	DAHS
K23	Dioxins/Furans	K23_23-3	10/25/19	17:10:00	20:25:00	DAHS
K23	Flow Verification	1	12/04/19	11:10:00	13:12:00	DAHS

Note: DAHS Time (EDT)

METHOD 23 (DIOXINS) - RESULTS

Plant Name	Alpena Plant
Sampling Location	Kiln 23
Project #	laf-19-alpena.mi-comp#5

Historical Data	K23_23-1	K23_23-2	K23_23-3	Average	Units
Run Start Time	09:24	13:27	17:10		hh:mm
Run Stop Time	12:42	16:43	20:25		hh:mm
Test Date	10/25/19	10/25/19	10/25/19		mm/dd/yy
Production Rate	70.00	72.00	72.00	71.33	ton/hr
Meter Calibration Factor	1.016	1.016	1.016		
Pitot Tube Coefficient	0.8225	0.8225	0.8225		
Average Nozzle Diameter	0.298	0.298	0.298		in
Stack Test Data	**K23_23-1**	**K23_23-2**	**K23_23-3**	**Average**	**Units**
Initial Meter Volume	0.000	0.000	0.000		ft³
Final Meter Volume	142.455	144.825	149.352		ft³
Total Meter Volume	142.455	144.825	149.352	145.544	ft³
Total Sampling Time	180.00	180.00	180.00	180.00	min
Average Meter Temperature	62.25	68.58	67.21	66.01	°F
Average Stack Temperature	424.88	435.13	436.13	432.04	°F
Barometric Pressure	29.54	29.51	29.46	29.50	in Hg
Stack Static Pressure	-1.20	-1.20	-1.20	-1.20	in H_2O
Absolute Stack Pressure	29.45	29.42	29.37	29.42	in Hg
Average Orifice Pressure Drop	2.40	2.40	2.58	2.46	in H_2O
Absolute Meter Pressure	29.68	29.65	29.60	29.64	in Hg
Avg Square Root Pitot Pressure	0.70	0.72	0.74	0.72	$\sqrt{(\text{in } H_2O)}$
Moisture Content Data	**K23_23-1**	**K23_23-2**	**K23_23-3**	**Average**	**Units**
Impinger Water Weight Gain	120.50	120.30	132.50	124.43	g
Silica Gel Weight Gain	34.60	27.40	31.30	31.10	g
Total Water Volume Collected	155.38	147.97	164.10	155.81	ml
Standard Water Vapor Volume	7.31	6.96	7.72	7.33	scf
Standard Meter Volume	145.3	145.8	150.6	147.3	dscf
Standard Metric Meter Volume	4.1	4.1	4.3	4.2	dscm
Calculated Stack Moisture	4.79	4.56	4.88	4.74	%
Saturated Stack Moisture	100.00	100.00	100.00	100.00	%
Reported Stack Moisture Content	4.79	4.56	4.88	4.74	%

METHOD 23 (DIOXINS) - RESULTS

Plant Name	Alpena Plant
Sampling Location	Kiln 23
Project #	laf-19-alpena.mi-comp#5

Gas Analysis Data	K23_23-1	K23_23-2	K23_23-3	Average	Units
Carbon Dioxide Content	19.2	18.9	19.8	19.3	%
Oxygen Content	7.8	8.0	7.5	7.8	%
Carbon Monoxide Content	0.0	0.0	0.0	0.0	ppm
Nitrogen Content	73.0	73.2	72.7	72.9	%
Stack Dry Molecular Weight	31.38	31.34	31.47	31.40	lb/lb-mole
Stack Wet Molecular Weight	30.74	30.73	30.81	30.76	lb/lb-mole
Volumetric Flow Rate Data	**K23_23-1**	**K23_23-2**	**K23_23-3**	**Average**	**Units**
Average Stack Gas Velocity	48.58	50.06	51.79	50.14	ft/sec
Stack Cross-Sectional Area	78.54	78.54	78.54	78.54	ft^2
Actual Stack Flow Rate	228,939	235,886	244,047	236,290	acfm
Wet Standard Stack Flow Rate	8,068	8,209	8,470	8,249	wkscfh
Dry Standard Stack Flow Rate	7,681,582	7,835,217	8,056,338	7,857,712	dscfh
Percent of Isokinetic Rate	102.7	101.1	101.4	101.7	%
Emission Rate Data	**K23_23-1**	**K23_23-2**	**K23_23-3**	**Average**	**Units**
PCDD/Fs (TEF: NATO) Mass	1.52E-08	1.20E-08	9.45E-09	1.22E-08	mg
PCDD/Fs (TEF: NATO) Concentration	1.04E-13	8.19E-14	6.28E-14	8.30E-14	g/dscf
	1.61E-12	1.26E-12	9.68E-13	1.28E-12	gr/dscf
PCDD/Fs (TEF: NATO) Emission Rate	3.90E-03	3.11E-03	2.30E-03	3.11E-03	ngTEQ/dscm@7%O_2
	1.77E-09	1.42E-09	1.11E-09	1.43E-09	lb/hr
PCDD/Fs (total mass) Mass	1.22E-06	8.98E-07	8.00E-07	9.72E-07	mg
PCDD/Fs (total mass) Concentration	8.39E-12	6.16E-12	5.31E-12	6.62E-12	g/dscf
	2.96E-01	2.17E-01	1.88E-01	2.34E-01	ng/dscm
PCDD/Fs (total mass) Emission Rate	3.14E-01	2.34E-01	1.95E-01	2.48E-01	ng/dscm@7%O_2
	1.42E-07	1.06E-07	9.44E-08	1.14E-07	lb/hr

EXAMPLE CALCULATIONS (Reference Method 1 - Circular Stack)

Diameter of Stack (in.)

$$D(in.) = L_{fw} - L_{inv}$$

D (in.) = 128.00 in. - 8.00 in. = 120.00 in.

Area of Stack (ft²)

$$A_s(ft^2) = \pi \times \left(\frac{D}{2 \times 12} \right)^2$$

$$A_s (ft^2) = 3.14 \times \left(\frac{120.00 \text{ in.}}{2 \times 12 \text{in./ft}} \right)^2 = 78.54 \text{ ft}^2$$

Stack Diameters Downstream

$$B_D(dia.) = \frac{B}{D}$$

$$B_D (dia.) = \frac{175.00 \text{ in.}}{120.00 \text{ in.}} = 1.46 \text{ diameters}$$

Stack Diameters Upstream

$$A_D(dia.) = \frac{A}{D}$$

$$A_D (dia.) = \frac{23.00 \text{ in.}}{120.00 \text{ in.}} = 0.19 \text{ diameters}$$

Note: Lack of significant figures may cause rounding errors between actual calculations and example calculations.

EXAMPLE CALCULATIONS (Reference Method 3a) [Values from Run 1 test]

Carbon Monoxide Concentration (%)

$$\%CO = \frac{ppmCO}{10,000}$$

%CO (%) = $\dfrac{0.00 \quad ppm}{10,000 \ ppm/\%}$ = 0.0000 %

Nitrogen Concentration (%)

$$\%N_2 = 100 - \%CO_2 - \%O_2 - \%CO$$

%N$_2$ (%) = 100 - 19.19 % - 7.79 % - 0.00 / 10,000 % = 73.02 %

Stack Dry Molecular Weight (lb/lb-mole)

$$M_d (lb / lb - mol) = \sum \left(\frac{MW_{comp}}{100} \times \%component \right) \qquad M_d \text{ (lb/lb-mol)} = (\frac{44 \ lb/lb\text{-}mol}{100} \ x \ 19.19 \ \%) +$$

$(\dfrac{32 \ lb/lb\text{-}mol}{100} \ x \ 7.79 \ \%) + (\dfrac{28 \ lb/lb\text{-}mol}{100} \ x \ [\dfrac{0.00}{10,000} + 73.02 \ ]) = \dfrac{31.38 \ lb}{lb\text{-}mol}$

Stack Wet Molecular Weight (lb/lb-mole)

$$M_S (lb / lb - mol) = \left[M_d \times \left(1 - \frac{B_{WS}}{100} \right) \right] + \left[MW_{H_2O} \times \frac{B_{WS}}{100} \right]$$

M$_S$ (lb/lb-mol) = { $\dfrac{31.38 \ lb}{lb\text{-}mol}$ x (1 - $\dfrac{4.79 \ \%}{100}$) } + { $\dfrac{18 \ lb}{lb\text{-}mol}$ x $\dfrac{4.79 \ \%}{100}$ } = $\dfrac{30.74 \ lb}{lb\text{-}mol}$

Average Calculated Fuel Factor (F$_o$)

$$F_{o(avg)} = \frac{\left[20.9 - (\%O_2)_{avg} - \left(0.5 \times (\%CO)_{avg} \right) \right]}{(\%CO_2)_{avg} + (\%CO)_{avg}}$$

F$_{o(avg)}$ = $\dfrac{20.9\% - 7.79 \ \% - (0.5 \ x \ 0.000 \ \%)}{19.19 \ \% \ + \ 0.000 \ \%}$ = 0.683

Average Excess Air (%)

$$\%EA_{avg} (\%) = \frac{100 \times \left[(\%O_2)_{avg} - \left(0.5 \times (\%CO)_{avg} \right) \right]}{\left(0.264 \times (N_2)_{avg} \right) - \left[(\%O_2)_{avg} - \left(0.5 \times (\%CO)_{avg} \right) \right]}$$

(%EA)$_{AVG}$ = $\dfrac{100 \ x \ \{ 7.79 \ \% - (0.5 \ x \ 0.000 \ \% \ ) \}}{(0.264 \ x \ 73.02 \ \%) - \{ 7.79 \ \% - (0.5 \ x \ 0.000 \ \%) \}}$ = 67.75 %

Note: Lack of significant figures may cause rounding errors between actual calculations and example calculations.

EXAMPLE CALCULATIONS (Reference Method 2) [Values from Run 1 test]

Absolute Stack Pressure (in. Hg)

$$P_S(in.Hg) = P_b + \frac{P_{static}}{13.6}$$

P_s (in. Hg) = 29.54 in. Hg + $\dfrac{-1.20 \text{ in. } H_2O}{13.6 \text{ in. } H_2O/in. Hg}$ = 29.45 in. Hg

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Average Stack Gas Velocity (ft/sec)

$$v_s(ft/sec) = K_p \times C_p \times \left(\sqrt{\Delta p}\right)_{avg} \times \sqrt{\frac{(t_s)_{avg} + T_u}{P_s \times M_s}}$$

v_{sl} (ft/sec) =

$\left(\dfrac{85.49 \text{ ft} \quad (lb/lb\text{-}mol)(in. Hg)}{sec \quad (°R)(in. H_2O)}\right)^{1/2}$ x 0.82 x 0.70 in.$H_2O^{1/2}$ x$\sqrt{\dfrac{424.88 + 460 \text{ °R}}{29.45 \text{ in. Hg} \times 30.74 \text{ lb/lb-mol}}}$ = $\dfrac{48.5 \text{ ft}}{sec}$

Average Stack Dry Standard Flow Rate (dscfh)

$$Q_{sd}(dscfh) = \frac{60 \times 60 \times \left(1 - \dfrac{B_{ws}}{100}\right) \times v_s \times A_s \times T_{std} \times P_s}{(t_s + T_u) \times P_{std}}$$

Q_{sd} (dscf/hr) = $\dfrac{3600 \text{ sec}}{hr}$ x $\left(1 - \dfrac{4.79 \text{ \%}}{100}\right)$ x $\dfrac{48.58 \text{ ft}}{sec}$ x 78.54 ft² x

$\dfrac{68.00 + 460 \text{ °R}}{424.88 + 460 \text{ °R}}$ x $\dfrac{29.45 \text{ in. Hg}}{29.92 \text{ in. Hg}}$ = $\dfrac{7,681,581.51 \text{ dscf}}{hr}$

Average Stack Wet Flow Rate (acfm)

$$Q_{aw}(acfm) = 60 \times v_s \times A_s$$

Q_{aw} (acf/min) = $\dfrac{60 \text{ sec}}{min}$ x $\dfrac{48.58 \text{ ft}}{sec}$ x 78.54 ft² = $\dfrac{228,938.61 \text{ acf}}{min}$

Average Stack Wet Standard Flow Rate (ascfh)

$$Q_{sw}(ascfh) = \frac{60 \times Q_{aw} \times T_{std} \times P_s}{(t_s + T_u) \times P_{std}}$$

Q_{sw} (ascf/hr) = $\dfrac{60 \text{ min}}{hr}$ x $\dfrac{228,938.61 \text{ acf}}{min}$ x

$\dfrac{68.00 + 460 \text{ °R}}{424.88 + 460 \text{ °R}}$ x $\dfrac{29.45 \text{ in. Hg}}{29.92 \text{ in. Hg}}$ = $\dfrac{8,068,114.08 \text{ ascf}}{hr}$

Note: Lack of significant figures may cause rounding errors between actual calculations and example calculations.

EXAMPLE CALCULATIONS (Reference Method 4) [Values from Run 1 test]

Water Volume Weighed (scf)

$$V_{wsg\,(std)}\,(scf) = W_t \times K_5$$

$V_{wsg(std)} = $ 155.10 g x 0.04715 ft^3/g = 7.313 scf

Standard Meter Volume (dscf)

$$V_{m(std)}\,(dscf) = \frac{K_1 \times Y \times V_m \times \left(P_b + \dfrac{\Delta H_{avg}}{13.6}\right)}{\left(t_m\right)_{avg} + T_u}$$

$V_{m(std)} = \dfrac{17.65\ ^{\circ}R}{in.\ Hg}$ x 1.02 x 142.46 dcf x (29.54 in. Hg + $\dfrac{2.40\ \ in.\ H_2O}{13.6\ in.\ H_2O\,/\,in.\ Hg}$) = 145.33 dscf

over 62.25 °F + 460 °R

Calculated Moisture Content (%)

$$B_{ws(calc)}\,(\%) = 100 \times \frac{V_{wsg\,(std)}}{V_{wsg\,(std)} + V_{m\,(std)}}$$

$B_{ws(calc)} = 100$ x $\dfrac{7.31\ \ dscf}{7.31\ \ dscf + 145.33\ \ dscf}$ = 4.79 %

Saturated Moisture Content (%)

$$B_{ws(svp)}\,(\%) = 100 \times \frac{10^{\,6.691 - \frac{3144}{t_{s(avg)} + 390.86}}}{P_b + \dfrac{P_{static}}{13.6}} \leq 100$$

$B_{ws(svp)} = 100$ x $\dfrac{10^{\left(6.691 - \frac{3144}{424.88\ ^{\circ}F + 390.86}\right)}}{29.54\ \ in.\ Hg + \dfrac{-1.20\ \ \ in.\ H_2O}{13.6\ in.\ H_2O\,/\,in.\ Hg}}$ $\leq 100 =$ 100.00 %

Note: Lack of significant figures may cause rounding errors between actual calculations and example calculations.