

Using FTIR to measure stack emissions _ Reviewing test methods

Presented by:

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Gasmet Technologies inc.

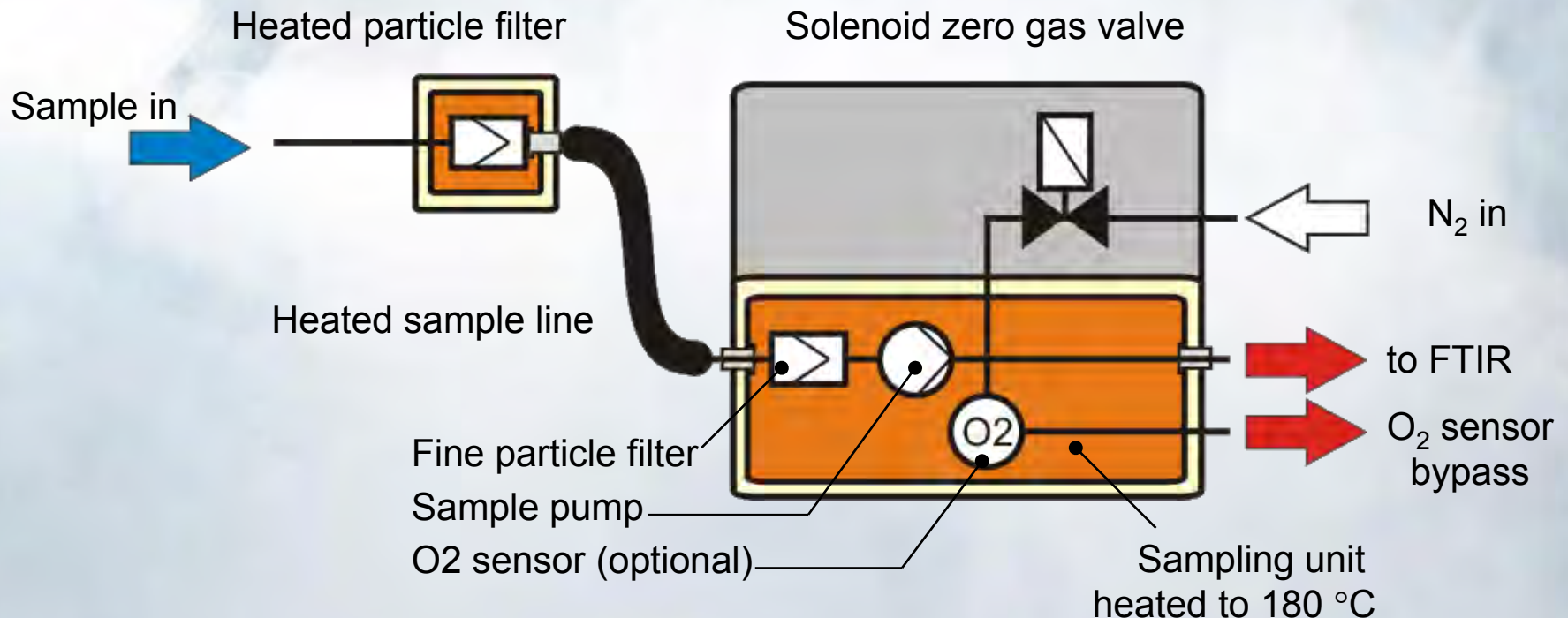


Agenda

- 1. FTIR Measurement Technology**
- 2. Anatomy of a FTIR Gas Analyzer**
- 3. Types of FTIR Gas Analyzers –
Portable, CEMS, In-Situ**
- 4. Validation & Certification – Test Methods**
- 5. Case Studies**
- 6. FTIR Maintenance**

Hot Wet Extractive Sampling

Sample gas maintained at 180 °C from source right to FTIR Gas Analyzer



- No sample gas dilution or drying!
- Always representative sample. Ideal to measure water-soluble gases such as
 - HCl, HF, HCHO, NH₃, SO₂ ... Dilution and drying may distort the results.

FTIR Gas Application List

#	Compound name	Formula	Typical Ranges		Unit
			min	max	
1	Water	H ₂ O	0 - 25	0 - 40	vol-%
2	Carbon dioxide	CO ₂	0 - 10	0 - 100	vol-%
3	Carbon monoxide	CO	0 - 70	0 - 10000	ppm
4	Nitrous oxide	N ₂ O	0 - 50	0 - 500	ppm
5	Nitric oxide	NO	0 - 100	0 - 1000	ppm
6	Nitrogen dioxide	NO ₂	0 - 100	0 - 1000	ppm
7	Sulfur dioxide	SO ₂	0 - 30	0 - 2000	ppm
8	Ammonia	NH ₃	0 - 20	0 - 500	ppm
9	Hydrogen chloride	HCl	0 - 5	0 - 500	ppm
10	Methane	CH ₄	0 - 50	0 - 1000	ppm
11	Ethane	C ₂ H ₆	0 - 50	0 - 500	ppm
12	Ethylene	C ₂ H ₄	0 - 50	0 - 500	ppm
13	n-Propane	C ₃ H ₈	0 - 50	0 - 500	ppm
14	n-Hexane	C ₆ H ₁₄	0 - 50	0 - 500	ppm
15	Formaldehyde	CHOH	0 - 50	0 - 500	ppm
16	Hydrogen Fluoride	HF	0 - 5	0 - 200	ppm

Typical ranges for CEM applications, Gasmeter offers many other components and calibrations outside those ranges

Portable FTIR Emissions Measurement System



Portable Sampling Unit



Sample probe

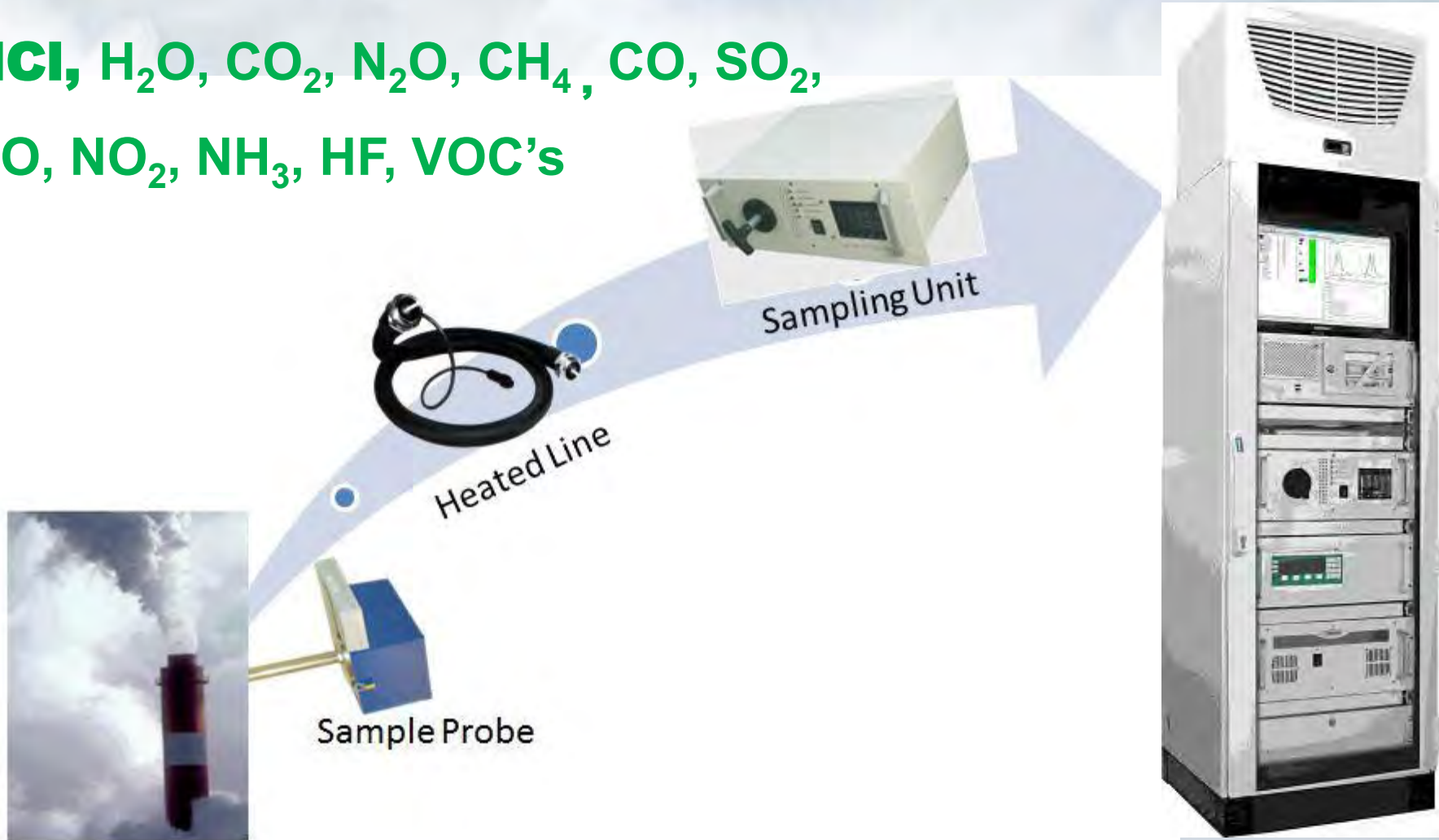
Heated Sample Lines

DX-4000 FTIR Gas Analyzer

FTIR EXTRACTIVE CEMS

Monitors up to 16 priority pollutants simultaneously

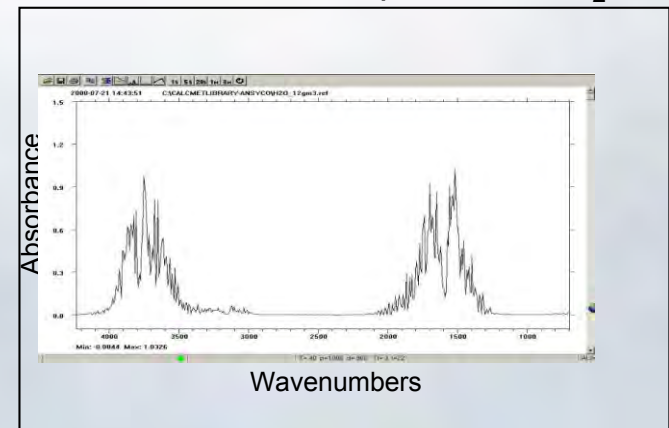
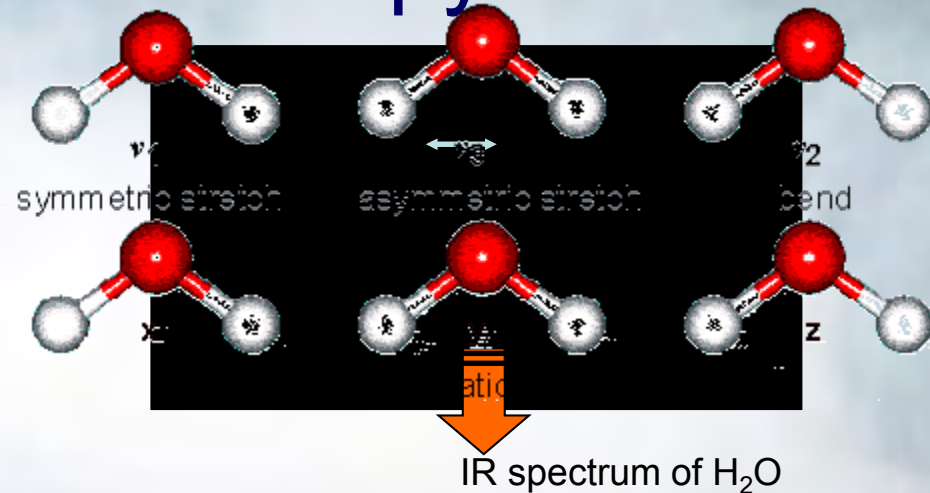
**HCl, H₂O, CO₂, N₂O, CH₄, CO, SO₂,
NO, NO₂, NH₃, HF, VOC's**



Measurement Technology

Infrared Spectroscopy

- IR absorption spectrum is a fingerprint unique to each molecule
- Beer's law: **$A = \epsilon \cdot b \cdot c$**
- **Identification AND quantification**



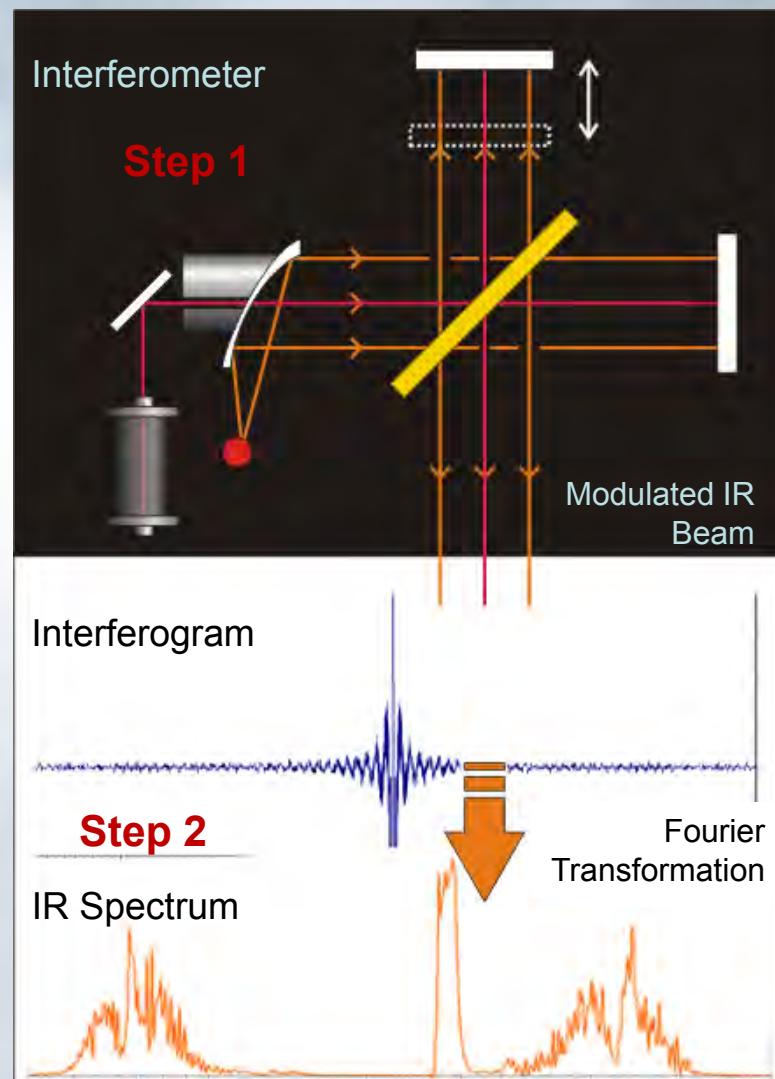
All gases absorb IR light except diatomic homonuclear molecules such as O₂, N₂, H₂, Cl₂, F₂, & the noble gases (He, Ne, Ar..) & "H₂S" is a very weak IR absorber

FT-IR Spectroscopy

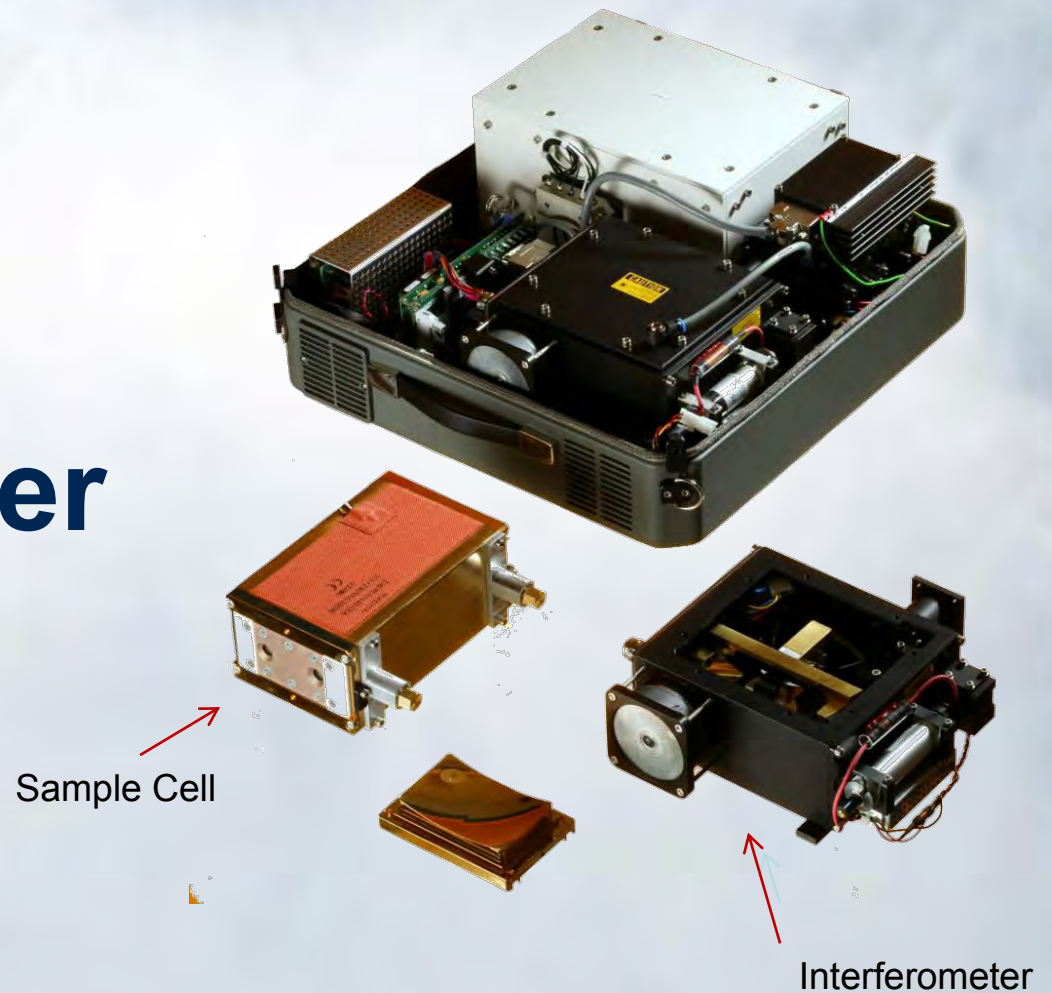
- Based on the use of an optical modulator: *interferometer* (Michelson, circa 1890's)

Two Steps –

- 1).** Interferometer modulates radiation emitted by an IR-source, producing an *interferogram* that has all infrared frequencies encoded into it
- 2).** Apply mathematics (Fourier Transform) to produce IR Spectrum
- IR spectrum measured 10 cycles/sec (10Hz)
- Internal calibration** with precise laser
- Daily Zero calibration, no recalibration required
- Fast, extremely accurate measurements

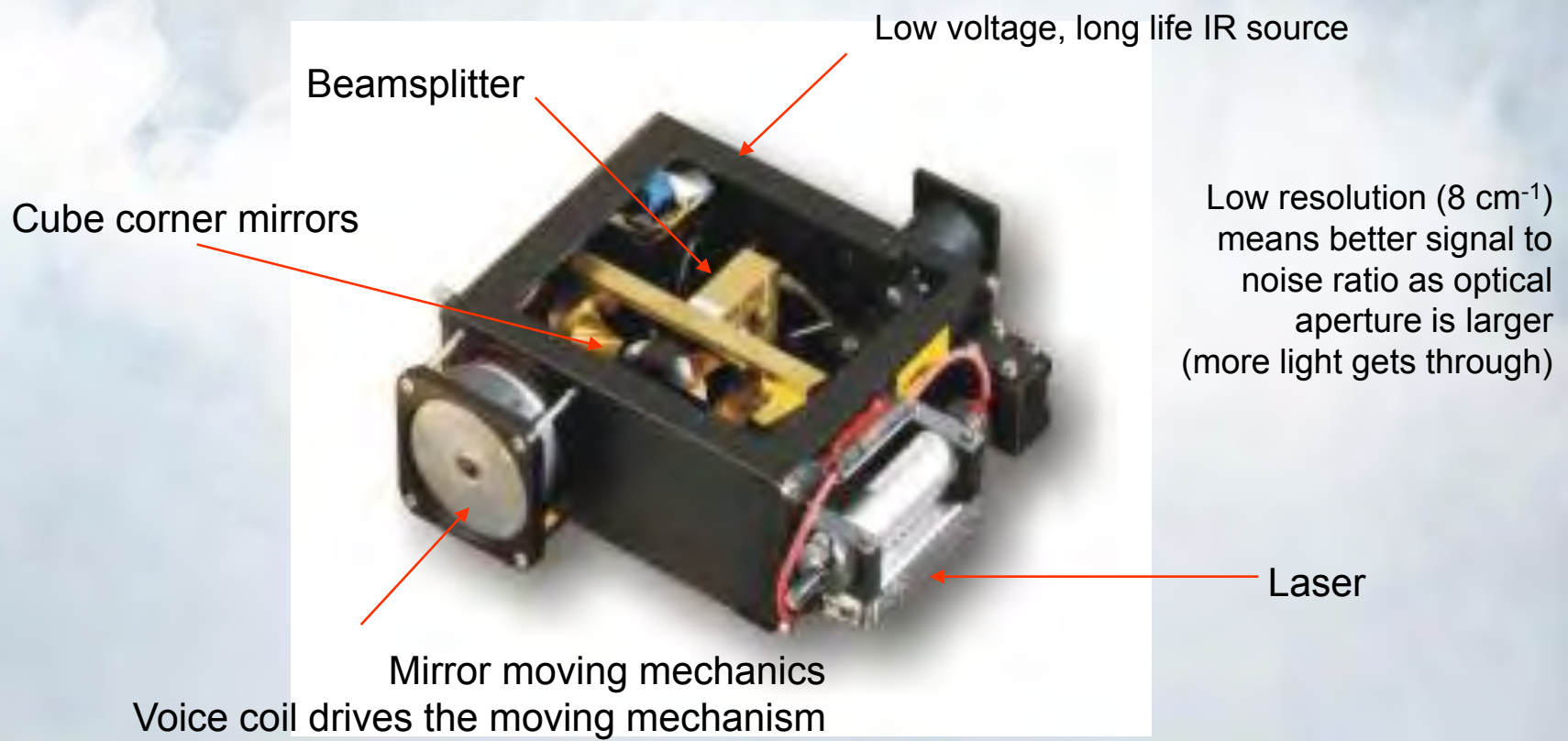


The FTIR Gas Analyzer



Interferometer (Giccor)

Compact size – Rugged – Fast scanning – Excellent stability



The Algorithm (Mod. CLS) Calcmet™ Software Gas Measurements

Measured Components

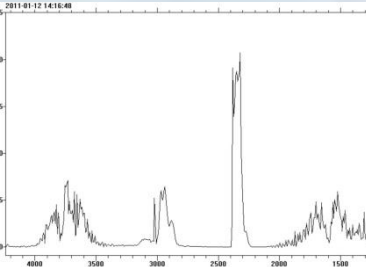
Calculated concentration

Calibration Range /
Output scale

Residual value
QA/QC indicator

The screenshot shows the Calcmet software window with a menu bar (File, Edit, View, Measure, Options, Tools) and a toolbar. The main window displays a table of gas measurements for a sample taken on 2002-03-20 at 08:20:00. The table has columns for Component, Concentration, Range, and Resid. The components listed include Water vapor H2O, Carbon dioxide CO2, Carbon monoxide CO, Methane CH4, Nitrous oxide N2O, Nitrogen monoxide NO, Nitrogen dioxide NO2, Sulfur dioxide SO2, Hydrogen chloride HCl, Hydrogen fluoride HF, NOx, Relays 1, Zero Gas Alarm, Probe Alarm, Sampling Unit Alarm, Heated Lines Alarm, and Flow Alarm. The concentration values are shown in various units (vol-%, mg/Nm, ppm). The Range and Resid columns are color-coded: blue for components with a residual value of 0.0031 or less, green for 0.0034 to 0.0105, and red for 100. A status bar at the bottom shows a green LED indicator and the text 'T=179 p=984 d=500 Ti=51 l=37'. A spectrum plot is visible in the bottom-left corner of the software window.

Ch	Component	Concentration	Range	Resid
1	Water vapor H2O	26.1 vol-%	35	0.0031
2	Carbon dioxide CO2	10.8 vol-%	35	0.0034
3	Carbon monoxide CO	260 mg/Nm	1300	0.0050
4	Methane CH4	5.6 mg/Nm	300	0.0051
5	Nitrous oxide N2O	14.2 mg/Nm	300	0.0105
6	Nitrogen monoxide NO	347 mg NO	600	0.0062
7	Nitrogen dioxide NO2	0.83 mg/Nm	300	0.0054
8	Sulfur dioxide SO2	344 mg/Nm	600	0.0073
9	Hydrogen chloride HCl	9.9 mg/Nm	300	0.0053
11	Hydrogen fluoride HF	7.4 ppm	100	0.0031
201	NOx	347 mg/Nm	600	
223	Relays 1	257	100	
226	Zero Gas Alarm	0.00	1	
227	Probe Alarm	0.00	1	
228	Sampling Unit Alarm	0.00	1	
229	Heated Lines Alarm	0.00	1	
230	Flow Alarm	0.00	1	



Saving Results

- Text file
- Spectrum file

Status led: ● or ● or ●




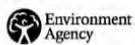
Spectrum file is the raw measurement data, which can be re-analysed if necessary. Spectrum files also contain important hardware status information (tamperproof).

Validation & Certification

FTIR Methodology accepted by leading test organizations including :

- **European standard** EN 15267 -3 Performance standards and test requirements for the AMS which measure stack emissions.
- TUV & MCERTS 3rd party verification
- **USEPA** Test Method 320
- **ASTM** Test Method D6348
- **MCERTS** M22



PRODUCT CONFORMITY CERTIFICATE

This is to certify that the
GASMET MULTI-GAS ANALYSER
CX4000 with Oxitec 500 E SME 5 Oxygen Analyser,
DX4000 & EN4000 Multi-gas Analyser
 manufactured by:
Gasmet Technologies OY
 Pulttie 8 A 1
 FIN-00880 Helsinki
 Finland

has been assessed by Sira Certification Service
 and for the conditions stated on this certificate complies with:
**MCERTS Performance Standards for Continuous Emission
 Monitoring Systems, Version 3.1 dated July 2008,**
EN 15267-3:2007,
 & QAL 1 as defined in EN 14181: 2004

Certification Ranges	
CO 0 to 75 mg/m ³	0 to 300mg/m ³
SO ₂ 0 to 75 mg/m ³	0 to 500mg/m ³
HCl 0 to 15 mg/m ³	0 to 50mg/m ³
NO _x 0 to 200 mg/m ³	0 to 500mg/m ³
H ₂ O 0 to 100 mg/m ³	
NH ₃ 0 to 15 mg/m ³	
CO ₂ 0 to 25 % vol	
O ₂ 0 to 25 % vol*	
H ₂ O 0 to 30 % vol	

* Certification range only applies to CX4000 analyser with Oxitec 500 E SME 5 oxygen analyser option.

Project No: 6740062 & 6740334
 Certificate No: SIRA MC 030014/04
 Issue Date: 04 July 2008
 This Certificate issued: 16 March 2010
 Renewal Date: 03 July 2013

Technical Director

MCERTS is operated on behalf of the Environment Agency by
Sira Certification Service
 12 Aoom Industrial Park, Crayford Road, Crayford
 Dartford, Kent, UK, DA1 4AE
 Tel: 01322 520500, Fax: 01322 520501

This certificate may only be reproduced in its entirety and without change.

$\Delta X_{max,i}$	$\sqrt{\sum_{i=1}^n (\Delta X_{max,i})^2}$	$\frac{\Delta X}{L}$	$\frac{\Delta X_{max,i}}{L}$
-0.26 mg/m ³	-0.15 mg/m ³	0.022	0.022
0.53 mg/m ³	0.34 mg/m ³	2.116	2.116
0.33 mg/m ³	0.18 mg/m ³	0.033	0.033
0.05 mg/m ³	0.03 mg/m ³	0.001	0.001
0.05 mg/m ³	0.03 mg/m ³	0.000	0.000
-0.28 mg/m ³	-0.16 mg/m ³	0.027	0.027
-0.26 mg/m ³	-0.15 mg/m ³	0.022	0.022
0.09 mg/m ³	0.05 mg/m ³	0.003	0.003
0.14 mg/m ³	0.08 mg/m ³	0.006	0.006
0.30 mg/m ³	0.17 mg/m ³	0.030	0.030
$\Delta X_{max} = \sqrt{\sum_{i=1}^n (\Delta X_{max,i})^2}$		0.567	0.567
$L_0 = 14 \cdot 1.56$		0.994	0.994
L_0 in % of the limit 15 mg/m ³		6.6	6.6
L_0 in % of the limit 15 mg/m ³		40.0	40.0

QAL 1 of EN 14181

US EPA TM 320 Summary

Circa mid 1990's based on report prepared for USEPA by spectroscopists [Grant Plummer, Tom Dunder, Tom Geyer]

TM seeks the FTIR vendor to supply - 1. Raw spectra 2. Calibration References 3. Algorithm and a 3rd party can then replicate results as measured on the FTIR in the field.

- Self Validating
- Requires challenging the system with span gas rather the system
- No consideration in the method that the same analyzer is measuring all the gases

Typical analytical procedure to complete method 320 / 321 test
From paper by Maxwell Lee and John B. Koogler: Gas Emissions Testing By EPA Methods 320: Procedures And Results, Florida Section of the Air and Waste Management Association on Sept. 7-9, 2003

PRE-TEST

- 1) Background spectrum
 - Evaluate diagnostics of the instrumentation
- 2) Baseline (cylinder UHP-N₂) (i.e. zero check)
 - Determine the level of background noise
 - Observe spectrum for baseline fit, i.e., indicates vibrations/perturbations affecting instrument
- 3) Calibration Transfer Standard (cylinder 100-ppm ethylene, i.e. span check)
 - Determine level of response to inert gas (e.g., C₄H₁₀) to evaluate the spectral response and stability of the instrument
- 4) Direct analyte measure (e.g. cylinder 50-ppm HCl)
 - Create a field Reference Spectrum
- 5) Baseline
 - Note baseline flush/clean out FTIR sample cell
 - Observe spectrum for baseline fit
- 6) Spectra of stack gas
 - Determine approximate stack gas analyte concentration
- 7) Optional - 3 Spectra of QA-spike gas and makeup of UHP-N₂
 - Create field Reference Spectrum of analyte at approx. stack gas concentration
- 8) Optional - 3 Spectra of QA-spike gas and makeup of ambient air (typical moisture 1-2%)
 - Determine potential interference from low moisture
- 9) Baseline
- 10) 3 Spectra of QA-spike gas
 - Ensure acceptable analyte recovery

TEST - Run 1, 2, and 3 (repeat each run)

- 1) Baseline
- 2) 10 sequential spectra of stack gas (typical averaging time is 3 minutes)
- 3) Baseline
- 4) 3 Spectra of QA-spiked stack gas
 - must indicate ±30 percent expected recovery

POST-TEST

- 1) Baseline
- 2) Calibration Transfer Standard (i.e span check)
- 3) Direct analyte measure
- 4) Baseline

Fractional Model Uncertainty (FMU)
Minimum Analyte Uncertainty, (MAU)

ASTM D-6348

- More intuitive document, Comprehensive details on mechanics, construction, software associated with an FTIR Gas Analyzer
- Also Self-Validating
- Still onerous on spiking but not to the same extent as Method 320
- Similar requirements as Method 320 in challenging the sample probe & transport system not just the gas analyzer


Designation: D 6348 – 03

Standard Test Method for Determination of Gaseous Compounds by Extractive Direct Interface Fourier Transform Infrared (FTIR) Spectroscopy¹

This standard is issued under the fixed designation D 6348; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last approval. A superscript symbol (1) indicates an editorial change since the last revision or approval.

INTRODUCTION

This extractive FTIR based field test method is used to quantify gas phase concentrations of multiple target analytes from stationary source effluent. Because an FTIR analyzer is potentially capable of analyzing hundreds of compounds, this test method is not analyte or source specific. The analytes, detection levels, and data quality objectives are expected to change for any particular testing situation. It is the responsibility of the tester to define the target analytes, the associated detection limits for those analytes in the particular source effluent, and the required data quality objectives for each specific test program. Provisions are included in this test method that require the tester to determine critical sampling system and instrument operational parameters, and for the conduct of QA/QC procedures. Testers following this test method will generate data that will allow an independent observer to verify the valid collection, identification, and quantification of the subject target analytes.

1. Scope

1.1 This field test method employs an extractive sampling system to direct stationary source effluent to an FTIR spectrometer for the identification and quantification of gaseous compounds. This test method is potentially applicable for the determination of compounds that (1) have sufficient vapor pressure to be transported to the FTIR spectrometer and (2) absorb a sufficient amount of infrared radiation to be detected.

1.2 This field test method provides near real time analysis of extracted gas samples from stationary sources. Gas streams with high moisture content may require conditioning to minimize the excessive spectral absorption features imposed by water vapor.

1.3 This field test method requires the preparation of a source specific field test plan. The test plan must include the following: (1) the identification of the specific target analytes (2) the known analytical interferences specific to the test facility source effluent (3) the test data quality necessary to meet the specific test requirements and (4) the results obtained from the laboratory testing (see Annex A1 for test plan requirements).

1.4 The FTIR instrument range should be sufficient to measure from high ppm(v) to ppb(v) and may be extended to higher or lower concentrations using any or all of the following procedures:

1.4.1 The gas absorption cell path length may be either increased or decreased.

1.4.2 The sample conditioning system may be modified to reduce the water vapor, CO₂, and other interfering compounds to levels that allow for quantification of the target compound(s), and

1.4.3 The analytical algorithm may be modified such that interfering absorbance bands are minimized or stronger/weaker absorbance bands are employed for the target analytes.

1.5 The practical minimum detectable concentration is instrument, compound, and interference specific (see Annex A2 for procedures to estimate the achievable minimum detectable concentrations (MDCs)). The actual sensitivity of the FTIR measurement system for the individual target analytes depends upon the following:

1.5.1 The specific infrared absorptivity (signal) and wavelength analysis region for each target analyte,

1.5.2 The amount of instrument noise (See Annex A6), and

1.5.3 The concentration of interfering compounds in the sample gas (in particular, percent moisture and CO₂), and the amount of spectral overlap imparted by these compounds in the wavelength region(s) used for the quantification of the target analytes.

1.5.4 Any sampling system interferences such as absorption or outgassing.

1.6 Practices E 168 and E 1252 are suggested for additional reading.

1.7 This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and

¹ This test method is under the jurisdiction of Committee D22 on Sampling and Analysis of Atmospheres and is the direct responsibility of Subcommittee D22.02 on Ambient Atmospheres and Source Emissions.
 Current edition approved October 1, 2003. Published December 2003. Originally approved in 1995. Last previous edition approved in 1995 as D 6348 – 95.

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Minimum Detectible Concentration (MDC)
Noise Equivalent Absorbance (NEA)

Taking measurements following ASTM D6348-03 method.

- **A). Pre-Test** (performed prior to going to field)
 - 1. N₂ (5.0 purity) gas directed through entire sampling system, record background after stabilization occurs.
 - 2. Select suitable CTS (ie Ethylene), challenge the system & record response time & recovery, verify results $\pm 5\%$ expected value
 - 3. Ambient air is sampled & spiked with most reactive analyte to verify dilution apparatus (1:10 dilution or less) is working (verify $\pm 50\%$ target reading)
- **B). Field Sampling & Analysis**
 - 1. Conduct system leak check
 - 2. Flow N₂ gas, wait stabilization and then record background spectrum
 - 3. Flow CTS gas to FTIR gas cell, verify results $\pm 5\%$ expected value
 - 4. Spiking is performed for each analyte gas (normally CO₂ & H₂O are exempt) (verify $\pm 50\%$ target reading)
 - 5. Test runs – 60 mins or longer
 - 6. At test conclusion, repeat CTS gas test to FTIR to verify results $\pm 5\%$ expected value
 -
 -

The above is intended to provide an outline of the ASTM D6348-03 method before proceeding with any regulatory testing please read and follow all steps as outlined in ASTM documentation.

MCERTS M22

Development by MCERTS in Great Britain to replace ASTM D 6348-03.

“Suitable check gases shall be selected (from the target components, where possible) to demonstrate that the FTIR is capable of producing valid and accurate spectra at the frequencies and absorbance ranges that the analytical model will be using.

Note: The check gas should not be considered as a traditional span of its constituent components (as no adjustment to the analyser is made) but rather an intrinsic validation of the analyser functionality.”

Truly FTIR friendly



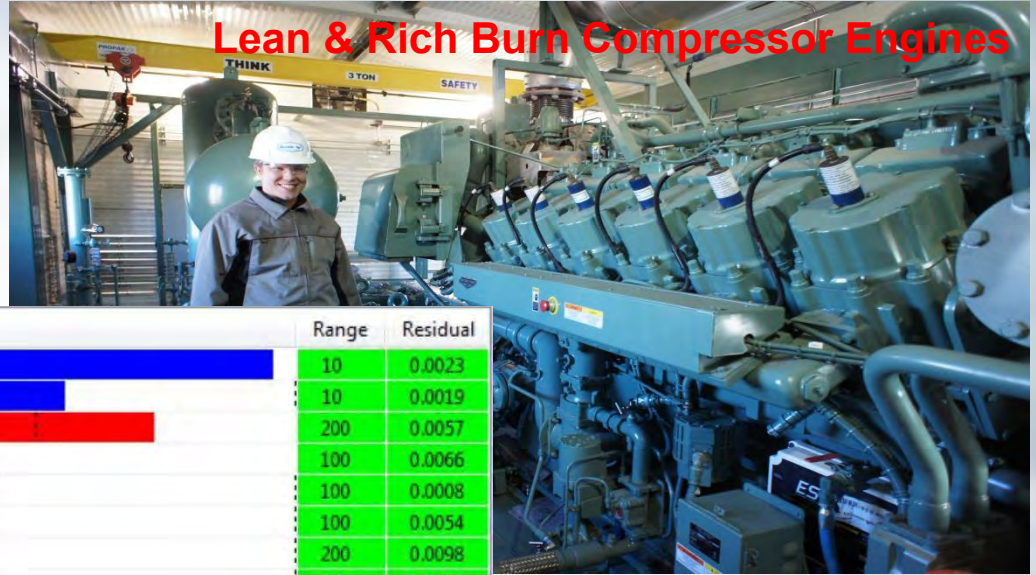
Technical Guidance Note
(Monitoring) **M22**

Measuring stack gas emissions
using FTIR instruments

Environment Agency
Version 2
March 2011

Formaldehyde Emissions - RICE MACT

40CFR63 subpart ZZZZ (Quad Z)



Ch	Component	Concent...	Unit	Range	Residual
1	Water vapor H2O	9.34	vol-%	10	0.0023
2	Carbon dioxide CO2	2.96	vol-%	10	0.0019
3	Carbon monoxide CO	113.85	ppm	200	0.0057
4	Nitrogen monoxide NO	6.52	ppm	100	0.0066
5	Nitrogen dioxide NO2	4.66	ppm	100	0.0008
6	Nitrous oxide N2O	0.91	ppm	100	0.0054
7	Sulfur dioxide SO2	2.07	ppm	200	0.0098
8	Ammonia NH3	0.00	ppm	15	0.0019
11	Methane CH4 200 ppm	33.72	ppm	50	0.0046
13	Ethane C2H6	1.17	ppm	50	0.0046
16	Formaldehyde CHOH	3.053	ppm	15	0.0004



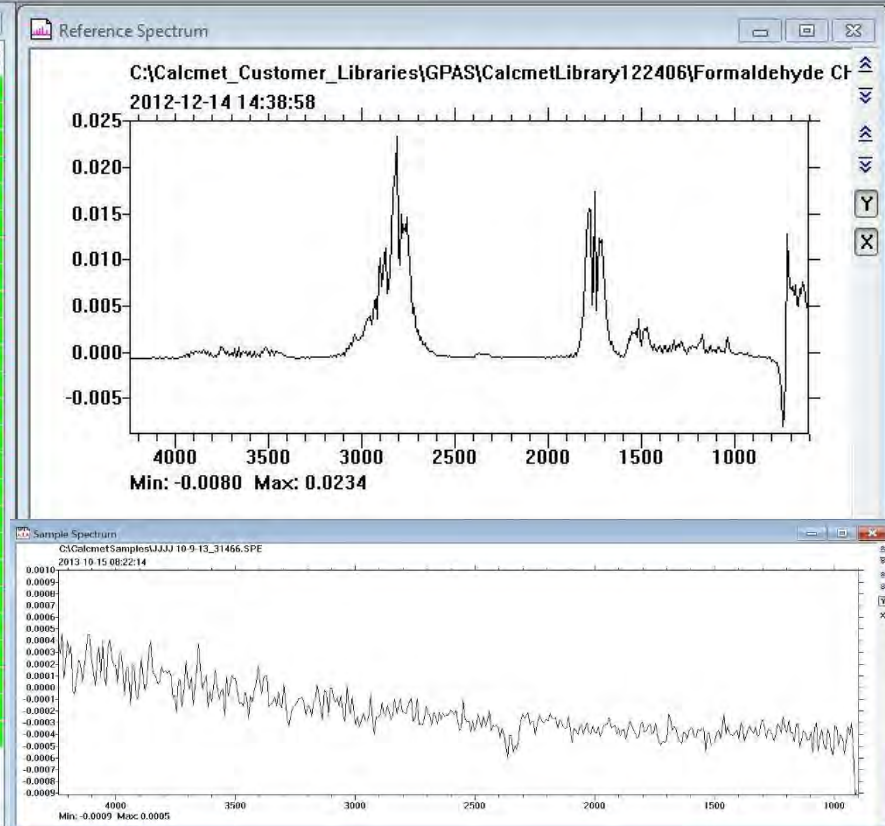
Formaldehyde Emissions - RICE MACT

ASTM D6348 Steps :

- Pre-Test : Determining the level of noise of the FTIR_Running UHP Nitrogen through analyzer
- Calculating MAU (Baseline spectrum + lowest HCHO reference in spectral region of interest)
- Calculating FMU (Analyze Sample at varying HCHO concentrations)

Analysis Results - SN122406_c11_11_Rev1.lib.LIB: Formaldehyde CH2O_24.9 ppm permeation.ref

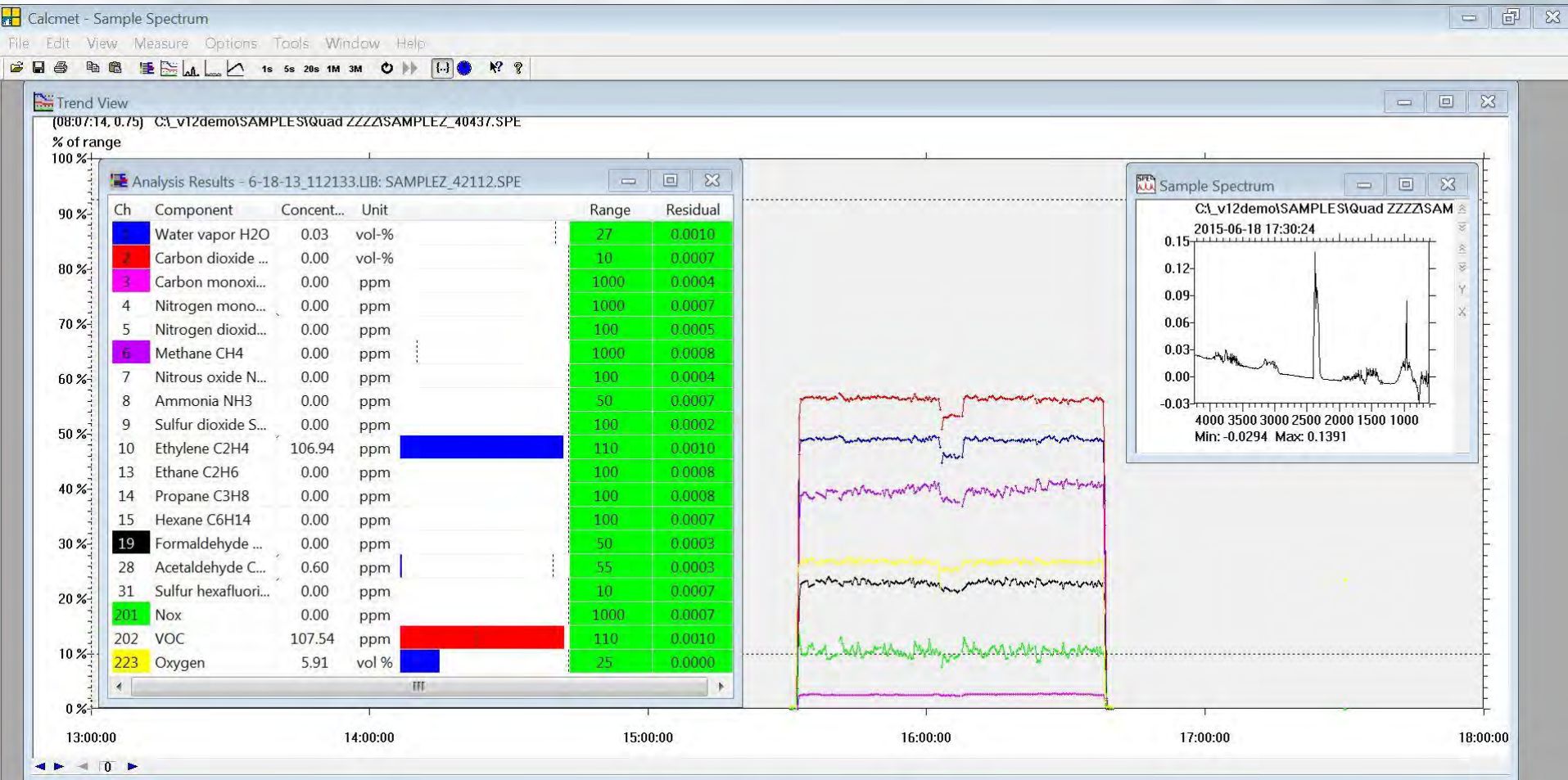
Ch	Component	Concentration	Unit	Range	Residual
1	Water vapor H2O	0.00	vol-%	25	0.0002
2	Carbon dioxide CO2	0.00	vol-%	10	0.0000
3	Carbon monoxide CO	0.00	ppm	1000	0.0001
4	Nitrous oxide N2O	0.00	ppm	100	0.0001
5	Nitrogen monoxide NO	0.00	ppm	1000	0.0000
6	Nitrogen dioxide NO2	0.00	ppm	100	0.0000
7	Sulfur dioxide SO2	0.00	ppm	100	0.0009
8	Ammonia NH3	0.06	ppm	50	0.0016
9	Hydrogen chloride HCl	0.00	ppm	50	0.0000
10	Hydrogen fluoride HF	0.02	ppm	50	0.0000
11	Methane CH4	0.00	ppm	1000	0.0000
12	Ethane C2H6	0.00	ppm	100	0.0000
13	Ethylene C2H4	0.00	ppm	100	0.0016
14	Propane C3H8	0.00	ppm	100	0.0000
15	Hexane C6H14	0.00	ppm	100	0.0000
16	Formaldehyde CHOH	24.90	ppm	50	0.0000
17	Sulfur hexafluoride SF6	0.00	ppm	10	0.0000
18	Acetaldehyde C2H4O	0.00	ppm	50	0.0000
19	NOx as NO2	0.00	ppm	1000	0.0000
221	Ambient pressure	1027.00	mbar	1200	0.0000
223	Oxygen	4.42	vol %	25	0.0000
226	Cell temperature	180.00	°C	200	0.0000
301	Formaldehyde Referenc...	24.90	ppm	100	0.0000
302	Formaldehyde MAU	1.33	ppm	100	0.0000
303	Formaldehyde FMU	0.00	ppm	100	0.0000



Formaldehyde Emissions - RICE MACT

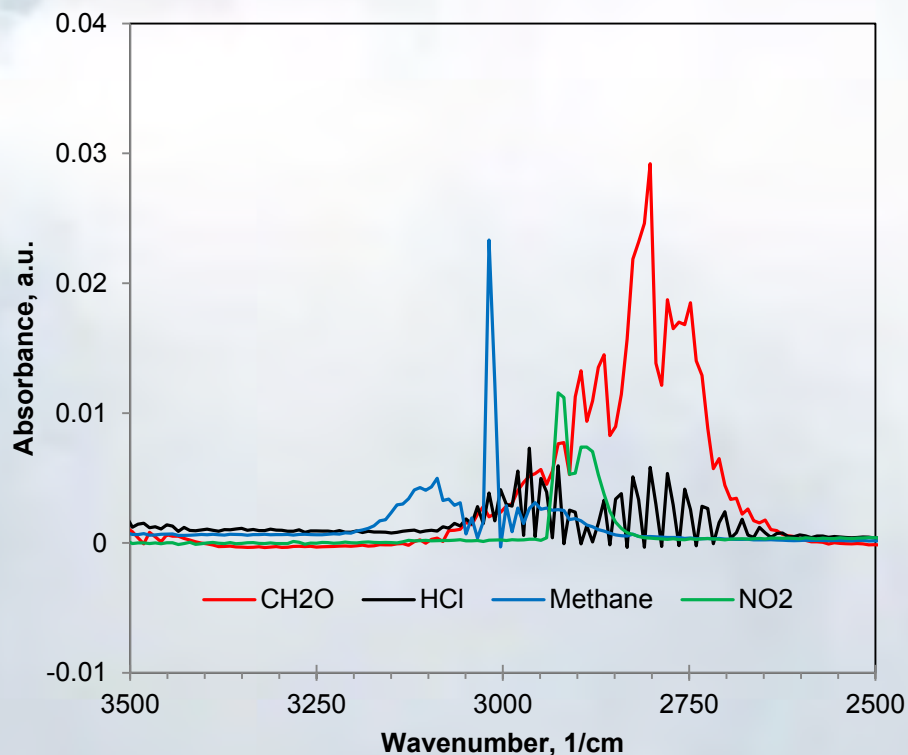
ASTM D6348 Steps:

- Apply CTS (Typically ~ 100 ppm Ethylene) Pre & Post Test run
- Dynamic Spiking for analyte (Formaldehyde), 10x dilution
- Test Runs



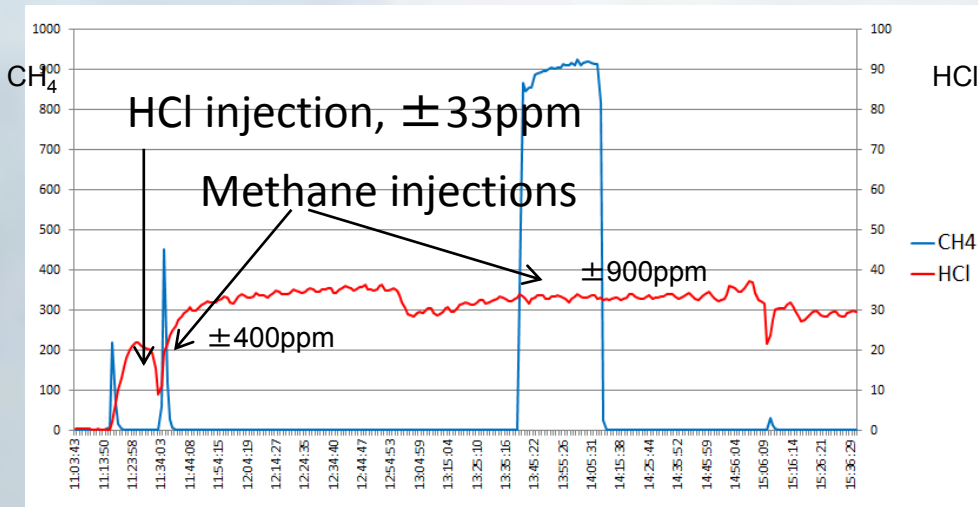
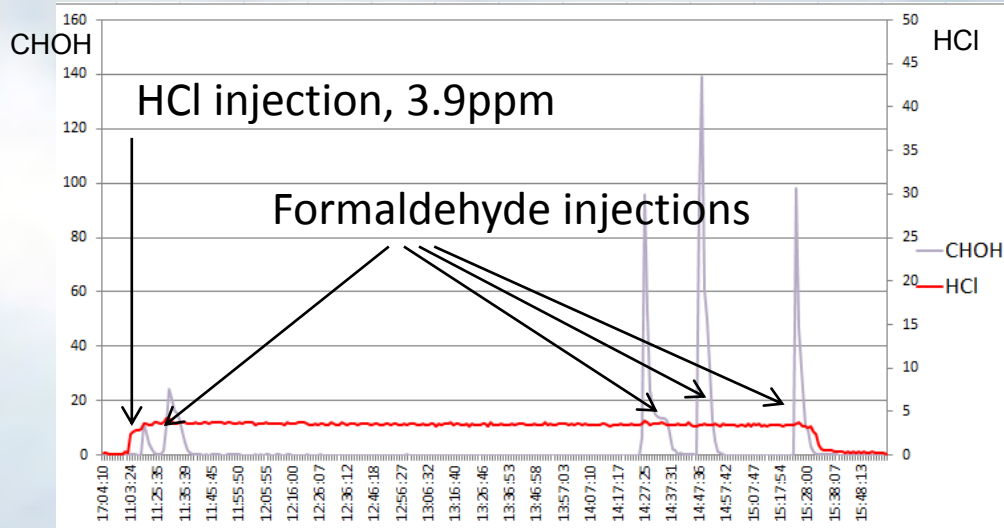
HCl Emissions _ Cement & Boiler MACT

Special challenges for low level measurement of HCl.
Sample transport, Analytical & Traceable HCl Standards



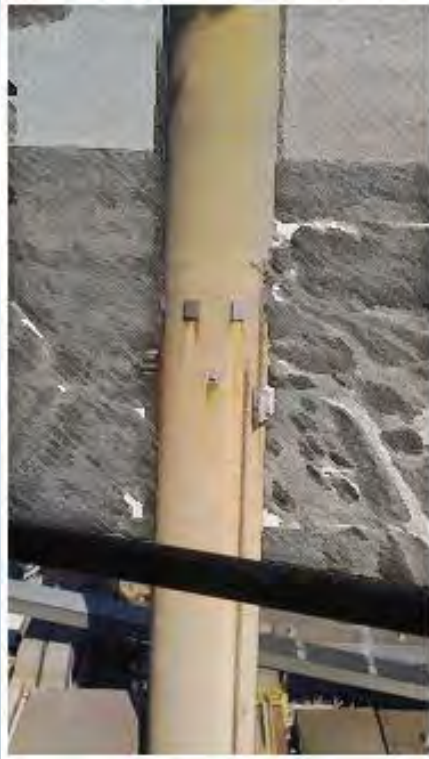
EPA ORD's Multi-Pollutant Combustion Research Facility

Interference Tests



- As per proposed PS18, interference test required for:
 - CO,
 - CO₂,
 - H₂O,
 - CHOH,
 - CH₄,
 - SO₂,
 - NO₂
 - O₂
- No interference on Gasmeter System.

HCl emissions measurement 300 ft. stack challenge



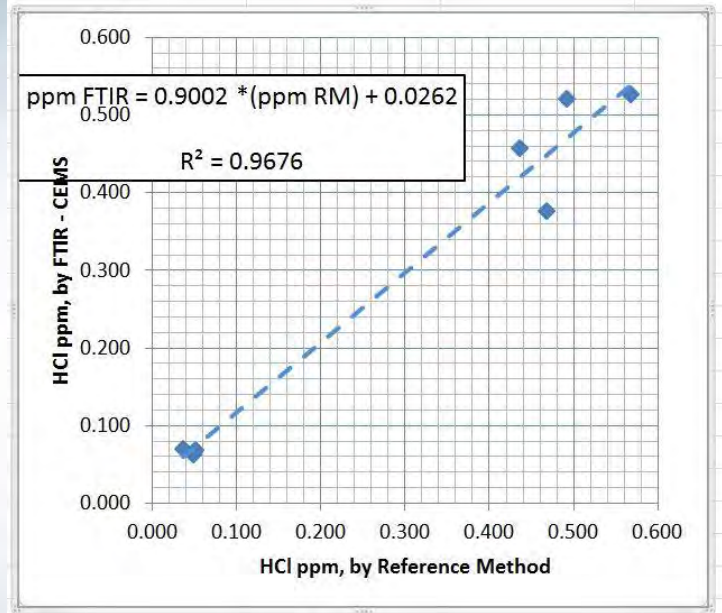
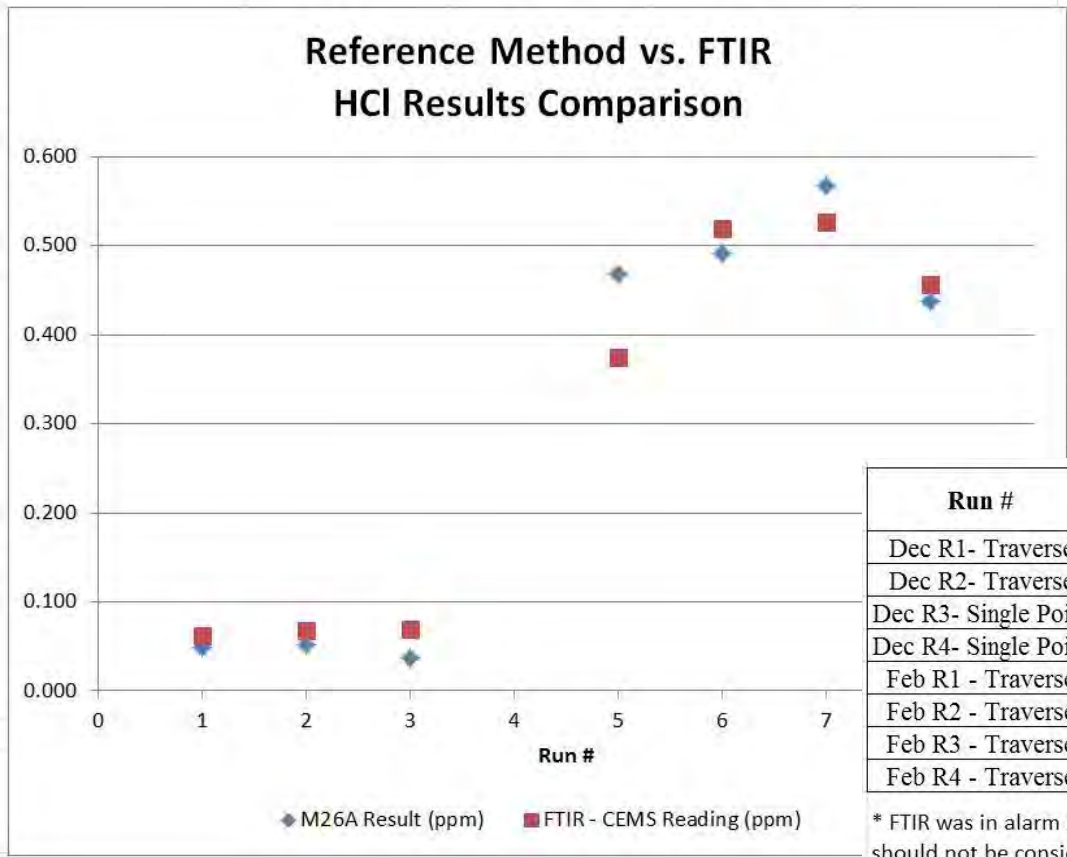
- 300ft between the sample point and the CEMS shelter
- Full extractive not possible
- CEMs installed at the stack, on the sampling walkway



Comparative HCl Measurement Data

FTIR vs M26A

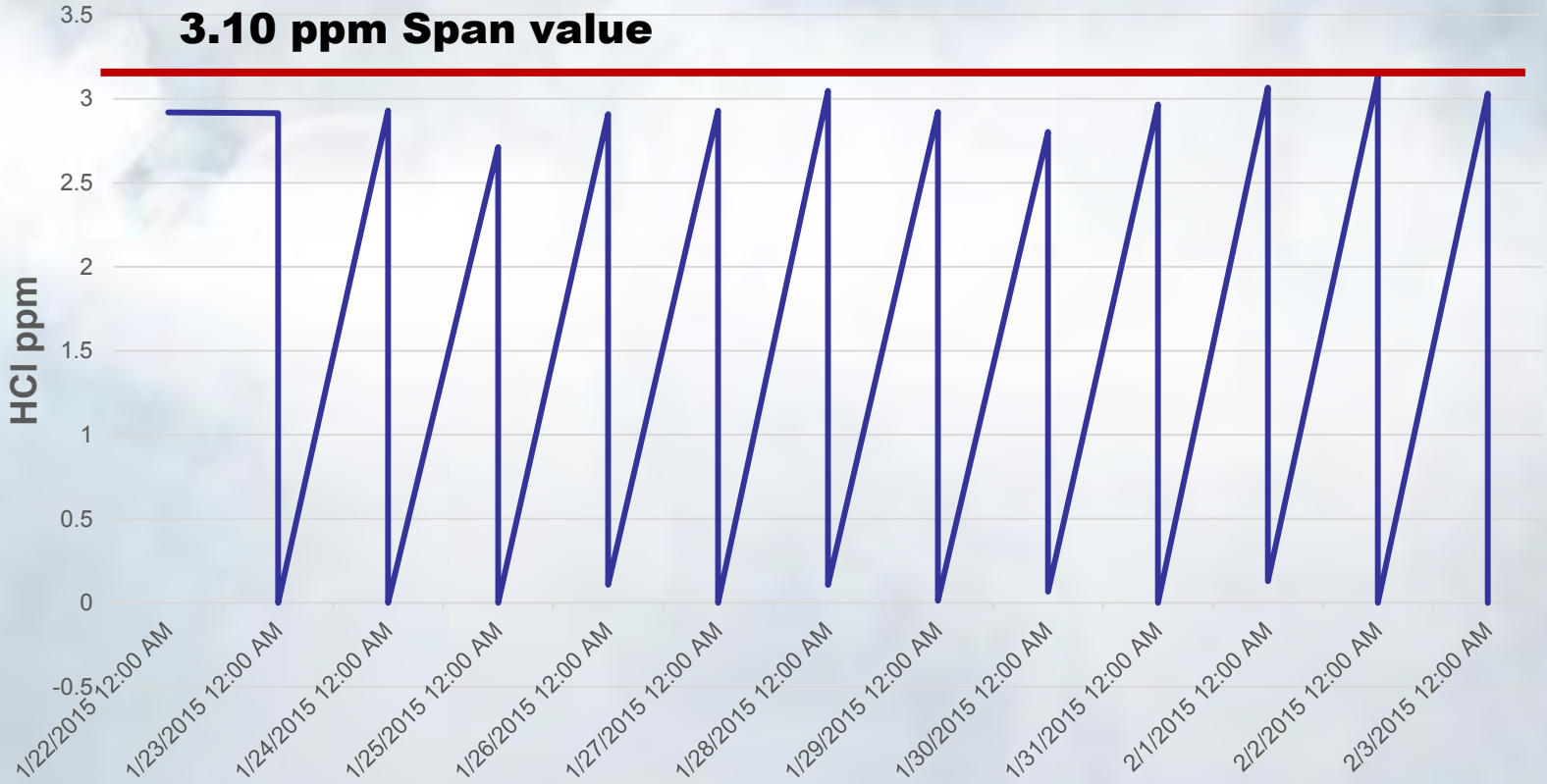
Reference Method vs. FTIR
HCl Results Comparison



Run #	Date	Test Time	M26A Result (ppm)	FTIR - CEMS Reading (ppm)
Dec R1- Traverse	12/12/2013	11:54-13:41	0.050	0.062
Dec R2- Traverse	12/12/2013	14:02-15:35	0.052	0.068
Dec R3- Single Point	12/12/2013	14:03-15:33	0.037	0.070
Dec R4- Single Point	12/12/2013	16:00-17:30	0.179	0.027
Feb R1 - Traverse	26/02/2014	07:42-09:18	0.468	0.375
Feb R2 - Traverse	26/02/2014	09:39-11:11	0.492	0.519
Feb R3 - Traverse	26/02/2014	11:26-12:59	0.568	0.526
Feb R4 - Traverse	26/02/2014	13:30-15:02	0.437	0.457

* FTIR was in alarm mode during a portion of this test run. Data point presented; however should not be considered valid in any interpretation.

FTIR HCl CEMS _ Daily Zero & Span Challenge



**Gasmet FTIR HCl monitor readings (ppm)
Jan - Feb 2015**

FTIR & System Maintenance

- Automatic background measurement once a day
- Nitrogen and pressured air always available
- Visual inspection once a week
- Replace particle filters of the sampling system and probe regularly (2-4 times a year)
- Never introduce condensed sample into the sample cell
- Always purge the sample cell after the measurement
- Service visit and water calibration once a year
- Remote access via TCP/IP



Advantages of FTIR in Emission monitoring applications

- **Simultaneous, real time and fast measurement of multi- gases**
NH₃, NO, NO₂, CO, CO₂, CH₄, HCHO, SO₂, HCl, HF, N₂O, H₂O, PFC's, SF₆,
all VOC 's + many other gases –
- No water removal, no dilution, no sample preparation
- Wide dynamic calibration range, very specific
- Ideal to measure reactive gases like NH₃, HCl, Formaldehyde, H₂O
- Results reported either on wet or dry basis and/or to ref O₂ level
- Low Cost of Ownership - Only one analyzer to calibrate and maintain
- Validation of results - Sample spectrum contains all information regarding sample gas matrix and analyzer parameters
- **Staying one step ahead** - Future testing requirements. Simply add gas to application library

**Thank you for this opportunity to
present the FTIR Multi-Gas
measurement technology**

Questions ???



Acknowledgements:

USEPA Jeff Ryan et al

AQS Dan Todd et al

Great Plains Analytical Services Jordan Williamson et al