PROTOCOL FOR ETHYLENE OXIDE TESTING

Willowbrook I Facility

Ethylene Oxide Control System

Sterigenics US, LLC	CleanAir Project No. 13990-1
2015 Spring Road, Suite 650	A2LA ISO 17025 Certificate No. 4342.01
Oak Brook, IL 60523	A2LA / STAC Certificate No. 4342.02
Client Reference No. (Pending)	Revision 0, Final Protocol
	October 4, 2019

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Willowbrook I Facility - Willowbrook, IL
Protocol for Ethylene Oxide Testing

CleanAir Project No. 13990-1
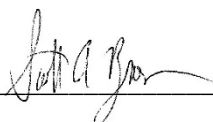Revision 0, Final Protocol
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COMMITMENT TO QUALITY

To the best of our knowledge, the test plan and any state and federal regulations presented in this protocol have met all pre-determined program requirements. Modifications to the test plan or methodology presented in this original protocol will be performed only at the discretion of CleanAir and in accordance with all applicable parties involved. CleanAir operates in conformance with the requirements of ASTM D7036-04 Standard Practice for Competence of Air Emission Testing Bodies.

_____   October 4, 2019
                                                    _____

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PROTOCOL REVISION HISTORY

Version	Revision	Date	Pages	Comments
Draft	D0a	10/03/19	All	Draft version of original document.
Final	0	10/04/19	All	Final version of original document.

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ACRONYMS & ABBREVIATIONS

AAS (atomic absorption spectrometry)
acfm (actual cubic feet per minute)
ACI (activated carbon injection)
ADL (above detection limit)
AIG (ammonia injection grid)
APC (air pollution control)
AQCS (air quality control system(s))
ASME (American Society of Mechanical Engineers)
ASTM (American Society for Testing and Materials)
BDL (below detection limit)
Btu (British thermal units)
CAM (compliance assurance monitoring)
CARB (California Air Resources Board)
CCM (Controlled Condensation Method)
CE (capture efficiency)
°C (degrees Celsius)
CEMS (continuous emissions monitoring system(s))
CFB (circulating fluidized bed)
CFR (Code of Federal Regulations)
cm (centimeter(s))
COMS (continuous opacity monitoring system(s))
CT (combustion turbine)
CTI (Cooling Technology Institute)
CTM (Conditional Test Method)
CVAAS (cold vapor atomic absorption spectroscopy)
CVAFS (cold vapor atomic fluorescence spectrometry)
DI H$_2$O (de-ionized water)
%dv (percent, dry volume)
DLL (detection level limited)
DE (destruction efficiency)
DCI (dry carbon injection)
DGM (dry gas meter)
dscf (dry standard cubic feet)
dscfm (dry standard cubic feet per minute)
dscm (dry standard cubic meter)
ESP (electrostatic precipitator)
FAMS (flue gas adsorbent mercury speciation)
°F (degrees Fahrenheit)
FB (field blank)
FCC (fluidized catalytic cracking)
FCCU (fluidized catalytic cracking unit)
FEGT (furnace exit gas temperatures)
FF (fabric filter)
FGD (flue gas desulfurization)
FIA (flame ionization analyzer)
FID (flame ionization detector)
FPD (flame photometric detection)
FRB (field reagent blank)
FSTM (flue gas sorbent total mercury)
ft (feet or foot)

ft^2 (square feet)
ft^3 (cubic feet)
ft/sec (feet per second)
FTIR (Fourier Transform Infrared Spectroscopy)
FTRB (field train reagent blank)
g (gram(s))
GC (gas chromatography)
GFAAS (graphite furnace atomic absorption spectroscopy)
GFC (gas filter correlation)
gr/dscf (grains per dry standard cubic feet)
> (greater than)/ ≥ (greater than or equal to)
g/s (grams per second)
H$_2$O (water)
HAP(s) (hazardous air pollutant(s))
HI (heat input)
hr (hour(s))
HR GC/MS (high-resolution gas chromatography and mass spectrometry)
HRVOC (highly reactive volatile organic compounds)
HSRG(s) (heat recovery steam generator(s))
HVT (high velocity thermocouple)
IC (ion chromatography)
IC/PCR (ion chromatography with post column reactor)
ICP/MS (inductively coupled argon plasma mass spectroscopy)
ID (induced draft)
in. (inch(es))
in. H$_2$O (inches water)
in. Hg (inches mercury)
IPA (isopropyl alcohol)
ISE (ion-specific electrode)
kg (kilogram(s))
kg/hr (kilogram(s) per hour)
< (less than)/ ≤ (less than or equal to)
L (liter(s))
lb (pound(s))
lb/hr (pound per hour)
lb/MMBtu (pound per million British thermal units)
lb/TBtu (pound per trillion British thermal units)
lb/lb-mole (pound per pound mole)
LR GC/MS (low-resolution gas chromatography and mass spectrometry)
m (meter)
m^3 (cubic meter)
MACT (maximum achievable control technology)
MASS® (Multi-Point Automated Sampling System)
MATS (Mercury and Air Toxics Standards)
MDL (method detection limit)
μg (microgram(s))
min. (minute(s))
mg (milligram(s))

ml (milliliter(s))
MMBtu (million British thermal units)
MW (megawatt(s))
NCASI (National Council for Air and Stream Improvement)
ND (non-detect)
NDIR (non-dispersive infrared)
NDO (natural draft opening)
NESHAP (National Emission Standards for Hazardous Air Pollutants)
ng (nanogram(s))
Nm^3 (Normal cubic meter)
% (percent)
PEMS (predictive emissions monitoring systems)
PFGC (pneumatic focusing gas chromatography)
pg (picogram(s))
PJFF (pulse jet fabric filter)
ppb (parts per billion)
PPE (personal protective equipment)
ppm (parts per million)
ppmdv (parts per million, dry volume)
ppmwv (parts per million, wet volume)
PSD (particle size distribution)
psi (pound(s) per square inch)
PTE (permanent total enclosure)
PTFE (polytetrafluoroethylene)
QA/QC (quality assurance/quality control)
QI (qualified individual)
QSTI (qualified source testing individual)
QSTO (qualified source testing observer)
RA (relative accuracy)
RATA (relative accuracy test audit)
RB (reagent blank)
RE (removal or reduction efficiency)
RM (reference method)
scf (standard cubic feet)
scfm (standard cubic feet per minute)
SCR (selective catalytic reduction)
SDA (spray dryer absorber)
SNCR (selective non-catalytic reduction)
STD (standard)
STMS (sorbent trap monitoring system)
TBtu (trillion British thermal units)
TEOM (Tapered Element Oscillating Microbalance)
TEQ (toxic equivalency quotient)
ton/hr (ton per hour)
ton/yr (ton per year)
TSS (third stage separator)
USEPA or EPA (United States Environmental Protection Agency)
UVA (ultraviolet absorption)
WFGD (wet flue gas desulfurization)
%wv (percent, wet volume)

1.   PROJECT OVERVIEW

Test Program Summary

Sterigenics US, LLC contracted CleanAir Engineering (CleanAir) to complete testing on the ethylene oxide (EtO) control system at the Willowbrook I facility, located in Willowbrook, Illinois. The purpose of this test program is to perform testing to demonstrate compliance with:

- The Illinois Clean Air Act Permit Program (CAAPP) Construction Permit Application No. 19060030 (Facility I.D. No. 043110AAC);

- The SB 1852/Public Act 101-0022, also Environmental Protection Act 415 ILCS 5/9.16;

- A Consent Order signed on September 6, 2019.

A summary of the permit limits is shown below.

Table 1-1:
Summary of Permit / Regulatory Limits

Source Constituent	Sampling Method	Permit Limit[1]
EtO Control System		
EtO Emission Output (ppm)	EPA 320	0.2
EtO Removal Efficiency (%)[2]	EPA 320, EPA 1-4	99.9

[1] Permit standards applicable to IL CAAPP Permit I.D. No. 043110AAC.

[2] Removal efficiency mass emission-based calculated from pounds per hour (lb/hr) measurements.

Test Program Details

PARAMETERS

The test program will include the following measurements:

- EtO in parts per million (ppm)
- EtO in pounds per hour (lb/hr)
- EtO removal efficiency (RE%), measure as the total EtO output mass emission, in lb/hr as a percentage (%) of total EtO input mass emission, in lb/hr
- flue gas composition (e.g., O_2, CO_2, H_2O) in volume-based percentage (%v)
- flue gas temperature in degrees Fahrenheit (˚F)
- flue gas flow rate in dry standard cubic feet per minute (dscfm)

![CleanAir]

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The above measurements will be collected from the following sample locations:

- DEOXX[TM] Acid Scrubber Inlet Duct (DEOXX Inlet); to determine input emission from outlet gas stream created by the evacuation of the sterilization chambers;

- Advanced Air Technologies (AAT) Acid Scrubber / Dry Bed Adsorption Device Inlet (AAT Inlet)[1]; to determine input emission from outlet gas streams exhausting from backvents on the sterilization chambers and the aeration rooms;

- Permanent total enclosure (PTE) Dry Scrubber Adsorption (DBA) Inlet (DBA Inlet); to determine input emission from outlet gas stream collected from the facility fugitive emission capture system;

- EtO Control System Stack (Stack); to determine output emission from outlet gas stream of the control system.

[1] The AAT Acid Scrubber is followed by a dry bed adsorption device.

SCHEDULE

The test program will be conducted after construction is complete and operation begins. It is necessary for Sterigenics to begin operation prior to testing to represent maximum operating conditions for the test. The proposed timetable for the test is outlined in Table 1-2.

Table 1-2:
Test Schedule

RUN	ACTIVITY	LOCATION	EPA TEST METHODS	REPLICATES	SAMPLE TIME
Pre	Mobilization / Set-up	DEOXX Inlet, AAT Inlet, DBA Inlet, Stack	1	1	Varies
1	EtO Testing	DEOXX Inlet, AAT Inlet, DBA Inlet, Stack	320[1]	1	TBD[2]
	Moisture, Molecular Weight Testing[3]	DEOXX Inlet, AAT Inlet, DBA Inlet, Stack	4, 3A	1	TBD[2]
	Continuous Flow Testing[4]	DEOXX Inlet	2	1	TBD[2]
	Flow Traverse Testing	AAT Inlet, DBA Inlet, Stack	2	TBD[5]	Varies
2	EtO Testing	DEOXX Inlet, AAT Inlet, DBA Inlet, Stack	320[1]	1	TBD[2]
	Moisture, Molecular Weight Testing[3]	DEOXX Inlet, AAT Inlet, DBA Inlet, Stack	4, 3A	1	TBD[2]
	Continuous Flow Testing[4]	DEOXX Inlet	2	1	TBD[2]
	Flow Traverse Testing	AAT Inlet, DBA Inlet, Stack	2	TBD[5]	Varies
3	EtO Testing	DEOXX Inlet, AAT Inlet, DBA Inlet, Stack	320[1]	1	TBD[2]
	Moisture, Molecular Weight Testing[3]	DEOXX Inlet, AAT Inlet, DBA Inlet, Stack	4, 3A	1	TBD[2]
	Continuous Flow Testing[4]	DEOXX Inlet	2	1	TBD[2]
	Flow Traverse Testing	AAT Inlet, DBA Inlet, Stack	2	TBD[5]	Varies
Post	Demobilization				

[1] Stack FTIR Spectrometer will utilize MAX-Starboost technology.

[2] Run duration defined by the timespan that begins with the initial evacuation of EtO-laden air from a chamber and ends 60 minutes after the sterilized material from that chamber is transferred to an aeration room. Duration of this timespan varies based on product and process conditions.

[3] Moisture, O_2, and CO_2 will be measured concurrently with EtO utilizing the same sampling system.

[4] Velocity and temperature will be measured continuously on a minute-by-minute basis utilizing a pressure/temperature transducer.

[5] A velocity and temperature traverse will be conducted once per clock hour for the duration of the test run.

DISCUSSION

Determination of Ethylene Oxide Emissions

EtO concentrations will be determined in accordance with procedures outlined in EPA Method 320. Three (3) Method 320 runs, with variable run durations, will be conducted. EtO concentrations will be sampled concurrently at the DEOXX Inlet, AAT Inlet, DBA Inlet, and Stack sample locations.

EtO concentrations at the inlet locations will be measured by a typical MKS MultiGas 2030 Fourier transform infrared (FTIR) spectrometer. EtO at the Stack location will be measured by an MKS MultiGas 2030 FTIR with MAX-StarBoost enhancement technology. The MAX-StarBoost algorithm narrows the spectral bands utilized to quantify EtO, creating increased sensitivity, linearity, and dynamic range. The technology specializes in readily quantifying parts per billion volume-based (ppbdv) concentration levels in source testing applications. The MAX-StarBoost technology is equipped with MAX-Analytics and MAX-Acquisition software. Refer to Appendix A of this protocol for further details and specifications.

EtO concentrations will be measured on a wet volumetric basis. EtO concentrations measured from each location, in conjunction with effluent gas volumetric flow, will be utilized to convert wet volumetric concentrations to mass emission rates in lb/hr.

Determination of Volumetric Flow

EPA Methods 1, 2, 3A, and 4 will be conducted, in conjunction with EPA Method 320, to determine volumetric flow rate that will be utilized to convert the concentrations of EtO to mass emission rates in lb/hr.

Velocity and temperature traverse points at each location will be determined from analyses performed on-site, in accordance with procedures outlined in EPA Method 1. A verification of absence of cyclonic flow check per EPA Method 1 will be conducted at each location prior to the performance testing.

Velocity and temperature measurements, in conjunction with effluent gas molecular weight, will be utilized to determine effluent gas velocity. EPA Method 2 measurements will be collected concurrently with EPA Methods 3A and 320 measurements. Velocity and temperature traverses will be conducted every clock hour for the duration of a test run at the AAT Inlet, DBA Inlet, and Stack locations in accordance with procedures outlined in EPA Method 2. Velocity and temperature will be continuously monitored at the DEOXX Inlet at a single point during the entirety of a test run. The velocity and temperature at the DEOXX Inlet will be measured at the average velocity point determined by a pre-run traverse.

Concentrations of oxygen (O_2) and carbon dioxide (CO_2) will be determined in accordance with procedures outlined in EPA Method 3A. O_2 and CO_2 concentrations will be measured on a wet volume-based percentage. O_2 and CO_2 concentrations will be utilized to determine molecular weight of the effluent gas and will be determined concurrently with EPA Method 320 sampling utilizing the same sample train. CO_2 concentration will be measured by an FTIR spectrometer. O_2 concentration will be measured by a wet Ametek analyzer, or similar in series, with and subsequent to the FTIR.

Moisture content (%H_2O) will be determined in accordance with EPA Method 4, Section 16.3, with reference to EPA Method 320. Moisture content will be determined by the FTIR. Moisture content will be utilized to convert wet-based concentrations to dry-based concentrations and to determine molecular weight of the effluent gas.

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Determination of Final Results

EtO results will be reported in units of lb/hr. For the DEOXX Inlet location, the final result will be the arithmetic average based on point-by-point lb/hr emissions. For the AAT Inlet, DBA Inlet, and Stack locations, the final results will be presented as a composite emission rate based on an arithmetic average EtO concentration and arithmetic average of volumetric flows from each EPA Method 2 traverse. Mass emission rates in units of lb/hr will be determined from EtO concentrations and volumetric flow rates. Removal efficiency (RE%) will be determined from the lb/hr difference in total input emission (sum of mass emission measured at the DEOXX Inlet, AAT Inlet, and DBA Inlet) and output emission as a percent of the total input emission. Sample calculations for concentrations, volumetric flow rates, and emission rates are presented in Appendix B of this protocol.

Test Plan Execution and Results

CleanAir will execute the test plan and present results as discussed above. The test report will mimic the format and structure of this protocol. The results section will include tables consisting of start/stop times, flue gas conditions, emission concentrations, and emission rates similar to the tables presented in Section 2 of this protocol. CleanAir will also include appendices presenting all sample parameters, field data, laboratory analyses, FTIR raw data, and all relevant process data.

End of Section

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2. RESULTS

The example tables summarize how test program data will be presented in the test report.

Table 2-1:
EtO Control System – EtO Emission and Removal Efficiency Results

Run No.		1	2	3	Average
Date (2019)		xxx xx	xxx xx	xxx xx	
Start Time (approx.)		xx:xx	xx:xx	xx:xx	
Stop Time (approx.)		xx:xx	xx:xx	xx:xx	
EtO Control System Emission Input					
DEOXX Inlet					
C_{sw}	Concentration (ppbw)	xx.x	xx.x	xx.x	**xx.x**
C_{sd}	Concentration (ppbdv)	xx.x	xx.x	xx.x	**xx.x**
$E_{lb/hr}$	Emission Rate (lb/hr)	x.xx	x.xx	x.xx	**x.xx**
AAT Inlet					
C_{sw}	Concentration (ppbw)	xx.x	xx.x	xx.x	**xx.x**
C_{sd}	Concentration (ppbdv)	xx.x	xx.x	xx.x	**xx.x**
$E_{lb/hr}$	Emission Rate (lb/hr)	x.xx	x.xx	x.xx	**x.xx**
DBA Inlet					
C_{sw}	Concentration (ppbw)	xx.x	xx.x	xx.x	**xx.x**
C_{sd}	Concentration (ppbdv)	xx.x	xx.x	xx.x	**xx.x**
$E_{lb/hr}$	Emission Rate (lb/hr)	x.xx	x.xx	x.xx	**x.xx**
Total Emission Input					
$E_{lb/hr}$	Emission Rate (lb/hr)	x.xx	x.xx	x.xx	**x.xx**
EtO Control System Emission Input					
Stack					
C_{sw}	Concentration (ppbw)	xx.x	xx.x	xx.x	**xx.x**
C_{sd}	Concentration (ppbdv)	xx.x	xx.x	xx.x	**xx.x**
$E_{lb/hr}$	Emission Rate (lb/hr)	x.xx	x.xx	x.xx	**x.xx**
EtO Control System					
RE%	EtO Removal Efficiency (%)	xx.x	xx.x	xx.x	**xx.x**

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Table 2-2:
DEOXX Inlet – EtO Emission Results

Run No.		1	2	3	Average
Date (2019)		xxx xx	xxx xx	xxx xx	
Start Time (approx.)		xx:xx	xx:xx	xx:xx	
Stop Time (approx.)		xx:xx	xx:xx	xx:xx	
DEOXX Inlet					
Gas Conditions					
O_2	Oxygen (dry volume %)	x.x	x.x	x.x	**x.x**
CO_2	Carbon Dioxide (dry volume %)	x.x	x.x	x.x	**x.x**
T_S	Sample Temperature (°F)	xx.x	xx.x	xx.x	**xx.x**
B_w	Actual water vapor in gas (% by volume)	x.xx	x.xx	x.xx	**x.xx**
Gas Flow Rate					
Q_a	Volumetric flow rate, actual (acfm)	xx,xxx	xx,xxx	xx,xxx	**xx,xxx**
Q_s	Volumetric flow rate, standard (scfm)	xx,xxx	xx,xxx	xx,xxx	**xx,xxx**
Q_{std}	Volumetric flow rate, dry standard (dscfm)	xx,xxx	xx,xxx	xx,xxx	**xx,xxx**
EtO Results					
C_{sw}	Concentration (ppbwv)	xx.x	xx.x	xx.x	**xx.x**
C_{sd}	Concentration (ppbdv)	xx.x	xx.x	xx.x	**xx.x**
$E_{lb/hr}$	Emission Rate (lb/hr)	x.xx	x.xx	x.xx	**x.xx**

Table 2-3:
AAT Inlet – EtO Emission Results

Run No.		1	2	3	Average
Date (2019)		xxx xx	xxx xx	xxx xx	
Start Time (approx.)		xx:xx	xx:xx	xx:xx	
Stop Time (approx.)		xx:xx	xx:xx	xx:xx	
AAT Inlet					
Gas Conditions					
O_2	Oxygen (dry volume %)	x.x	x.x	x.x	**x.x**
CO_2	Carbon Dioxide (dry volume %)	x.x	x.x	x.x	**x.x**
T_S	Sample Temperature (°F)	xx.x	xx.x	xx.x	**xx.x**
B_w	Actual water vapor in gas (% by volume)	x.xx	x.xx	x.xx	**x.xx**
Gas Flow Rate					
Q_a	Volumetric flow rate, actual (acfm)	xx,xxx	xx,xxx	xx,xxx	**xx,xxx**
Q_s	Volumetric flow rate, standard (scfm)	xx,xxx	xx,xxx	xx,xxx	**xx,xxx**
Q_{std}	Volumetric flow rate, dry standard (dscfm)	xx,xxx	xx,xxx	xx,xxx	**xx,xxx**
EtO Results					
C_{sw}	Concentration (ppbwv)	xx.x	xx.x	xx.x	**xx.x**
C_{sd}	Concentration (ppbdv)	xx.x	xx.x	xx.x	**xx.x**
$E_{lb/hr}$	Emission Rate (lb/hr)	x.xx	x.xx	x.xx	**x.xx**

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Table 2-4:
DBA Inlet – EtO Emission Results

Run No.		1	2	3	Average
Date (2019)		xxx xx	xxx xx	xxx xx	
Start Time (approx.)		xx:xx	xx:xx	xx:xx	
Stop Time (approx.)		xx:xx	xx:xx	xx:xx	
DBA Inlet					
Gas Conditions					
O_2	Oxygen (dry volume %)	x.x	x.x	x.x	**x.x**
CO_2	Carbon Dioxide (dry volume %)	x.x	x.x	x.x	**x.x**
T_S	Sample Temperature (°F)	xx.x	xx.x	xx.x	**xx.x**
B_w	Actual water vapor in gas (% by volume)	x.xx	x.xx	x.xx	**x.xx**
Gas Flow Rate					
Q_a	Volumetric flow rate, actual (acfm)	xx,xxx	xx,xxx	xx,xxx	**xx,xxx**
Q_s	Volumetric flow rate, standard (scfm)	xx,xxx	xx,xxx	xx,xxx	**xx,xxx**
Q_{std}	Volumetric flow rate, dry standard (dscfm)	xx,xxx	xx,xxx	xx,xxx	**xx,xxx**
EtO Results					
C_{sw}	Concentration (ppbwv)	xx.x	xx.x	xx.x	**xx.x**
C_{sd}	Concentration (ppbdv)	xx.x	xx.x	xx.x	**xx.x**
$E_{lb/hr}$	Emission Rate (lb/hr)	x.xx	x.xx	x.xx	**x.xx**

Table 2-5:
Stack – EtO Emission Results

Run No.		1	2	3	Average
Date (2019)		xxx xx	xxx xx	xxx xx	
Start Time (approx.)		xx:xx	xx:xx	xx:xx	
Stop Time (approx.)		xx:xx	xx:xx	xx:xx	
Stack					
Gas Conditions					
O_2	Oxygen (dry volume %)	x.x	x.x	x.x	**x.x**
CO_2	Carbon Dioxide (dry volume %)	x.x	x.x	x.x	**x.x**
T_S	Sample Temperature (°F)	xx.x	xx.x	xx.x	**xx.x**
B_w	Actual water vapor in gas (% by volume)	x.xx	x.xx	x.xx	**x.xx**
Gas Flow Rate					
Q_a	Volumetric flow rate, actual (acfm)	xx,xxx	xx,xxx	xx,xxx	**xx,xxx**
Q_s	Volumetric flow rate, standard (scfm)	xx,xxx	xx,xxx	xx,xxx	**xx,xxx**
Q_{std}	Volumetric flow rate, dry standard (dscfm)	xx,xxx	xx,xxx	xx,xxx	**xx,xxx**
EtO Results					
C_{sw}	Concentration (ppbwv)	xx.x	xx.x	xx.x	**xx.x**
C_{sd}	Concentration (ppbdv)	xx.x	xx.x	xx.x	**xx.x**
$E_{lb/hr}$	Emission Rate (lb/hr)	x.xx	x.xx	x.xx	**x.xx**

End of Section

3.   DESCRIPTION OF INSTALLATION

Process Description and Data Collection

DESCRIPTION

Sterigenics US LLC operates a commercial contract sterilization facility in Willowbrook, Illinois. Sterigenics' Willowbrook I facility utilizes EtO to sterilize its customers' product. It also has the ability to use propylene oxide to treat spices and nutmeats.

When EtO is used for medical device sterilization, the medical devices must have a specifically defined sterilization process, which is validated for a specific sterilization chamber or chambers. The Willowbrook I facility uses 14 sterilization chambers ranging in size from 1 pallet to up to 13 pallets. While all 14 sterilization chambers are similar in design, each chamber may only process products approved for that chamber and cannot process other products that have not been validated and approved by the appropriate regulatory agency for that specific chamber.

The sterilization process begins with evacuating the air from the chamber and introducing nitrogen (N_2). While under negative pressure inside the chamber, EtO is introduced into the sterilization chamber to sterilize the product. Once EtO is introduced, the dwell stage can last from 30 minutes to up to several hours, according to the validated cycle for the product. Once complete, the sterilization chamber vacuum pumps remove most of the EtO from the chamber by exhausting and purging with N_2 multiple times. Vacuum pump emissions are routed to the DEOXX^{TM} wet acid scrubber, which will be routed to the existing AAT wet acid scrubber with dry bed reactor (WB1-Scrubber #2), then to additional polishing beds, and then to a common stack.
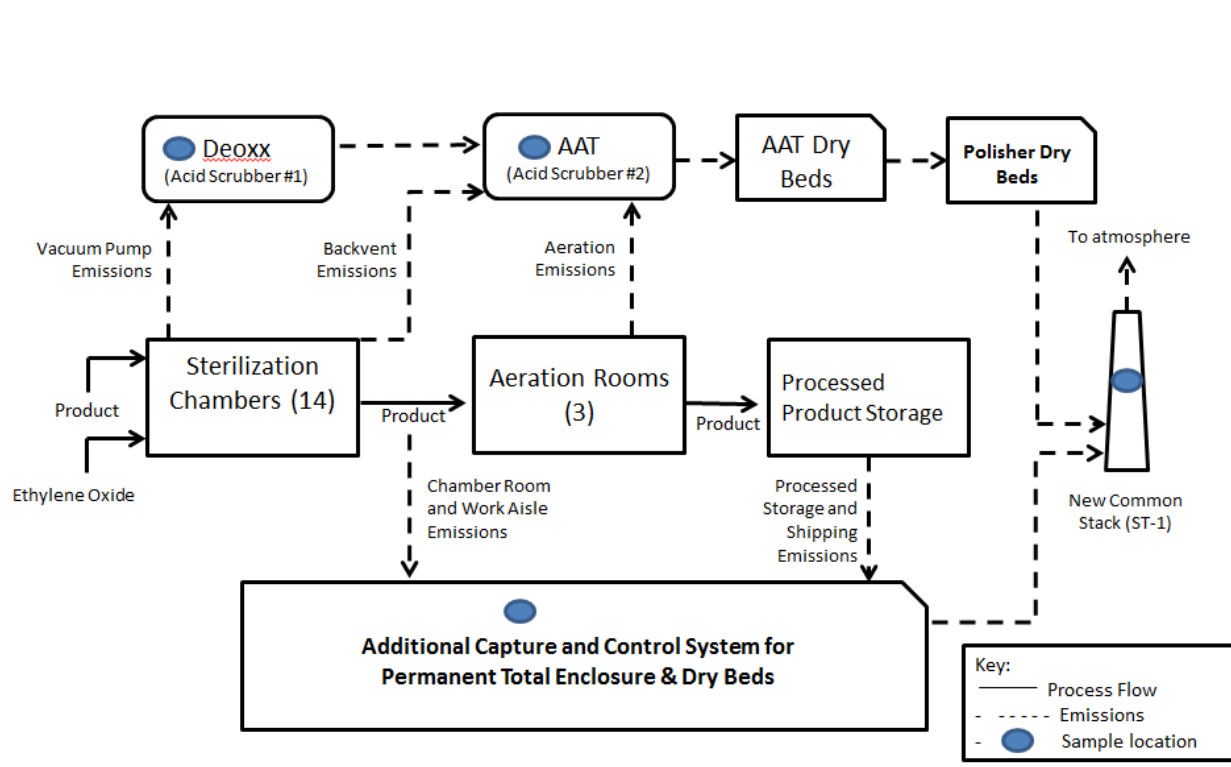
Once the sterilization chamber process is complete and the chamber door is partially opened, the backvent fan activates to extract residual amounts of EtO from the chamber. This fan remains on while the chamber door is open. After 15 minutes, the pallets of product are removed from the sterilization chamber and placed into aeration rooms to further off-gas residual EtO. Both the backvents and aeration rooms are ducted to the WB1-Scrubber #2 and treated with 16 dry bed reactors, which will be additional polishing beds, and then to a common stack.

In addition, a PTE system will be installed to capture air internally from chamber rooms, dispensing stations, work aisles, processed product storage, and shipping areas. This captured air will be ducted to a new dry bed control system consisting of 18 dry beds and then to a common stack.

Sterigenics will conduct each test beginning with the initial evacuation of EtO from one sterilization test chamber and ending 60 minutes after the sterilized product is moved from this chamber into aeration. This sterilization test chamber will be identified by chamber number in the process data collection. Operations will include running additional product through the sterilization process in other chambers to create conditions representative of maximum emissions.

The testing reported in this document will be performed at the DEOXX Inlet, AAT Inlet, DBA Inlet, and Stack sample locations. A schematic of the process, indicating proposed sampling locations, is shown in Figure 3-1 on the following page.

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Willowbrook I Facility - Willowbrook, IL
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Figure 3-1:
Process Schematic

DATA COLLECTION

Sterigenics will provide information initially and during each test run to identify the test sterilization chamber. Process data will be recorded and provided to CleanAir for inclusion in the test report. Summarized data, including raw supporting data and electronically-recorded chamber-phase data, will be presented in an appendix of the test report.

Sterilization Process Data

For each test run, Sterigenics will provide the following process data:

- Sterilization test chamber number used
- Initial evacuation time
- End cycle time
- Backvent opening time
- Ending chamber EtO concentration
- Initial transfer time
- Ending transfer time

Emission Control Data

The emission control operating data collected during the test and the manufacturer design specifications will be evaluated prior to setting new operating parameters. At the start and end of each test run, Sterigenics will provide the following emission control data:

- For the DEOXX™ wet acid scrubber:
  - scrubber flow
  - pH
  - temperature

- For the AAT wet acid scrubber with dry bed reactor (WB1-Scrubber #2):
  - scrubber flow
  - pH
  - temperature
  - dry bed temperature differential

- For the polishing beds:
  - temperature differential

- For the PTE dry beds:
  - temperature differential

Test Locations

The sample point placement will be determined by EPA Methods 1 and 320 specifications. Sample ports to be installed will meet EPA Method 1 requirements. Test location layouts will be presented in the final test report.

An EPA Method 1 sample location analysis will be conducted at each sample location on-site prior to testing. An absence of cyclonic flow will be verified per EPA Method 1 specifications at each location prior to testing. At the AAT Inlet, DBA Inlet, and Stack, velocity and temperature will be measured at points determined by the EPA Method 1 analyses. At the DEOXX Inlet, a velocity and temperature traverse will be conducted prior to testing. Velocity and temperature during the test run at the DEOXX Inlet will be measured at the average velocity traverse point determined by the traverse conducted prior to testing.

Stratification checks at each sample location will be conducted prior to testing per procedures obtained from EPA Method 7E. The point closest to the average EtO will be chosen as the EtO sample point.

The EPA Method 1 analysis, absence of cyclonic flow verification, and stratification check data will be presented in Appendix D of the test report. Table 3-1, on the following page, presents the sampling information for the test location.

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Table 3-1:
Sampling Information

Source Constituent	Method (USEPA)	Run No.	Ports	Points per Port	Hours per Point	Total Hours
DEOXX Inlet						
EtO, O_2, CO_2, H_2O	Strat. Check[1]	3	1	3	2x RT[2]	6x RT
EtO, O_2, CO_2, H_2O	320, 4, 3A	3	1	1	TBD	TBD
Velocity & Temperature (continuous)[3]	2	3	1	1	TBD	TBD
AAT Inlet						
EtO, O_2, CO_2, H_2O	Strat. Check[1]	3	1	3	2x RT[2]	6x RT
EtO, O_2, CO_2, H_2O	320, 4, 3A	3	1	1	TBD	TBD
Velocity & Temperature (traverse)	2	TBD[4]	2	TBD	Varies	Varies
DBA Inlet						
EtO, O_2, CO_2, H_2O	Strat. Check[1]	3	1	3	2x RT[2]	6x RT
EtO, O_2, CO_2, H_2O	320, 4, 3A	3	1	1	TBD	TBD
Velocity & Temperature (traverse)	2	TBD[4]	2	TBD	Varies	Varies
Stack						
EtO, O_2, CO_2, H_2O	Strat. Check[1]	3	1	3	2x RT[2]	6x RT
EtO, O_2, CO_2, H_2O	320, 4, 3A	3	1	1	TBD	TBD
Velocity & Temperature (traverse)	2	TBD[4]	2	TBD	Varies	Varies

[1] Strat. Check = stratification check, conducted per procedures outlined in EPA Method 7E.

[2] RT = sample system response time.

[3] Measurement point determined from EPA Method 2 traverse conducted prior to test run.

[4] Velocity & temperature traverse conducted once per clock hour for the duration of the test run.

End of Section

4. METHODOLOGY

Procedures and Regulations

The test program sampling measurements will follow procedures and regulations outlined by the United States Environmental Protection Agency (USEPA) and the Illinois Environmental Protection Agency (IEPA). These methods appear in detail in Title 40 of the CFR and at https://www.epa.gov/emc. Appendix A includes diagrams of the sampling apparatus, as well as specifications for sampling, recovery and analytical procedures.

CleanAir will follow specific QA/QC procedures outlined in the individual methods and in USEPA "Quality Assurance Handbook for Air Pollution Measurement Systems: Volume III Stationary Source-Specific Methods," EPA/600/R-94/038C. Additional QA/QC measures are outlined in CleanAir's internal Quality Manual.

TITLE 40 CFR PART 60, APPENDIX A

Method 1   "Sample and Velocity Traverses for Stationary Sources"

Method 2   "Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)"

Method 3   "Gas Analysis for the Determination of Dry Molecular Weight"

Method 3A   "Determination of Oxygen and Carbon Dioxide Concentrations in Emissions from Stationary Sources (Instrumental Analyzer Procedure)"

Method 4   "Determination of Moisture Content in Stack Gases"

TITLE 40 CFR PART 63, APPENDIX A

Method 320   "Measurement of Vapor Phase Organic and Inorganic Emissions by Extractive Fourier Transform Infrared (FTIR) Spectroscopy"

Methodology Discussion

EPA METHOD 320 – EtO AND H_2O TESTING

EtO emissions will be determined using an FTIR per EPA Method 320. EtO testing will adhere to all specifications and procedures outlined in EPA Method 320.

A calibration transfer standard (CTS) will be used to demonstrate suitable agreement between sample spectra and reference spectra. During the test program, a dynamic spike will be conducted for each sampling system. A spike/tracer gas at a constant flow rate at or below 10% of the total sample flow, when possible, will be introduced into the sampled exhaust gas stream prior to the external filter. The system will "pass" the QA spikes if the average spiked concentration is within 0.7 to 1.3 times the expected concentration. All QA spike checks will be included in the QA/QC section of the final test report. Following each test run, another CTS spectrum will be recorded. The pre- and post-test CTS spectra will then be compared. The peak absorbance in pre- and post-test CTS will be compared to the required ±5% of the mean value for the run to be valid.

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In accordance with the method, for each sampling system, the flue gas will be continuously extracted through a heated stainless-steel probe, filter, and Teflon sample lines, and then directly interfaced with the instrumentation. The sampling system will be assembled and leak-checked (<200 ml/min) and will be allowed to reach and stabilize at the operating temperature of approximately 150°C to 175°C. Sample gas will be extracted at a constant rate and delivered hot and wet to the FTIR.

On-site minimum detection limit (MDL) studies will be performed for each sampling system using procedures outlined in ASTM D 6348 A2.3. The MDL is calculated as three times the standard deviation of the concentrations from 10 representative spectra taken during the MDL study. Results calculated from sample concentrations less than the calculated MDL will be reported as 'less than' the MDL.

Minute data points for EtO (wet basis) will be collected over the duration of the test run. Each sample spectrum will be documented with the sampling conditions, the sampling time (period when the cell is being filled), the time the spectrum was recorded, the instrumental conditions (path length, temperature, pressure, resolution, and signal integration time), and a spectral filename.

EPA METHODS 1 AND 2 – GAS VELOCITY TESTING

EPA Methods 1 and 2 of 40 CFR 60, Appendix A, will be used to measure the average flow rate. These methods will determine the velocity of the effluent gas stream. The effluent gas velocity will be measured by a calibrated Type-S pitot probe and pressure transducer meeting all specifications of EPA Method 2. The temperature will be measured by a Type K thermocouple attached to the pitot probe. A determination of sampling points and verification of absence of cyclonic flow will be performed for each sample location prior to testing.

EPA METHOD 3A – O_2/CO_2 TESTING

CO_2 concentrations will be measured using the FTIR. O_2 concentrations will be measured using a wet Ametek O_2 analyzer, or similar in series, subsequent to the FTIR. O_2/CO_2 testing will adhere to all specifications and QA/QC procedures outlined in EPA Method 3A.

Calibration error checks will be performed daily by introducing zero N_2, high range and mid-range calibration gases to the inlet of the FTIR during calibration error checks. Bias checks will be performed before and after each test run by introducing calibration gas to the inlet of the sampling system's heated filter. Data points for O_2/CO_2 (wet basis) will be collected over the duration of the test run. Per EPA Method 3A, the average results for the run will be drift-corrected.

EPA METHOD 4 – EtO AND H_2O TESTING

Moisture content will be determined using an FTIR per EPA Method 4, which references EPA Method 320. Per Section 16.3 of EPA Method 4, "Method 320 is an acceptable alternative to Method 4 for determining moisture." Moisture testing will adhere to all specifications and procedures outlined in EPA Method 320.

Refer to the section "EPA Method 320 – EtO Testing" above for specific methodology.

End of Section

5.   APPENDIX

Appendix A: Test Method Specifications

Appendix B: Sample Calculations

Appendix C: Field Data Sheets

Appendix D: CleanAir Resumes and Certifications

APPENDIX A: TEST METHOD SPECIFICATIONS

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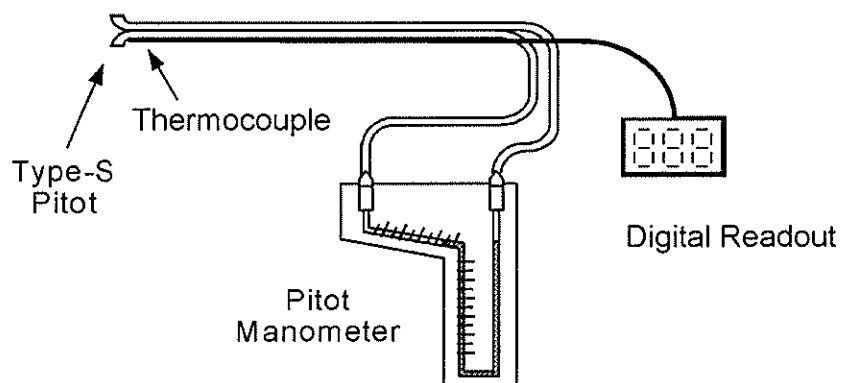
Specification Sheet for   EPA Method 2

Source Location Name(s)   AAT Inlet, DBA Inlet, Stack
Pollutant(s) to be Determined   None
Other Parameters to be Determined from Train Flow Rate

	Standard Method Specification	Actual Specification Used
Pollutant Sampling Information		
Duration of Run	N/A	Varied
No. of Sample Traverse Points	N/A	TBD
Sample Time per Point	N/A	Varied
Sampling Rate	N/A	N/A
Sampling Probe		
Nozzle Material	N/A	N/A
Nozzle Design	N/A	N/A
Probe Liner Material	N/A	N/A
Effective Probe Length	Sufficient to Traverse Points	TBD
Probe Temperature Set-Point	N/A	N/A
Velocity Measuring Equipment		
Pitot Tube Design	Type S	Type S
Pitot Tube Coefficient	N/A	TBD
Pitot Tube Calibration by	Geometric or Wind Tunnel	Wind-Tunnel
Pitot Tube Attachment	Attached to Probe	Attached to Probe
Metering System Console		
Meter Type	Dry Gas Meter	N/A
Meter Accuracy	N/A	N/A
Meter Resolution	N/A	N/A
Meter Size	N/A	N/A
Meter Calibrated Against	N/A	N/A
Pump Type	N/A	N/A
Temperature Measurements	N/A	Type K Thermocouple/Pyrometer
Temperature Resolution	5.4˚F	1.0˚F
ΔP Differential Pressure Gauge	Inclined Manometer or Equivalent	Inclined Manometer/Digital Manometer
ΔH Differential Pressure Gauge	Inclined Manometer or Equivalent	N/A
Barometer	Mercury or Aneroid	Digital Barometer calibrated w/Mercury Aneroid
Filter Description		
Filter Location	N/A	N/A
Filter Holder Material	N/A	N/A
Filter Support Material	N/A	N/A
Cyclone Material	N/A	N/A
Filter Heater Set-Point	N/A	N/A
Filter Material	N/A	N/A
Other Components		
Description	N/A	N/A
Location	N/A	N/A
Operating Temperature	N/A	N/A

EPA Method 2
Sampling Train Configuration

Type-S
Pitot

Thermocouple

Digital Readout

Pitot
Manometer
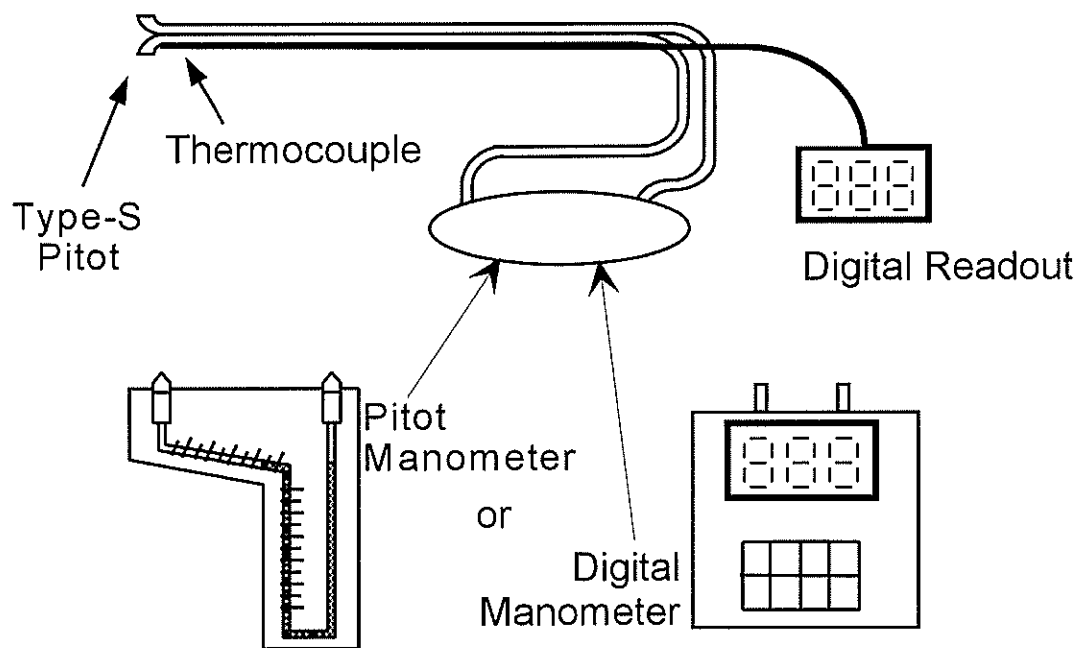
Specification Sheet for EPA Method 2

Source Location Name(s)   DEOXX Inlet
Pollutant(s) to be Determined   None
Other Parameters to be Determined from Train   Flow Rate

	Standard Method Specification	Actual Specification Used
Pollutant Sampling Information		
Duration of Run	N/A	TBD
No. of Sample Traverse Points	N/A	1
Sample Time per Point	N/A	TBD
Sampling Rate	N/A	N/A
Sampling Probe		
Nozzle Material	N/A	N/A
Nozzle Design	N/A	N/A
Probe Liner Material	N/A	N/A
Effective Probe Length	Sufficient to Traverse Points	TBD
Probe Temperature Set-Point	N/A	N/A
Velocity Measuring Equipment		
Pitot Tube Design	Type S	Type S
Pitot Tube Coefficient	N/A	TBD
Pitot Tube Calibration by	Geometric or Wind Tunnel	Wind-Tunnel
Pitot Tube Attachment	Attached to Probe	Attached to Probe
Metering System Console		
Meter Type	Dry Gas Meter	N/A
Meter Accuracy	N/A	N/A
Meter Resolution	N/A	N/A
Meter Size	N/A	N/A
Meter Calibrated Against	N/A	N/A
Pump Type	N/A	N/A
Temperature Measurements	N/A	Type K Thermocouple/Pyrometer/Transducer
Temperature Resolution	5.4°F	1.0°F
ΔP Differential Pressure Gauge	Inclined Manometer or Equivalent	Inclined Manometer/Digital Manometer
ΔH Differential Pressure Gauge	Inclined Manometer or Equivalent	N/A
Barometer	Mercury or Aneroid	Digital Barometer calibrated w/Mercury Aneroid
Filter Description		
Filter Location	N/A	N/A
Filter Holder Material	N/A	N/A
Filter Support Material	N/A	N/A
Cyclone Material	N/A	N/A
Filter Heater Set-Point	N/A	N/A
Filter Material	N/A	N/A
Other Components		
Description	N/A	N/A
Location	N/A	N/A
Operating Temperature	N/A	N/A

**EPA Method 2
Sampling Train Configuration**

Thermocouple

Type-S
Pitot

Digital Readout

Pitot
Manometer

or

Digital
Manometer

Specification Sheet for EPA Method 320 & 3A

Source Location Name(s)   DEOXX Inlet, AAT Inlet, DBA Inlet, Stack
Pollutant(s) to be Determined   Ethylene Oxide (EtO)
Also Measures   Moisture, O_2, and CO_2

	Standard Method Specification	Actual Specification Used
Pollutant Sampling Information		
Duration of Run	N/A	TBD
No. of Sample Traverse Points	N/A	1
Sample Time per Point	N/A	TBD
Sampling Rate	Constant Rate	Constant Rate
Sampling Probe		
Nozzle Material	N/A	None
Nozzle Design	N/A	N/A
Probe Liner Material	Stainless Steel or Equivalent	Stainless Steel
Effective Probe Length	Sufficient to Traverse Points	3 feet
Probe Temperature Set-Point	Prevent Condensation (Min. 250°F)	375°F±10°F
Particulate Filter		
In-Stack Filter	Optional	N/A
In-Stack Filter Material	N/A	N/A
External Filter	Yes	Yes
External Filter Material	Glass Fiber Mat	Borosilicate Glass Fiber Mat
External Filter Set-Point	Prevent Condensation (Min. 250°F)	375°F±10°F
Sample Delivery System		
Heated Sample Line Material	Stainless Steel or Teflon	Teflon
Heated Sample Line Set-Point	Prevent Condensation (Min. 250°F)	375°F±10°F
Heated Sample Line Connections	Probe Exit to Pump to FTIR	Probe to Pump to FTIR
Moisture Removal System	N/A	N/A
Sample Pump Type	N/A	Diaphragm
Sample Pump Material	Non-reactive to sample gases	Teflon
Sample Flow Control	Constant Rate	Constant Rate
Non-Heated Sample Line Material	N/A	N/A
Non-Heated Sample Line Connections	N/A	N/A
Additional Filters	Optional	N/A
Additional Filter Type	N/A	N/A
Additional Filter Location	N/A	N/A
Filter Material	N/A	N/A
Analyzer Description		
Ethylene Oxide (C_2H_4O)	EPA Method 320 (FTIR)	EPA Method 320 (FTIR)
Propylene Oxide (C_3H_6O)	EPA Method 320 (FTIR)	N/A
Hydrogen Chloride (HCl)	EPA Method 320 (FTIR)	N/A
Carbon Dioxide (CO_2)	EPA Method 320 (FTIR)	EPA Method 320 (FTIR)
Oxygen (O_2)	EPA Method 320 (FTIR)	EPA Method 3A (Paramagnetic)
Nitrogen Dioxides (NO_2)	EPA Method 320 (FTIR)	N/A
Nitrogen Monoxides (NO)	EPA Method 320 (FTIR)	N/A
Carbon Monoxide (CO)	EPA Method 320 (FTIR)	N/A

EPA Method 320 & 3A

	Standard Method Specification	Actual Specification Used
Calibration Gas Span		
Ethylene Oxide (C_2H_4O)	N/A	0-2,000 ppm, 0-10 ppm
Propylene Oxide (C_3H_6O)	N/A	N/A
Hydrogen Chloride (HCl)	N/A	N/A
Carbon Dioxide (CO_2)	N/A	N/A
Sulfur Dioxide (SO_2)	N/A	N/A
Nitrogen Dioxides (NO_2)	N/A	N/A
Nitrogen Monoxides (NO)	N/A	N/A
Carbon Monoxide (CO)	N/A	N/A
Data Acquisition		
Data Recorder	Computer with Software for Automated Collection	Analog Computer
Scan Rate	No Requirement (64 Scans ~ 1 minute)	64 Scans
Data Storage	Automatic	Automatic
Calibration Gas Specifications		
Ethylene Oxide (C_2H_4O)	Best Commercially Available Accuracy (±5%)	Best Commercial Accuracy (±5%)
Methane (CH_4)	Best Commercially Available Accuracy (±5%)	Best Commercial Accuracy (±5%)
Hydrogen Chloride (HCl)	Best Commercially Available Accuracy (±5%)	N/A
Carbon Dioxide (CO_2)	N/A	EPA Protocol 1
Oxygen (O_2)	N/A	EPA Protocol 1
Nitrogen Dioxides (NO_2)	N/A	N/A
Nitrogen Monoxides (NO)	N/A	N/A
Carbon Monoxide (CO)	N/A	N/A

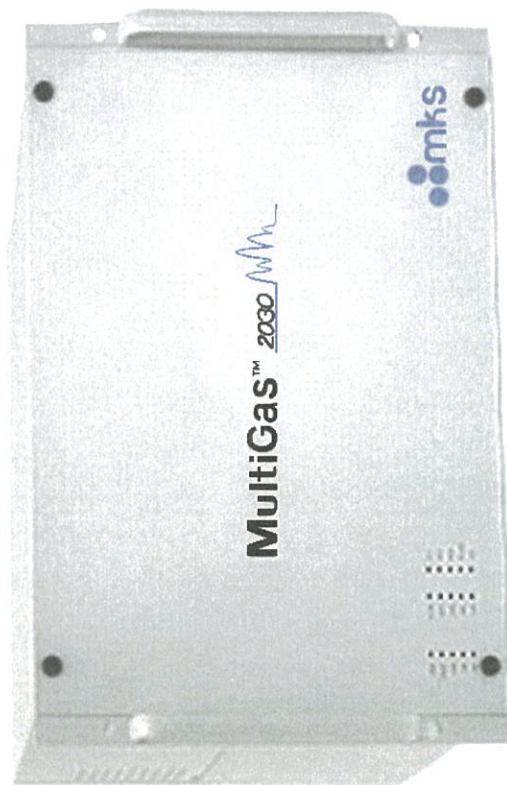* Note: M320 only requires that the gases used come with a certificate of accuracy

EPA Method 320 & 3A
Sampling Train Configuration

Filter

Heated Connection Box[1]

Heated Probe[1]

Sample Line

FLW-6
Flow Panel

Calibration Gases

Heated Sample Line

Outlet Paths

Calibration Line

Sample
Calibrate

A B C D Probe
Tip

1 2 3 4 5 6

N2 Form/SF6 Eth O2 O2 O2

Inlet Gases

Calibration Line

Vent

Heated

MKS FTIR[2]

In Out

Heated

Ametek
O2

In Out

Vent

Heated Pump[1]

Vent

Heated Double Valve

Data Acquisition System
(DAS)
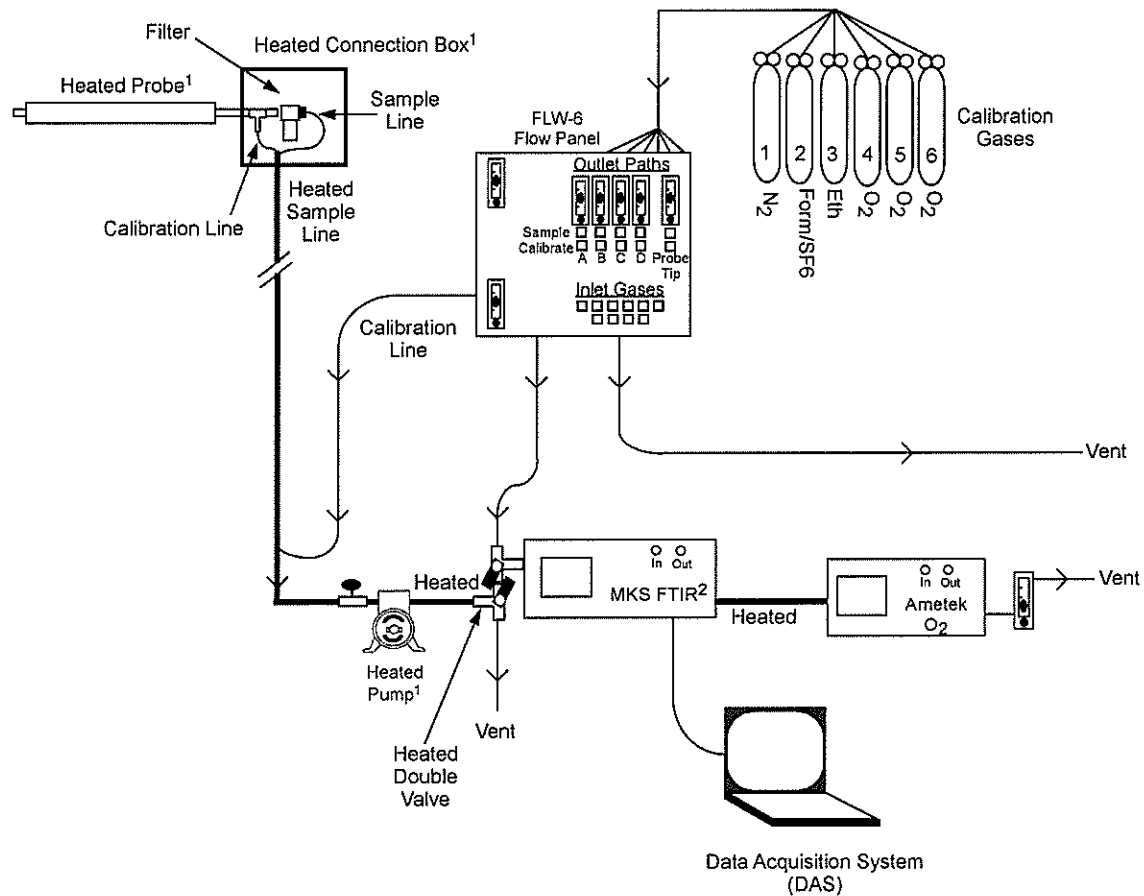
[1] Sample delivery system maintained at 191C. / Heated umbilical length kept as short as possible.
[2] FTIR maintained at 191C.
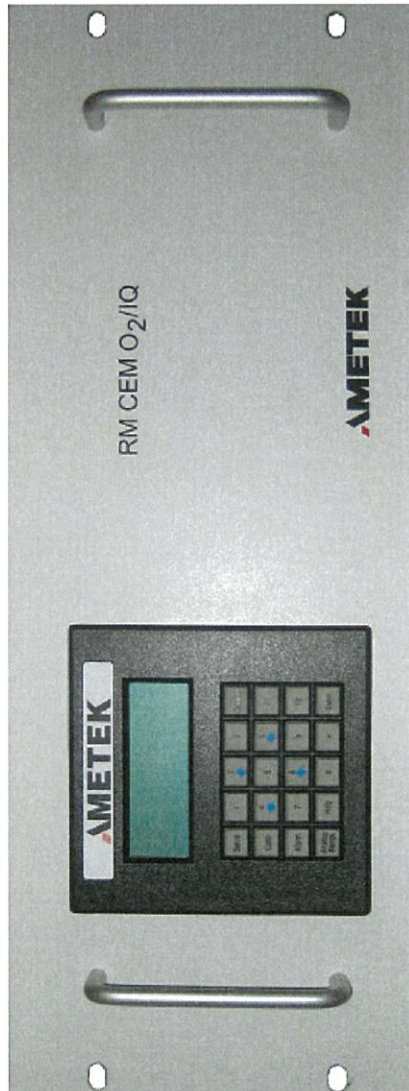
MKS MultiGas 2030 FTIR

SPECIFICATIONS:

- Weight: 100 lbs.
- Power 120 or 240VAC, 50/60 Hz, 3amps.
- Measurement Techinque: FTIR Spectrometry.
- 21µm 0.25mm LN_2 cooled detector, 7µm 0.25mm TE cooled also available.
- Ranges: Full scale setting < 100ppb to 100% concentration.
- Averaging Time: 0.2 sec to 5 min.
- Spectral Range: 2µm - 20µm (500 - 5,000cm^{-1}).
- Temperature and pressure measured internally.
- Sample Flow: 0.2 - 10 L/min.
- Sample Pressure: 0.01 - 4 Atm.
- N_2 Purge: 20psig (1.5 bar) max, 0.1 L/min.
- Gas Cell: Nickel coated Aluminum.
- Cell Temperature: Ambient to 191° C.
- Cell Mirrors: Nickel plated Aluminum Substrate with rugged gold coating.
- Cell Windows: KBr or ZnSe.

RENTAL AND APPLICATION NOTES:

- Shipping Weight: 120 lbs.
- Designed to meet EPA Method 318,320,321 and various VOC and inorganic gas sampling including Formaldehyde, Ammonia and HCl.
- Nitrogen and Ethylene calibration gases are needed.
- Liquid Nitrogen is needed for most applications.
- Instrument rental of the MKS FTIR is accompanied with an operator unless otherwise arranged through CleanAir Intstrument Rental.

![CleanAir INSTRUMENT RENTAL logo]

Ametek RM CEM O$_2$

SPECIFICATIONS:

- Weight: 15 lbs.

- Power Requirements: 115VAC, 50-60 Hz, ±10%; 230VAC, 50-60 Hz, ±10%; 100 VA max.

- Principle of Operation: Zirconium Oxide.

- Output: 4-20mA, 0-20mA.

- Operating Range: 0.1% - 100% Oxygen.

- Accuracy: ±0.75% of reading or 0.05% oxygen, whichever is greater.

- Maximum Inlet Tempurature: 204°C (400°F).

- Sample flow: 2 to 15 scfh (0.94 to 7.08L/min.).

RENTAL AND APPLICATION NOTE:

- Shipping Weight: 20 lbs.

- Ideal for hot and wet samples.

- Zero calibration gas must be between 1.0% and 3.0% O$_2$.

![StarBoost Technology logo]

MAX-StarBoost™ Technology
FTIR Reinvented

MAX StarBoost™ is a breakthrough commercial FTIR gas analyzer enhancement technology that dramatically increases sensitivity, linearity and dynamic range over narrow spectral bands of interest. Proven in demanding applications such as ethylene oxide and formaldehyde measurement, MAX StarBoost™ enables source testing, industrial process monitoring and IH Professionals a new level of real-time, in-process analytical capability. Supplied as a turnkey add-on to the widely used and accepted MKS MultiGas™ 2030 FTIR, MAX StarBoost™ is compliant with existing methods and is easy to deploy with a quick learning curve for testing professionals!

Max StarBoost™ Key Features

- Single digit ppb detection limits
- Quick learning curve for existing 2030 users
- Specificity over GC-FID
- EPA Method 320 & ASTM D6348 compliant
- Max-Acquisition™/ MAX-Analytics™ Software
- Spectral Regions:
  - Aldehyde filter – formaldehyde, acrolein, acetaldehyde, HCl
  - Aromatic filter – ethylene oxide, BTEX
- Ideal for CEM Applications
- Switch between standard FTIR & StarBoost™
- Available on all MultiGas™ 2030 config.

Shown with Optional Max ASC-10-ST™ Sampler

MAX-Aquisition™ and MAX-Analytics™ Software are included (depending on package) to seamlessly integrate with MultiGas™ software providing state-of-the-art FTIR spectral analysis. See MAX-Aquisition™ and MAX-Analytics™ software product brochure for further information. Two spectral bands are included with optional bands available on request.

For more information on MAX StarBoost™ please contact our Applications Group to discuss your specific requirements at 860-386-6878 or email: applications@maxanalytical.com

MAX StarBoost™ Filter Bands

MAX StarBoost™ technology is available in several stock filter bands and can be deployed on any Max Analytical product utilizing the MKS MultiGas™ 2030. Available stock filter bands, compounds and detection limits are shown below. Custom filter and compounds are available on request.

Stock Filter Bands	Sample Stream	Compounds	Detection Limit (1min average)
Aldehyde	Combustion Source (8.8% Water)	Formaldehyde	9ppb
		HCl	8ppb
		Acetaldehyde	500ppb
		Methane	650ppb
		Ethane	550ppb
		Water	110ppb
Aromatic	Ambient Air	Methane	4ppb
		Ethane	50ppb
		Ethylene Oxide	Summer 2019

MAX-Acquisition™ Software

Real-time data analysis with MKS 2030 driver (available Summer 2019), AutoReference algorithm to eliminate baseline drift, manual validation and reporting functions. See MAX-Acquisition™ Software brochure for more detail.

MAX

Analytical Technologies
Max Analytical Technologies
32 North Road • East Windsor, CT 06088

1-860-386-6878 • info@maxanalytical.com
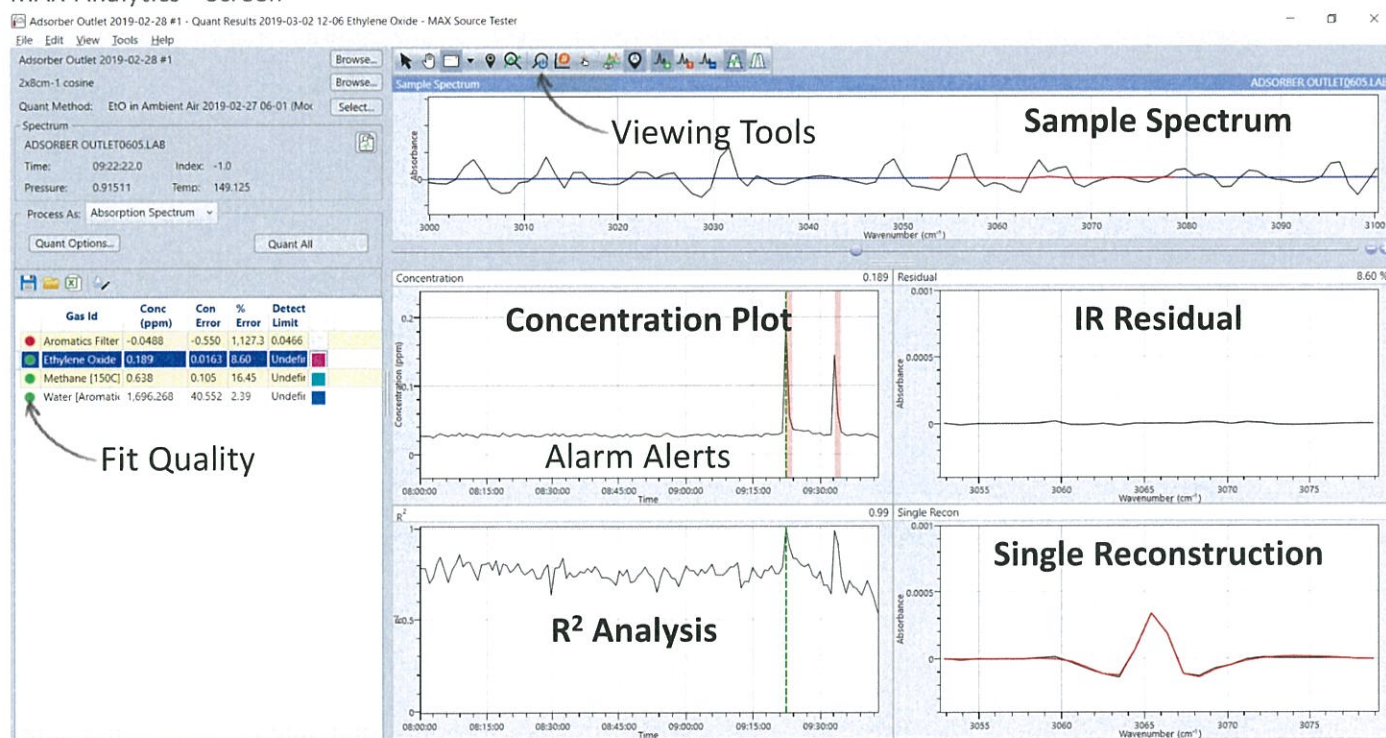www.maxanalytical.com

MAX-∧nalytics™ Advanced FTIR Analysis Software

MAX-Analytics™ is the most powerful gas/liquid FTIR data analysis program commercially available. Providing a large suite of tools that seamlessly stores results in one file, MAX-Analytics™ can take your data reprocessing time from minutes to seconds, dramatically increasing productivity. For users analyzing samples with unknowns, the powerful Peak Matching function can quickly identify compounds using the included quantitative/qualitative libraries with over 5200 compounds. Other features such as adding conditional interferences, multiple quant regions, and editable fencing masks based on residual, reference spectrum, or sample spectrum are just a few of the included features. MAX-Analytics™ is also supplied with a standalone Gas Reference File Editor that provides features such as traceability documentation, gas aliases, spectral subtraction, baseline correction and automatic fencing masks just to name a few. A complete list of features is provided in the specification section of this document.

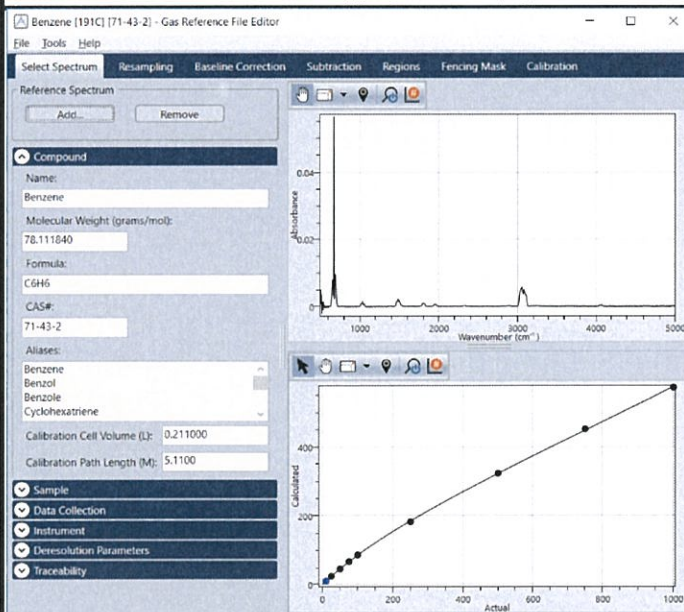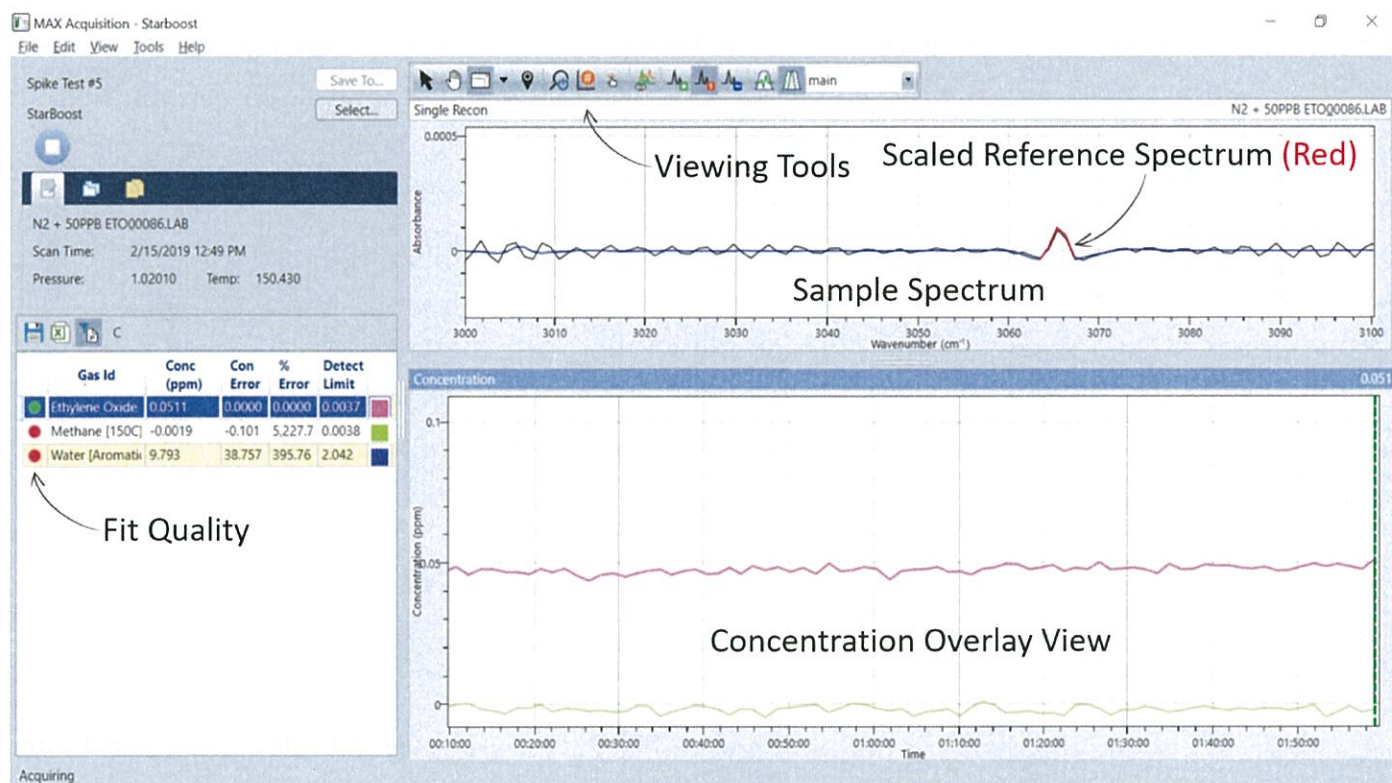MAX-Analytics™ Screen

Getting the most out of FTIR spectra takes world class data analysis software to generate high confidence results. Contact our applications group today to arrange a demo at 1-860-386-6878 or software@maxanalytical.com.

MAX-Analytics™ Advanced FTIR Analysis Software

Feature Specification (Available Summer 2019)

MAX-Analytics™	Gas Reference File Editor
Quantitative Gas Reference Library (200 compounds)	Includes traceability documentation for all gases in library
Qualitative NIST & EPA Gas Reference Library (5500 compounds)	Automatic baseline correction of reference spectra
Analyze FTIR, StarBoost™ or GC-FTIR data	Subtract interferences from reference spectra
Fast reprocessing of data	Define Primary & Secondary quantification regions
Peak Matching Tool for identification of unknown compounds	Define Interference retions
View and open previous results summary file	Deresolve reference spectra
Export results file to Excel spreadsheet	Automatically apply fencing mask using absorbance threshold
Average spectra	Apply fencing mask to reference gas or interferents
Manual Validation Mode	Units include both concentration (ppm) and mass (ng)
Add conditional interferences to analysis method	
Multiple (Primary & Secondary) quantification regions	
Edit and save quantification regions in analysis method, without modifying gas library	
Edit and save fencing masks in analysis method, without modifying gas library	
Apply a fencing mask based on residual, reference spectrum, or sample spectrum	
Save a computed spectrum (averaged, residual, or single reconstruction)	
Easily add a sample spectrum to analysis method	
Seach for compounds by aliases, formula or CAS number	
Add dataset and spectrum comments and save with results file	
Set Alarm Alerts when a concentration exceeds a selected threshold	
Customize viewing options for either detailed analysis or concentration overlay	
MAX™ Algorithm for GC-FTIR data analysis with automated retention index search	

MAX
Analytical Technologies

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MAX-Acquisition™

Advanced FTIR/GC-FTIR Data Acquisition

MAX-Acquisition™ allows for seamless data acquisition using MAX-Crossmark™ GC-FTIR or the MKS MultiGas™ 2030 FTIR analyzer upgraded with MAX-StarBoost™ Technology. Designed for technicians and power users alike, MAX-Acquisition™ can control all data acquisition from a single user interface with flexible display options for fast and easy assessment of data quality. Advanced features include an updated AutoReference algorithm that, when used in conjunction with ultra-sensitive hardware configurations like MAX-StarBoost™, eliminates biases from baseline drift and does not require the user to collect a nitrogen background. Users can also view real-time data results and easily configure alarms to alert when a compound's concentration exceeds a selected threshold. **Whether in the field or in the lab, MAX-Acquisition™ maximizes instrument productivity and ensures high quality data collection.**

Getting the most out of FTIR spectra takes world class data analysis software to generate high confidence results. Contact our applications group today to arrange a demo at 1-860-386-6878 or software@maxanalytical.com.

MAX-∿nalytics™

Feature Specification

MAX Acquisition
Compatible with all MAX hardware configurations and MKS MultiGas 2030™
Instrument method includes data collection parameters & analysis method
Easily modify analysis method
Real-time quantification of FTIR data
Real-time chromatogram for GC-FTIR data
Control data acquisition on MKS MultiGas 2030™ in StarBoost™ or standard mode
Acquire Temperature and Pressure in real-time for FTIR data
AutoReference Mode
Store spectral data with Igrams and Sbeams
Store results summary file
Export results file to Excel reporting template
Automatically create a new summary results file and spectral folder at certain time of day for CEM applications
View real-time sample spectra
View real-time single reconstructions and residuals for FTIR data
View real-time fit quality metrics (R^2) for FTIR data
View sample spectrum with overlay of scaled reference spectra of gases in analysis method
Add a sample spectrum to method in real time for FTIR data
View real-time alarm alerts when concentration exceeds a selected threshold
Customize viewing options for either detailed analysis or concentration overlay for FTIR data

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APPENDIX B: SAMPLE CALCULATIONS

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Sterigenics
Clean Air Project No. 13990

EtO Control System

EPA Method 320
EtO FTIR Sample Calcs

Note: The tables presenting the results are generated electronically from raw data. It may not be possible to exactly duplicate these results using a calculator. The reference method data, results and all calculations are carried to sixteen decimal places throughout. The final table is formatted to an appropriate number of significant figures.

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1. Dilution Factor of Spike Gas

$$DF = \frac{SF6_{spike}}{SF6_{direct}}$$

Where:

$SF6_{spike}$	= diluted SF6 concentration measured in spiked sample	=	ppmwv
$SF6_{direct}$	= SF6 concentration measured directly in undiluted spike gas	=	ppmwv
DF	= dulution factor of spike gas	=	

2. Concentration of Analyte Corrected for Dilution

$$Udil = Ua \times (1 - DF)$$

Where:

Ua	= concentration of analyte in unspiked sample	=	ppmwv
DF	= dilution factor of spike gas	=	
Udil	= concentration of analyte corrected for dilution	=	ppmwv

3. Bias at spike level

$$B = Sa - Udil - Cs$$

Where:

Sa	= total concentration of analytes in spiked sample	=	ppmwv
Udil	= concentration of analyte corrected for dilution	=	ppmwv
Cs	= certified concentration of calibration standard * DF		ppmwv
B	= bias at spike level	=	ppmwv

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EtO Control System

4. Expected in spiked sample (ppm)

$$X_E = (X_D)(DF) + (X_O)(1 - DF)$$

Where:

X_D	= response, direct to analyzer	=	ppmwv
DF	= dilution factor (dimensionless)	=	ppmwv
X_O	= native concentration in flue gas (ppm)	=	ppmwv
X_E	= expected in spiked sample (ppm)	=	ppmwv

5. Spike recovery (%)

$$\%SR = \left(\frac{X_S}{X_E}\right) \times 100$$

Where:

X_S	= spiked concentration (ppm)	=	ppmwv
X_E	= expected in spiked sample (ppm)	=	ppmwv
100	= conversion constant (%/decimal)	=	
%SR	= spike recovery (%)	=	%

6. Correction Factor (CF)

$$CF = \frac{1}{\left(1 + \dfrac{B}{X_E}\right)}$$

Where:

B	= bias at spike level	=	
X_E	= expected in spiked sample (ppm)	=	
CF	= analyte correction factor	=	

7. Minimum Detection Limit (MDL)

$$MDL = 3 \ x \ Stdev(C_i)$$

MDL	= Minimum detection Limit (MDL)	=	ppbdv
$Stdev(C_i)$	Standard deviation of the concentrations from ten representative = spectra taken directly after a background while nitrogen is running through the system.	=	ppbdv
C_i	= Concentrations of i spectra where i = 1 through 10	=	ppbdv

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Willowbrook, IL

EtO Control System

Method 3A Field Sample Calculations
for O2, EtO Control System

Note: The tables presenting the results are generated electronically from raw data. It may not be possible to exactly duplicate these results using a calculator. The reference method data, results and all calculations are carried to sixteen decimal places throughout. The final table is formatted to an appropriate number of significant figures.

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1. Average of a calibration series

$$C_{mce} = \frac{(C_1 + C_2 + C_3)}{3}$$

Where:

C_1, C_2, C_3	= concentrations of 3 consecutive gas samples that are representative of the calibration gas		
C_{mce}	= average concentration of a calibration series	=	%dv
	In this case the low cal series for channel 1		

2a. Calibration Error Check for Hydrocarbons (5% of actual calibration gas value error allowed by Method 25A)

$$E_{HC} = abs\left|\frac{C_{mce} - C_{ma}}{C_{ma}}\right| \le l_{cal}$$

Where:

C_{mce}	= average concentration of a calibration series	=	%dv
	In this case the low cal series for channel 1		
C_{ma}	= concentration of actual calibration gas value	=	%dv
l_{cal}	= limit for calibration error for hydrocarbons	= 5.0%	
E_{HC}	= calibration error check value	= NA	

2b. Calibration Error Check for non-Hydrocarbons (2% of Instrument Span)

$$E = abs\left|\frac{C_{mce} - C_{ma}}{Span}\right| \le l_{cal}$$

Where:

C_{mce}	= average concentration of a calibration series	=	%dv
	In this case the low cal series for channel 1		
C_{ma}	= concentration of actual calibration gas value	=	%dv
Span	= instrument span value	=	
l_{cal}	= limit for calibration error for non-hydrocarbons	= 2.0%	
E	= calibration error check value	=	**Pass**

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EtO Control System

3. System Bias as Percent of Span Value (5% is allowed)

$$E_{Bias} = abs\left|\frac{C_{mf} - C_{mce}}{Span}\right| \le l_{bias}$$

Where:

C_{mce}	= average concentration of a calibration series	=		%dv
	in this case the High cal series for channel 1			
C_{mf}	= calibration error response concentration for Cal01	=		%dv
Span	= instrument span value	=		%dv
l_{bias}	= limit for system bias error	=	5.0%	
E_{bias}	= calibration bias error check value	=		**Pass**

4. System Drift as Percent of Span Value (3%)

$$E_{Drift} = abs\left|\frac{C_{mf} - C_{mi}}{Span}\right| \le l_{drift}$$

Where:

C_{mf}	= calibration error response concentration for Cal01 (final)	=		%dv
C_{mi}	= calibration error response concentration for Cal00 (initial)	=		%dv
Span	= instrument span value	=		%dv
l_{drift}	= limit for system drift error	=	3.0%	
E_{drift}	= calibration drift error check value	=		**Pass**

5. Average Concentration for an entire Run

$$C = \frac{\sum_{i=1}^{N} C_i}{N}$$

Where:

C_i	= All concentration readings for the entirety of Run 1	=		%dv
	for the monitor looking for O2 on channel 1			
N	= total number of readings in Run 1	=	0	
C	= average O2 concentration for Run 1	=		%dv

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6. Drift-Corrected Average Concentration for an entire Run

$$C_{DC} = \left(C - \frac{C_{oi} + C_{of}}{2} \right) \left(\frac{C_{ma}}{\dfrac{C_{mi} + C_{mf}}{2} - \dfrac{C_{oi} + C_{of}}{2}} \right)$$

C_{ma}	= concentration of actual calibration gas value	=	%dv
C	= average O2 concentration for Run 1	=	%dv
C_{mf}	= calibration error response concentration for Cal01 (final)	=	%dv
C_{mi}	= calibration error response concentration for Cal00 (initial)	=	%dv
C_{of}	= calibration error response concentration for Cal01 (final) for zero gas	=	%dv
C_{oi}	= calibration error response concentration for Cal00 (initial) for zero gas	=	%dv
C_{DC}	= drift corrected average concentration for Run 1	=	%dv

EtO Emissions Sample Calculations
for EtO, EtO Control System

Sample data taken from Run 1
and Channel 3

Note: The tables presenting the results are generated electronically from raw data. It may not be possible to exactly duplicate these results using a calculator. The reference method data, results and all calculations are carried to sixteen decimal places throughout. The final table is formatted to an appropriate number of significant figures.

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1. EtO concentration (ppmdv)

$$C(ppmdv) = k_1 \times C_{DC} \qquad if \qquad dry \qquad gas$$

$$C(ppmdv) = \frac{k_1 \times C_{DC}}{\left(1 - \frac{B_w}{100}\right)} \qquad if \qquad wet \qquad gas$$

Where:

C_{DC}	= drift corrected average concentration	=		ppmwv
B_w	= actual water vapor in gas (% v/v)	=		% v/v
100	= conversion factor to change percentage to decimal	=	100	
k_1	= ppm/% to ppm conversion factor for diluent gases	=	1	
C (ppmdv)	= EtO concentration (ppmdv)	=		ppmdv

2. EtO concentration (ppmwv)

$$C(ppmwv) = k_1 \times C_{DC} \qquad if \qquad wet \qquad gas$$

$$C(ppmwv) = k_1 \times C_{DC} \times \left(1 - \frac{B_w}{100}\right) \qquad if \qquad dry \qquad gas$$

Where:

C_{DC}	= drift corrected average concentration	=		ppmwv
B_w	= actual water vapor in gas (% v/v)	=		% v/v
100	= conversion factor to change percentage to decimal	=	100	
k_1	= ppm/% to ppm conversion factor for diluent gases	=	1	
C (ppmwv)	= EtO concentration (ppmwv)	=		ppmwv

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EtO Control System

3. EtO concentration (lb/dscf)

$$C(lb/dscf) = \frac{C(ppmdv) \times MW(gas)}{10^6 \, ppm \times 385.3}$$

Where:

C (ppmdv)	= EtO concentration (ppmdv)	=		ppmdv
MW	= Molecular Weight of EtO gas	=	44.05	lb/lb-mole
10^6	= conversion factor from decimal to ppm	=	1.00E+06	
385.3	= molar volume	=	385.3	dscf/lb-mole
C (lb/dscf)	= EtO concentration (lb/dscf)	=		lb/dscf

4. EtO concentration (lb/scf)

$$C(lb/scf) = C(lb/dscf) \times \frac{Q_{std}}{Q_s}$$

Where:

C (lb/dscf)	= EtO concentration (lb/dscf)	=	lb/dscf
Q_{std}	= volumetric flow rate at standard conditions, dry basis (dscfm)	=	dscf/min
Q_s	= volumetric flow rate (standard cubic feet/min)	=	scf/min
C (lb/scf)	= EtO concentration (lb/scf)	=	lb/scf

5. EtO concentration (lb/acf)

$$C(lb/acf) = C(lb/dscf) \times \frac{Q_{std}}{Q_a}$$

Where:

C (lb/dscf)	= EtO concentration (lb/dscf)	=	lb/dscf
Q_{std}	= volumetric flow rate at standard conditions, dry basis (dscfm)	=	dscf/min
Q_a	= volumetric flow rate (actual cubic feet/min)	=	acf/min
C (lb/acf)	= EtO concentration (lb/acf)	=	lb/acf

6. EtO concentration (%dv)

$$C(\% dv) = C(ppmdv) \times \frac{100}{10^6}$$

Where:

C (ppmdv)	= EtO concentration (ppmdv)	=		ppmdv
100	= conversion factor from decimal to percentage	=	1.00E+02	
10^6	= conversion factor from decimal to ppm	=	1.00E+06	
C (%dv)	= EtO concentration (%dv)	=		%dv

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EtO Control System

7. EtO concentration (mg/dscm)

$$C\left(mg/dscm\right) \quad = C\left(lb/dscf\right) \times k_2 \times 35.31$$

Where:

C (lb/dscf)	= EtO concentration (lb/dscf)	=		lb/dscf
k_2	= conversion factor from lb to mg	=	453515	mg/lb
35.31	= conversion factor from dscf to dscm	=	35.31	ft³/m³
C (mg/dscm)	= EtO concentration (mg/dscm)	=		mg/dscm

8. EtO concentration (mg/Nm3 dry)

$$C \quad \left(mg/Nm^3\ dry\right) \quad = C\left(lb/dscf\right) \times k_2 \times 35.31 \times \left(\frac{68+460}{32+460}\right)$$

Where:

C (lb/dscf)	= EtO concentration (lb/dscf)	=		lb/dscf
k_2	= conversion factor from lb to mg	=	453515	mg/lb
35.31	= conversion factor from dscf to dscm	=	35.31	ft³/m³
68	= standard temperature (°F)	=	68	°F
32	= normal temperature (°F)	=	32	°F
460	= °F to °R conversion constant	=	460	
C (mg/Nm3 dr	= EtO concentration (mg/Nm3 dry)	=		mg/Nm³ dry

9. EtO concentration corrected to 7% O2 (ppmdv example)

$$C(ppmdv@\,x\%02) \quad = C(ppmdv) \times \left(\frac{20.9-x}{20.9-O_2}\right)$$

Where:

C (ppmdv)	= EtO concentration (ppmdv)	=		ppmdv
x	= oxygen content of corrected gas (%)	=	7.00	%
O_2	= proportion of oxygen in the gas stream by volume (%)	=		%
20.9	= oxygen content of ambient air (%)	=	20.9	%
C (ppmdv - O₂	= EtO concentration corrected to 7% O2 (ppmdv example)	=		ppmdv @ 7%O2

10. EtO concentration corrected to 12% CO2 (ppmdv example)

$$C(ppmdv@\,y\%CO_2) = C(ppmdv) \times \left(\frac{y}{CO_2}\right)$$

Where:

C (ppmdv)	= EtO concentration (ppmdv)	=		ppmdv
y	= carbon dioxide content of corrected gas (%)	=	12.00	%
CO_2	= proportion of carbon dioxide in the gas stream by volume (%)	=		%
C (ppmdv -CO	= EtO concentration corrected to 12% CO2 (ppmdv example)	=		ppmdv @ 12%CO2

11. EtO emission rate (lb/hr)

$$E_{lb/hr} = C\left(lb/dscf\right) \times Q_{std} \times 60$$

Where:

C (lb/dscf)	= EtO concentration (lb/dscf)	=		lb/dscf
Q_{std}	= volumetric flow rate at standard conditions, dry basis (dscfm)	=		dscfm
60	= conversion factor (min/hr)	=	60	min/hr
$E_{lb/hr}$	= EtO emission rate (lb/hr)	=		lb/hr

12. EtO emission rate (kg/hr)

$$E_{kg/hr} = C\left(lb/dscf\right) \times Q_{std} \times 60 \times 0.454$$

Where:

C (lb/dscf)	= EtO concentration (lb/dscf)	=		lb/dscf
Q_{std}	= volumetric flow rate at standard conditions, dry basis (dscfm)	=		dscfm
60	= conversion factor (min/hr)	=	60	min/hr
0.454	= conversion factor (kg/lb)	=	0.454	kg/lb
$E_{kg/hr}$	= EtO emission rate (kg/hr)	=		kg/hr

13. EtO emission rate (gm/sec)

$$E_{gm/sec} = C\left(lb/dscf\right) \times Q_{std} \times \frac{454}{60}$$

Where:

C (lb/dscf)	= EtO concentration (lb/dscf)	=		lb/dscf
Q_{std}	= volumetric flow rate at standard conditions, dry basis (dscfm)	=		dscfm
60	= conversion factor (sec/min)	=	60	sec/min
454	= conversion factor (g/lb)	=	453.515	kg/lb
$E_{gm/sec}$	= EtO emission rate (gm/sec)	=		gm/sec

14. EtO emission rate (Ton/yr)

$$E_{T/yr} = C\left(lb/dscf\right) \times Q_{std} \times 60 \times \left(\frac{Cap}{2000}\right)$$

Where:

C (lb/dscf)	= EtO concentration (lb/dscf)	=		lb/dscf
Q_{std}	= volumetric flow rate at standard conditions, dry basis (dscfm)	=		dscfm
60	= conversion factor (min/hr)	=	60	min/hr
Cap	= capacity factor for process (hours operated/year)	=		hours/yr
2000	= conversion factor (lb/Ton)	=	2,000	lb/Ton
$E_{T/yr}$	= EtO emission rate (Ton/yr)	=		Ton/yr

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15. EtO total emission input (lb/hr)

$$C_i = \sum_{n=1}^{N} C_n$$

Where: i=1

$C_{p,i}$	= Emission input from emission source n	=	lb/hr
N	= total number of emission inputs	=	3
	(AAT Inlet, DEOXX Inlet, DBA Inlet)		
C_i	= Total emission input	=	lb/hr

16. EtO Removal Efficiency%

$$RE\% = \frac{(C_i - C_o)}{C_i}$$

Where:

C_i	= Total emission input	=	lb/hr
C_o	= Total emission output	=	lb/hr
RE%	= Recovery Efficiency (%)	=	%

USEPA Methods 1-4 (Velocity & Flow Rate)
Sampling, Velocity and Moisture Sample Calculations

Sample data taken from Run 1

Note: The tables presenting the results are generated electronically from raw data. It may not be possible to exactly duplicate these results using a calculator. The reference method data, results, and all calculations are carried to sixteen decimal places throughout. The final table is formatted to an appropriate number of significant figures.

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1. Volume of water collected (wscf)

$$V_{wstd} = (0.04706)(V_{lc})$$

Where:

V_{lc}	= total volume of liquid collected in impingers and silica gel (ml)	=		ml
0.04706	= ideal gas conversion factor (ft^3 water vapor/ml or gm)	=	0.04706	ft^3/ml
V_{wstd}	= volume of water vapor collected at standard conditions (ft^3)	=		ft^3

2. Sample gas pressure (in. Hg)

$$P_s = P_{bar} + \left(\frac{P_g}{13.6}\right)$$

Where:

P_{bar}	= barometric pressure (in. Hg)	=		in. Hg
P_g	= sample gas static pressure (in. H_2O)	=		in. H_2O
13.6	= conversion factor (in. H_2O/in. Hg)	=	13.6	in. H_2O/in. Hg
P_s	= absolute sample gas pressure (in. Hg)	=		in. Hg

3. Actual water vapor pressure at sample gas temperature less than 212°F (in. Hg)

$$P_v = \frac{e^{\left(18.3036 - \frac{3816.44}{\frac{5}{9}(T_s - 32) + 273.15 - 46.13}\right)}}{25.4}$$

Where:

T_s	= average sample gas temperature (°F)	=		°F
18.3036	= Antoine coefficient	=	18.3036	°K
3816.44	= Antoine coefficient	=	3816.44	°K
273.15	= temperature conversion factor	=	273.15	°K
46.13	= Antoine coefficient	=	46.13	°K
25.4	= conversion factor	=	25.4	mm Hg/in. Hg
5/9	= Fahrenheit to Celsius conversion factor	=	5/9	°C/°F
32	= temperature conversion (°F)	=	32	°F
P_v	= vapor pressure, actual (in. Hg)	=		in. Hg

4. Saturated moisture content (% by volume)

$$B_{ws} = \frac{P_v}{P_s}$$

Where:

P_s	= absolute sample gas pressure (in. Hg)	=	in. Hg
P_v	= water vapor pressure, actual (in. Hg)	=	in. Hg
B_{ws}	= proportion of water vapor in the gas stream by volume at saturated conditions	=	%

5. Nitrogen (plus carbon monoxide) in gas stream (% by volume, dry)

$$N_2 + CO = 100 - CO_2 - O_2$$

Where:

CO_2	= proportion of carbon dioxide in the gas stream by volume (%)	=		%
O_2	= proportion of oxygen in the gas stream by volume (%)	=		%
100	= conversion factor (%)	=	100	%
N_2+CO	= proportion of nitrogen and CO in the gas stream by volume (%)	=		%

6. Molecular weight of dry gas stream (lb/lb·mole)

$$M_d \quad = \left(M_{CO_2}\right)\frac{\left(CO_2\right)}{(100)} + \left(M_{O_2}\right)\frac{\left(O_2\right)}{(100)} + \left(M_{N_2+CO}\right)\frac{\left(N_2+CO\right)}{(100)}$$

Where:

M_{CO_2}	= molecular weight of carbon dioxide (lb/lb·mole)	=	44.00	lb/lb·mole
M_{O_2}	= molecular weight of oxygen (lb/lb·mole)	=	32.00	lb/lb·mole
M_{N_2+CO}	= molecular weight of nitrogen and carbon monoxide (lb/lb·mole)	=	28.00	lb/lb·mole
CO_2	= proportion of carbon dioxide in the gas stream by volume (%)	=		%
O_2	= proportion of oxygen in the gas stream by volume (%)	=		%
N_2+CO	= proportion of nitrogen and CO in the gas stream by volume (%)	=		%
100	= conversion factor (%)	=	100	%
M_d	= dry molecular weight of sample gas (lb/lb·mole)	=		lb/lb·mole

7. Molecular weight of sample gas (lb/lb·mole)

$$M_s \quad = \left(M_d\right)\left(1 - B_w\right) + \left(M_{H_2O}\right)\left(B_w\right)$$

Where:

B_w	= proportion of water vapor in the gas stream by volume	=		
M_d	= dry molecular weight of sample gas (lb/lb·mole)	=		lb/lb·mole
M_{H_2O}	= molecular weight of water (lb/lb·mole)	=	18.00	lb/lb·mole
M_s	= molecular weight of sample gas, wet basis (lb/lb·mole)	=		lb/lb·mole

8. Velocity of sample gas (ft/sec)

$$V_s \quad = \left(K_p\right)\left(C_P\right)\left(\overline{\sqrt{\Delta P}}\right)\left(\sqrt{\frac{\left(T_s+460\right)}{\left(M_s\right)\left(P_s\right)}}\right)$$

Where:

K_p	= velocity pressure constant	=	85.49	
C_p	= pitot tube coefficient	=		
M_s	= wet molecular weight of sample gas, wet basis (lb/lb·mole)	=		lb/lb·mole
P_s	= absolute sample gas pressure (in. Hg)	=		in. Hg
T_s	= average sample gas temperature (°F)	=		°F
$\sqrt{\Delta P}$	= average square roots of velocity heads of sample gas (in. H_2O)	=		√in. H_2O
460	= °F to °R conversion constant	=	460	
V_s	= sample gas velocity (ft/sec)	=		ft/sec

9. Volumetric flow rate of sample gas at actual gas conditions (acfm)

$$Q_a = (60)(A_s)(V_s)$$

Where:

A_s	= cross sectional area of sampling location (ft^2)	=		ft^2
V_s	= sample gas velocity (ft/sec)	=		ft/sec
60	conversion factor (sec/min)	=	60	sec/min
Q_a	= volumetric flow rate at actual conditions (acfm)	=		acfm

10. Total flow of sample gas (scfm)

$$Q_s = (Q_a)\left(\frac{P_s}{29.92}\right)\left(\frac{68+460}{T_s+460}\right)$$

Where:

Q_a	= volumetric flow rate at actual conditions (acfm)	=		acfm
P_s	= absolute sample gas pressure (in. Hg)	=		in. Hg
29.92	= standard pressure (in. Hg)	=	29.92	in. Hg
T_s	= average sample gas temperature (°F)	=	N/A	°F
68	= standard temperature (°F)	=	68	°F
460	= °F to °R conversion constant	=	460	
Q_s	= volumetric flow rate at standard conditions, wet basis (scfm)	=		scfm

11. Dry flow of sample gas (dscfm)

$$Q_{std} = (Q_s)(1 - B_w)$$

Where:

B_w	= proportion of water vapor in the gas stream by volume	=		
Q_s	= volumetric flow rate at standard conditions, wet basis (scfm)	=		scfm
Q_{std}	= volumetric flow rate at standard conditions, dry basis (dscfm)	=		dscfm

12. Dry flow of sample gas corrected to 7%O_2 (dscfm)

$$Q_{std\,7} = (Q_{std})\left(\frac{20.9 - O_2}{20.9 - 7}\right)$$

Where:

Q_{std}	= volumetric flow rate at standard conditions, dry basis (dscfm)	=		dscfm
O_2	= proportion of oxygen in the gas stream by volume (%)	=		%
20.9	= oxygen content of ambient air (%)	=	2.9	%
7	= oxygen content of corrected gas (%)	=	7.0	%
Q_{std7}	= volumetric flow rate at STP and 7%O_2, dry basis (dscfm)	=		dscfm

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APPENDIX C: FIELD DATA SHEETS

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METHOD 1 FIELD DATA SHEET

TEST LOCATION: _____

UNIT: _____

Data Recorded By: _____

Client		Project No.	
Plant		Date	
Source of Dimensional Info.	☐ Field Meas. ☐ Drawings ☐ Other:		
Duct Dimensions	(in.)	Area	(ft²)
Port Length	(in.)	Port Diameter	(in.)
Equivalent Diameter (Rectangular Ducts) Deq=2LW/(L+W)			(in.)
Disturbance to Port Distance Upstream (A)			x D
Disturbance to Port Distance Downstream (B)			x D
Number of Points Required			
Number of Points / Port Required			

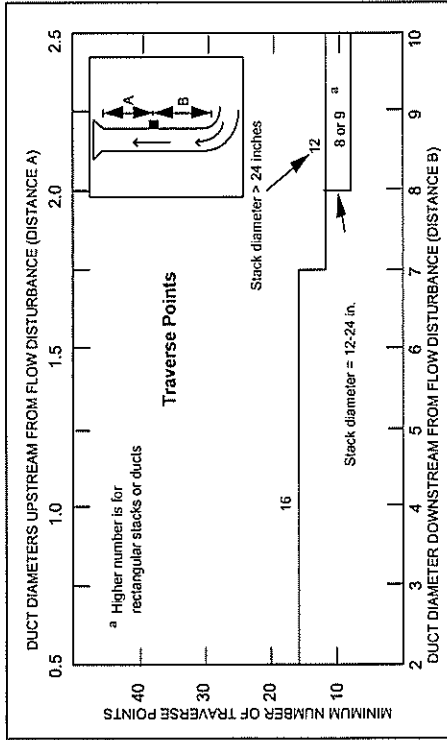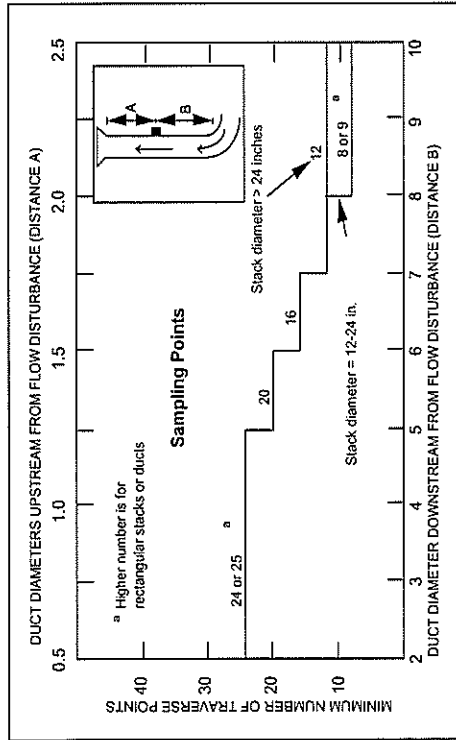| Point	% Diameter	Point Distance	Probe Mark
	Round Stacks Only	X	X + Port Depth

Location Schematic
Show side view of stack, including disturbances and port placement.

[N] [UP]

Port Schematic: (see reference on back)

Show cross-section of stack, indicating port placement.

Gas Flow: [IN] [OUT] of page

[N] [UP]

Note: condition of port (i.e - rusted, heavy build-up, etc.)
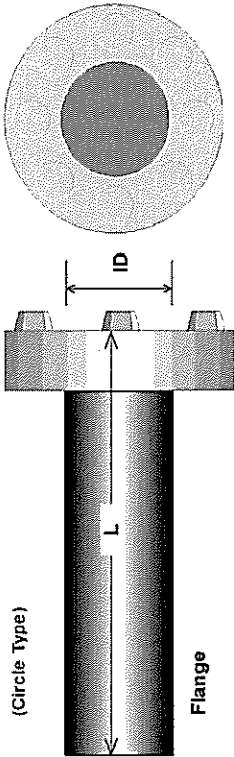
Circle correct bracketed directions on diagrams.

CleanAir
ENGINEERING

QA/QC _____
Date _____

Method 1 Reference Information

Flange Diameter OD

Flange Bolt Pattern

(Circle Type)

ID

Port Diameter

(ID) = _____

Port Length

(L) = _____

Flange

L ID

Nipple

L ID

Coupling

L ID

Pipe Size NPT

1/8" 1/4" 1/2" 3/4"

1" 2" 3" 4"

O.D, I.D., & Wall Thickness Dimensions For Given Pipe Sizes

Pipe Size	Schedule 40 Thickness		
	O.D.	I.D.	Wall Thickness
3/4	1.05	0.824	0.113
1	1.315	1.049	0.133
1-1/4	1.66	1.38	0.14
1-1/2	1.9	1.61	0.145
2	2.375	2.067	0.154
2-1/2	2.875	2.469	0.203
3	3.5	3.068	0.216
3-1/2	4	3.548	0.226
4	4.5	4.026	0.237
6	6.625	6.055	0.28
8	8.625	7.981	0.322

The table shows the outside (O.D) and inside (I.D) diameters, as well as the wall thicknesses for schedule 40 pipe sizes. The dimensions vary according to the schedule thickness (40, 10, or 5). The most common is 40.

For example, a 1-1/4 inch schedule 40 pipe size has a 1.660 inch O.D., a 1.380 inch I.D., and a 0.140 inch wall thickness. The wall thickness is the difference between the O.D. and I.D. divided by two ((1.66-1.38) / 2 = 0.140).

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Sampling Points (DISTANCE A / DISTANCE B)

DUCT DIAMETERS UPSTREAM FROM FLOW DISTURBANCE (DISTANCE A)

DUCT DIAMETER DOWNSTREAM FROM FLOW DISTURBANCE (DISTANCE B)

MINIMUM NUMBER OF TRAVERSE POINTS

a Higher number is for rectangular stacks or ducts

Stack diameter > 24 inches

Stack diameter = 12-24 in.

24 or 25 a   20   16   12   8 or 9 a

Traverse Points (DISTANCE A / DISTANCE B)

DUCT DIAMETERS UPSTREAM FROM FLOW DISTURBANCE (DISTANCE A)

DUCT DIAMETER DOWNSTREAM FROM FLOW DISTURBANCE (DISTANCE B)

MINIMUM NUMBER OF TRAVERSE POINTS

a Higher number is for rectangular stacks or ducts

Stack diameter > 24 inches

Stack diameter = 12-24 in.

16   12   8 or 9 a

Traverse point number	Number of traverse points on a diameter					
	2	4	6	8	10	12
1	85.4	93.3	95.6	96.8	97.4	97.9
2	14.6	75.0	85.4	89.5	91.8	93.3
3		25.0	70.4	80.6	85.4	88.2
4		6.7	29.6	67.7	77.4	82.3
5			14.6	32.3	65.8	75.0
6			4.4	19.4	34.2	64.4
7				10.5	22.6	35.6
8				3.2	14.6	25.0
9					8.2	17.7
10					2.6	11.8
11						6.7
12						2.1

VELOCITY & CYCLONIC FIELD DATA SHEET

TEST LOCATION: _____

UNIT: _____

Client		Project No.
Plant		Date
Meter Operator		
Probe Operator		
Source of Moisture and Molecular Weight Data		

Cross-Section of Test Location

←

[N] [UP]

Amb. Temp. (°F)		Pbar	[in. Hg] [mbar]
Pitot Cp		Probe I.D. No.	
Duct Diameters from Disturbance			
Downstream		Upstream	
First point all the way [In] [Out]		Port Len. (in.)	
Gas Flow [In] [Out] of page			
Duct Dimensions (in.)			

Run		Load	
Start Time		Stop Time	
Static Press. (in. H₂O)			
Post-Test Leak Check:	Pass ☐ Fail ☐		
Post-Test Pitot Check:	Good ☐ Bad ☐		

Procedure: Position the pitot perpendicular to the expected direction of gas flow (0 degrees reference). Note the velocity pressure. If zero, acceptable flow condition exists, if not zero, rotate the pitot up to +/- 90 degrees (rotation angle called alpha α). Determine and record the value of the rotation angle (α) to the nearest degree.

See Reference Method 1, Section 2.4. Calculate the average of the absolute values of zero to points which require no rotation. If the average of α is greater than 20 degrees, the overall condition of the flow is unacceptable and an alternative method of velocity and sample traversing must be used.

Traverse Point Number	Stack Temp. T_s (°F)	Velocity Head ΔP (in. H₂O)	Veclocity Pressure at 0⁰ (in. H₂O)	Rotation Angle α giving 0 v.p.	Notes
Total	*				
Average					Post-Test ALT-011: Good ☐ Bad ☐

* Sum of square roots. Circle correct bracketed units on data sheet.

QA/QC _____

Date _____

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VELOCITY DETERMINATION FIELD DATA SHEET

TEST LOCATION: _____

UNIT: _____

PAGE _____ OF _____

Cross-Section of Test Location

[N] [UP]

Client		Project No.	
Plant		Date	
Meter Operator		Upstream	
Probe Operator		First point all the way [In] [Out]	Port Len. (in.)
Source of Moisture and Molecular Weight Data		Gas Flow [In] [Out] of page	

Amb. Temp. (°F)		P_{bar}	[in. Hg] [mbar]
Pitot Cp		Probe I.D. No.	
Duct Diameters from Disturbance			
Downstream		Upstream	
First point all the way [In] [Out]		Port Len. (in.)	
Duct Dimensions (in.)			

Run	ALT-011 Ck. ☐ or NA ☐
Start Time	Stop Time
Static Press. (in. H₂O)	
Post-Test Leak Check:	Pass ☐ Fail ☐
Post-Test Pitot Check:	Good ☐ Bad ☐

Traverse Point Number	Velocity Head ΔP (in.H₂O)	Stack Temp. T_s (°F)	Notes

Total *

Average

* Sum of square roots.

Circle correct bracketed units on data sheet.

NIST Thermocouple Serial Number: _____

QA/QC _____
Date _____

FD5002-Velocity.bsx October 2016
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C - 6
End of Appendix

APPENDIX D: CLEANAIR RESUMES AND CERTIFICATIONS

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Ken Sullivan
Project Manager

Professional Profile

Mr. Sullivan has 10 years of experience in wet method and instrumental testing for engineering, diagnostic, performance guarantee, and compliance purposes. Initially hired as a field technician in 2009, Mr. Sullivan started leading test programs in 2011, and has been project managing since 2014. Mr. Sullivan has been involved with projects utilizing EPA Methods 1 through 29, 201, 201A, 202, 320, Conditional Test Method (CTM) 027, CTM-013, and Other Test Methods (OTM) 027 and OTM-028, from the planning stage to field testing and reporting. In addition, Mr. Sullivan has extensive experience leading Engineers and Field Technicians to execute applicable EPA methods for numerous projects worth hundreds of thousands of dollars to clients. Through his experience, he has attained valuable testing skills, such as setting up and operating continuous emissions monitoring systems (CEMS) for various pollutants, on-site mercury analysis with an Ohio Lumex spectrometer, on-site laboratory analysis for numerous methods, experience in Micro GC (gas chromatography), and in FTIR (Fourier Transform Infrared Spectrometer) analysis.

Mr Sullivan has been responsible for compliance and diagnostic test programs performed in a multitude of states across the country. He has also been responsible for engineering and consulting studies performed in Canada, Netherlands, Spain, and South Africa.

Relevant Experience

Coal Industry; Labadie and Meramec, MO

Led a large field crew in executing various EPA methods, including 30B, 5/202, 29, 26, 3A, 7E, and 10 at multiple locations to determine design variables for retrofitted wet scrubbers. Set-up and operated a CEMS showing real-time NO_X, O_2, CO_2, and CO emissions. Performed on-site mercury analysis with an Ohio Lumex spectrometer in accordance with EPA Method 30B. Assisted in determining the concentration deviation between elemental and oxidized mercury at the stack to establish scrubber performance, carbon injection interference, and other design constraints.

Natural Gas Delivery (Pipeline); Middlebourne, WV

Project managed a test program to determine sources and locations of black powder along various points of the pipeline, by utilizing a personally designed modified EPA Method 17 sampling apparatus. Led field execution, collected samples and recovered sample filters on-site while maintaining communication with the client and several other parties involved to resolve the issue of equipment malfunction and degradation due to the black powder buildup.

Manufacturing Industry; Apeldoorn, Netherlands

Planned, managed, led, and executed this job from start to finish. Ran an FTIR and performed EPA Methods 320 and 25A to provide the client with carbon monoxide, hydrocarbon, and formaldehyde diagnostic data at several key points along the process line. Processed and analyzed a plethora of raw data into utile and interpretable formats and drafted an in-depth report.

Carbon Capture; Cohasset, MN

Project managed a test program designed to determine the input/output chemistry of a non-commercial scale carbon capture system prototype. The test program included measurements for over 20 compounds of interest, utilizing FTIR, GC-FPD, Micro GC, FID, UV, and photometric technologies. Developed extensive analysis that included studies in atom balance, removal, minimum detection limit, and exponential decay.

Coal Industry; Secunda, South Africa

Aided in accumulating dust concentration data and mass loading at various points in the Fluidized Catalytic Cracking Unit (FCCU), utilizing EPA Method 17. Was involved in on-site recovery and particle size analysis, and used a TESTO 350XL to determine effluent gas composition. Also trained a South African testing company how to efficiently and accurately execute methods concerning filterable particulate matter (FPM) collection.

Oil Refining Industry; Detroit, MI

Aided multi-million net-worth client in meeting new emission limits required by a permit issued by the Michigan Department of Environmental Quality (MDEQ) and Sierra Club due to implications of the Detroit Heavy Oil Upgrade Project (DHOUP). Executed several different methods, including EPA Methods 1, 2, 3A, 4, 5/202, 6C, 7E, 25A, 10, and 18, and ASTM Draft CCM, at various locations throughout the Detroit refinery. Managed every test program from planning to reporting.

Professional Certifications & Qualifications

OSHA 10-Hour
NSC CPR/AED Certification
NSC First-Aid Certification

Qualified Source Testing Individual (QSTI) Test Exams (Certificate No. 2012-711):
– Group 1 (Manual Gas Volume and Flow Measurements and Isokinetic Particulate Sampling Methods) – exam passed on 10/22/2015 (certification attached)
– Group 2 (Manual Gaseous Pollutants Source Sampling Methods) – exam passed on 4/28/2016 (certification attached)
– Group 3 (Gaseous Pollutants Source Sampling Methods) – exam passed on 4/27/2016 (certification attached)
– Group 4 (Hazardous Metals Measurement Methods) – exam passed on 6/1/2017 (certification attached)

Qualified Individual (QI)

Field Test Leader	Ohio Lumex (EPA Method 30B Analysis)	EPA Methods 320/321 (Extractive FTIR)	Field Laboratory
Project Manager	Modified EPA Conditional Test Method 013 / Draft ASTM Controlled Condensation Method		

Education

Bachelor of Science in Civil Engineering with a focus in Environmental and Atmospheric Sciences (with honors), 2009
University of Illinois; Urbana-Champaign

Bachelor of Science in Physics, 2006
Elmhurst College; Elmhurst, Illinois

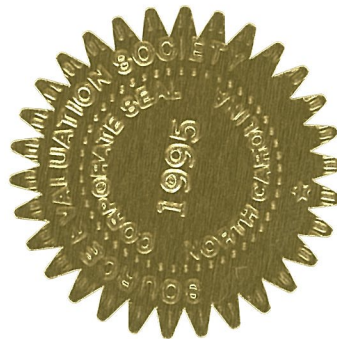# SOURCE EVALUATION SOCIETY

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Qualified Source Testing Individual

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KENNETH J. SULLIVAN

HAS SUCCESSFULLY PASSED A COMPREHENSIVE EXAMINATION AND SATISFIED EXPERIENCE REQUIREMENTS IN ACCORDANCE WITH THE GUIDELINES ISSUED BY THE SES QUALIFIED SOURCE TEST INDIVIDUAL REVIEW BOARD FOR

MANUAL GAS VOLUME MEASUREMENTS AND ISOKINETIC PARTICULATE SAMPLING METHODS

ISSUED THIS 22ND DAY OF OCTOBER 2015 AND EFFECTIVE UNTIL OCTOBER 21ST, 2020

CERTIFICATE NO. 2012-711

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Karen D. Kajiya-Mills , QSTI/QSTO Review Board

Bruce Randall QSTI/QSTO Review Board

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Peter S. Pakalnis, QSTI/QSTO Review Board

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MANUAL GASEOUS POLLUTANTS SOURCE SAMPLING METHODS

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2012-711

1995

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Peter S. Pakalnis, QSTI/QSTO Review Board

Theresa Lowe, QSTI/QSTO Review Board

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GASEOUS POLLUTANTS INSTRUMENTAL SAMPLING METHODS

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Qualified Source Testing Individual

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HAZARDOUS METALS MEASUREMENT METHODS

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Peter S. Pakalnis, QSTI/QSTO Review Board

Theresa Lowe, QSTI/QSTO Review Board

Scott Brown
Senior Project Manager / Quality Director

Professional Profile

Mr. Brown has more than 28 years of extensive environmental testing. He has been with Clean Air Engineering since March 2000. Presently, he is also the acting Corporate Quality Director in which he oversees all aspects of CleanAir's Quality Management System in terms of compliance with ISO 17025, Field Sampling and Measurement Organization Sector, and ASTM D7036 Standards.

Mr. Brown took a position as a Senior Project Manager for the Advanced Monitoring group in 2014. With this group, he oversaw the MET-80 Mercury Sorbent System projects, including Factory Acceptance Tests (FATs), installations, QA/QC Plans, test protocol development and oversight of PS 12A/B relative accuracy test audit programs (RATAs).

Prior to joining the CleanAir team, Mr. Brown worked as a Project Manager for Best Environmental in Hayward, California, and as a Technician, Senior Technician and, ultimately, Department Manager for Normandeau Associates in Richmond, California.

Relevant Experience

Municipal Solid Waste (MSW); Ft. Lauderdale, Pompano Beach, Tampa, and St. Petersburg, Florida

Managed and performed yearly Subpart Cb compliance and RATA testing at four (4) plants in Florida over the course of 14 years. Projects included protocol development, test leadership and final report creation writing for all plants. The testing included EPA Methods 5, 9, 13B, 16A, 22, 23 and 29, as well as RATAs on all units at all facilities.

Coal-Fired Power; Various Locations

Managed several engineering studies at various coal-fired power plants to assess flue gas desulfurization (FGD) scrubbers in regard to SO_2/SO_3, metals (including Hg) and hydrogen halides, and particulate abatement. Mr. Brown oversaw the planning, testing and final report writing for all associated projects. The testing included EPA Methods 5B/202, 26A and 29, as well as the Ontario Hydro Method or modified Method 30B for speciated mercury. These projects often included on-site analysis of SO_3 by ion chromatography, as well as on-site mercury analysis by thermal desorption atomic absorption spectrometry.

Coal-Fired Power; Various Locations

Project managed, test led and wrote the test reports for the APC performance guarantee on the newly installed selective catalytic reduction (SCR) systems, Jet Bubbling Reactors (JBR), FGDs, and electrostatic precipitators (ESP) at facilities in Indiana and Illinois. The testing included efficiencies of SO_2 to SO_3 conversion, mercury removal and conversion, particulate removal and NO_X removal, as well as ammonia slip. These projects often included on-site ion chromatography for SO_3 and ammonia, as well as analysis of mercury.

Secondary Aluminum; Various Locations

Managed and performed Subpart RRR NESHAP compliance tests at three (3) secondary aluminum plants across the United States. Mr. Brown has prepared testing protocols, designed the test programs and completed final reports for all three facilities. EPA Methods 23 and 5/26A were included in all test programs.

Paper Industry; Various Locations

Managed and tested various paper mill facilities in Wisconsin and California. Testing included EPA Methods 3A, 6C, 7E, 10 and 25A for gaseous components, Methods 5/202 and 201A (PM_{10}) for particulates, and Methods 16A and 16C for total reduced sulfur. Mr. Brown performed many of these tests himself and also designed the test protocol. Ultimately, he completed all reporting requirements for the projects.

Gas Turbine; Covert, Michigan

Managed start-up compliance tests for three (3) gas turbines. Testing included EPA Methods 5/202, 201A (PM_{10}), 320 (FTIR for formaldehyde), Conditional Method 0027 (ammonia), as well as all gaseous components (NO_X, CO and THC). Mr. Brown designed the test protocol and, ultimately, completed all reporting requirements for this project.

Refinery; Richmond, California

Managed and performed yearly compliance RATA, Method 8 (SO_2) and Method 5B (non-sulfuric acid particulate matter), as well as quarterly cal gas audits and Method 5B testing of the fluidized catalytic cracking unit. Also involved in testing many other processes at the refinery.

Chemical; Various Locations

Performed hazardous waste trial burn project on the MS-HAF and HS-HAF Units. Utilized BIF methodology for hexavalent chromium, hydrogen chloride, multiple metals and performance specifications for continuous emission monitoring of CO and O_2.

Steel Production; Freemont, California

Conducted PCDD/PCDF, multiple metals, hexavalent chromium and PAH tests on the main baghouse. Performed all laboratory duties, including chemical preparation and sample recovery.

Landfill; California

Conducted test programs on various landfill gas flares in California. Testing at all flares included CO, NO_X, THC, SO_2, landfill gas characterization and hazardous air pollutant (HAPS) destruction efficiency.

Asphalt Batch Plants; California

Tested many asphaltic rotary kiln batch plants run all over northern California. Performed particulate, THC, NO_X, O_2 and CO testing at the baghouse outlets.

Professional Certifications & Qualifications

Member of ASTM International
Member of the Source Evaluation Society
Acting Member of the Stack Testing Accreditation Council (STAC) Board of Directors

OSHA 10-Hour
Hazardous Materials Shipping Certification
NSC CPR/AED Certification
NSC First-Aid Certification

Qualified Source Testing Individual (QSTI) Test Exams (Certificate No. 2007-053):
- Group 1 (Manual Gas Volume and Flow Measurements and Isokinetic Particulate Sampling Methods) – exam passed on 06/01/2017 (certification attached)
- Group 2 (Manual Gaseous Pollutants Source Sampling Methods) – exam passed on 03/15/2019
- Group 3 (Gaseous Pollutants Source Sampling Methods) – exam passed on 06/01/2017 (certification attached)
- Group 4 (Hazardous Metals Measurement Methods) – exam passed on 04/10/2015 (certification attached)

Qualified Individual (QI)

Field Test Leader	Field Laboratory	Project Manager	Other Test Method 29 (Hydrogen Cyanide)
Performance Specification 12B (PS12B – Mercury Using Sorbent Trap)	EPA Method 22 (Fugitive Emissions)	EPA Methods 23 / SW-846 0010/0023A (PCDD/PCDF/SVOC)	EPA Method 25 (Total Gaseous Non-Methane Organics)
CARB Method 501 (Size Distribution of Particulate Matter)	Modified EPA Conditional Test Method 013 / Draft ASTM Controlled Condensation Method	SW-846 Test Method 0011 (Aldehydes & Ketones)	SW-846 Test Method 0030/0031 (Volatile Organic Compounds)
SW-846 Test Method 0061 / EPA Method 306 (Chromium)			

Education

Bachelor of Science in Environmental Science, 1986
University of Illinois; Urbana-Champaign, Illinois

SOURCE EVALUATION SOCIETY

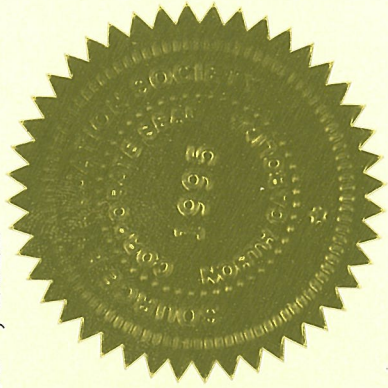SES

Qualified Source Testing Individual

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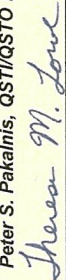
MANUAL GAS VOLUME MEASUREMENTS AND ISOKINETIC PARTICULATE SAMPLING METHODS

ISSUED THIS 1ST DAY OF JUNE 2017 AND EFFECTIVE UNTIL MAY 31ST, 2022

CERTIFICATE NO. 2007-053

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Bruce Randall QSTI/QSTO Review Board

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Peter S. Pakalnis, QSTI/QSTO Review Board

Theresa Lowe, QSTI/QSTO Review Board

D - 13

SOURCE EVALUATION SOCIETY

SES

Qualified Source Testing Individual

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GASEOUS POLLUTANTS INSTRUMENTAL SAMPLING METHODS

ISSUED THIS 1ST DAY OF JUNE 2017 AND EFFECTIVE UNTIL MAY 31ST, 2022

CERTIFICATE
NO.
2007-053

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Theresa Lowe, QSTI/QSTO Review Board

SOURCE EVALUATION SOCIETY

SES

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HAZARDOUS METALS MEASUREMENT METHODS

ISSUED THIS 16TH DAY OF APRIL 2015 AND EFFECTIVE UNTIL APRIL 15TH, 2020
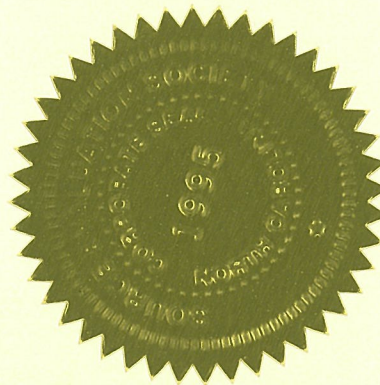
CERTIFICATE NO.
2007–053

J. Wade Bice, QSTI/QSTO Review Board

Karen D. Kajiya-Mills , QSTI/QSTO Review Board

Bruce Randall QSTI/QSTO Review Board

Peter R. Westlin, QSTI/QSTO Review Board

Peter S. Pakalnis, QSTI/QSTO Review Board

Theresa Lowe, QSTI/QSTO Review Board

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