Continuous Emissions Monitoring Systems
-CEMS-
…Sample Systems Considerations…

UNIVERSAL Analyzers Inc.

AMETEK®
O'BRIEN

September 2026

CISCO
CUSTOM INSTRUMENTATION SERVICES CORPORATION'S

14th Annual User's Group Meeting

Back-Ground for Bob Bertik…

- In the CEMS business for over 30 years

- Was a System Integrator in my early years, now concentrate on the "piece parts" that make up the sample conditioning system segment of most types of gas analysis systems

- Currently work for Universal Analyzers an Ametek company – 23 yrs in…

- Universal Analyzers manufactures sample conditioning systems and components "pieces-parts" in the USA (Carson City, Nevada specifically) and sells / consults and supports globally

PREAMBLE

- CEMS have been in play for +- 50 years…some used for compliance purposes and others for process measurements. ***FUN FACT…EPA WAS ESTABLISHED IN 1970***

- CEMS technology and practices for the most part have matured in the USA along with a few other areas in the world but there are still many areas globally that have requirements but little understanding of the importance of the "piece parts" that make up the system.

- Many of the godfathers of the industry have since retired or moved on leaving the new generation with little experience on the what can arguably be the most important part of any gas analysis system…that is the Sample Conditioning and Handling Components of a CEMS

PREAMBLE CON'T

- Many that have the responsibility to maintain and operate any CEMS most likely INHERITED what they have, didn't have a say in what might have been appropriate for their application and don't realize there may be a different way or a better way.

- Today's brief discussion will touch on many of the various considerations that should go into the thought process when specifying and designing or "after the fact" upgrading a **CEMS Sample Probe**…

Major Components of a CEMS

A

"Front-End" Sample Conditioning Components

-Gas Sample Probes
-Heated Sample Line
-Gas Coolers / Chillers
-Sample Pump
-Peristaltic Pump
-Ammonia Scrubber
 Flowmeters, Regulators,
 Pressure, Vacuum
Gauges, Alarms…

B

Analyzers

-NOx
-CO
-O2
-SOx
-CO2
-HCl
-Hg
-THC
. H2S
. CH4

C

Calibration Gas

-Span Gases
-Zero Gas

D

CeDAR CEMS software

Data Acquisition Handling and Reporting System

-Compliance Software

-Data Collection

-Housekeeping functions such as calibrations, blow back, alarms, etc.

LOTS TO THINK ABOUT AND CONSIDER

…Too much to read but you get the idea…

Water %, Sample Line Maintain temperature, Process Temperature, Analyzer flow rates, Stack Pressure; Vortex induced vibrations, wall effects, upstream equipment, proximate pipeline bends, positioning in gas flow, center 1/3 sampling, aerosol formation at tip of probe tube, flow eddies at tip of probe tube, particulate accumulation at tip of probe tube, Dust Load, minimizing diameter of sample path, maintaining constant sample pathway diameter, surface finish, selection of surface treatment, appropriate material selection for media, beware use of dissimilar material, minimize length of sample path, minimize number of components in sample pathway, minimize wetted surface areas, minimize internal volumes, dead legs in sample pathway, dead legs in valves and fittings, threaded connections, flanged connections, seals, avoid contamination accumulation, ability to clean entire sample pathway, ability to remove & replace filtered contamination, ability to validate sample system, minimize flow rate, stratification!!

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ONE SIZE DOES
NOT FIT ALL


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ONE
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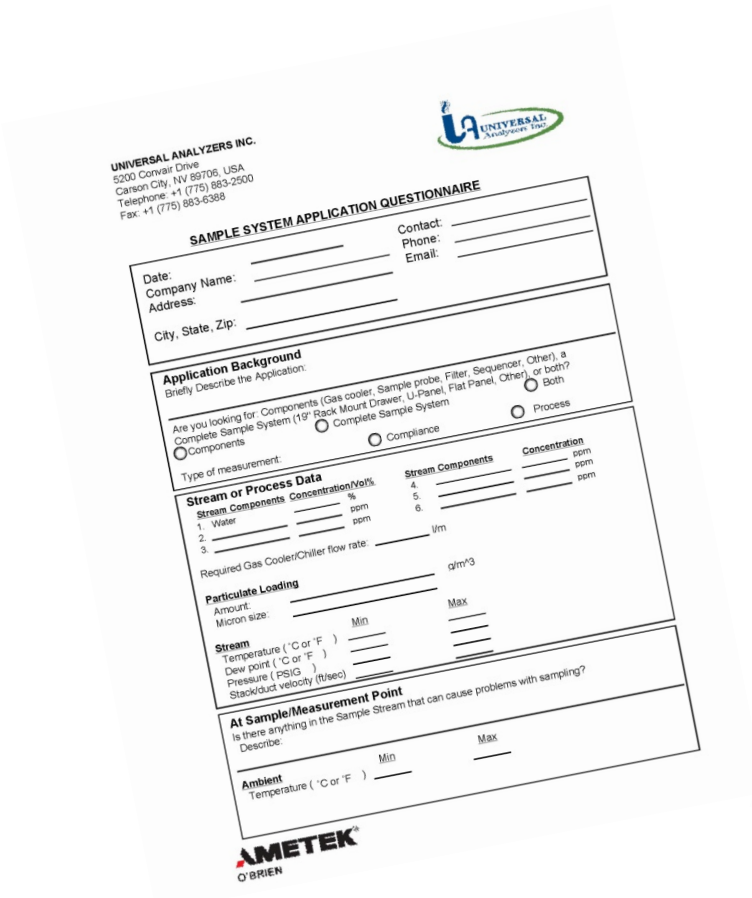
Application Questionnaire

When starting fresh, this or a written spec should always be the guiding document(s)



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Carson City, NV 89706, USA
Telephone: +1 (775) 883-2500
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SAMPLE SYSTEM APPLICATION QUESTIONNAIRE

Date:
Company Name:
Address:
City, State, Zip:
Contact:
Phone:
Email:

Application Background
Briefly Describe the Application:

Are you looking for: Components (Gas cooler, Sample probe, Filter, Sequencer, Other), a Complete Sample System (19" Rack Mount Drawer, U-Panel, Flat Panel, Other), or both?
Components / Complete Sample System / Both

Type of measurement: Compliance / Process

Stream or Process Data

Stream Components	Concentration/Vol%	Stream Components	Concentration
1. Water	%	4.	ppm
2.	ppm	5.	ppm
3.	ppm	6.	ppm

Required Gas Cooler/Chiller flow rate: l/m

Particulate Loading
Amount: g/m^3
Micron size:

Stream Min Max
Temperature (°C or °F)
Dew point (°C or °F)
Pressure (PSIG)
Stack/duct velocity (ft/sec)

At Sample/Measurement Point
Is there anything in the Sample Stream that can cause problems with sampling?
Describe:

Ambient Min Max
Temperature (°C or °F)

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At Sample Point (continued)
Where is the point of measurement in relation to any Pollution Control Device (e.g. SCR, Scrubber, Baghouse, ESP, Flare, Incinerator, etc.)?
Upstream / Downstream / Not Applicable
Is there any excess stack/duct vibration? (e.g. Simple Cycle Gas Turbine) Yes / No

At Mounting Point
Ambient Min Max
Temperature (°C or °F)

Distance to Analyzer:
Length of Sample Line: ft
Return sample to process? Yes, Pressure at Return Point: No
Diameter of stack at Sample Location: ft
Mating Flange Size: ANSI in
Flange Spool length from stack/duct wall: in
Is there an Annulus? Yes, I.: in x w: in x d: in No
I.D. of Sample Line: in

Miscellaneous
Are you interested in PLC services? Yes / No
Are you interested in PLC communications to control room or other (e.g. ModBus, Ethernet, RS232, Internet)? Yes / No
Any special requests for material? SS / Hasteloy / PVDF / PTFE / Ceramic / Other:
Describe any physical sizing constraints:

Thank you for your inquiry.
To submit via Email, select the **"Submit Form"** function from the Tool Bar at the top of your screen.
To submit via Fax, select the **"Print"** function from the Tool Bar at the top of your screen, and send Attn: Sales to (775) 883-6388.
You will be contacted shortly.

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Examples of considerations for an Extractive Sampling System

- Straight Extractive

- “Cold Dry” or “Hot Wet”
  - **Determines the style of probe and analyzer(s)**

- What are we measuring & how many analyzers will be used?
  - **Used to determine flow rate requirement & pump / gas cooler sizing**

- How much dust should we expect at the point of measurement?
  - **Used to determine filter sizing, filter staging and blow back / back purge requirement**

Examples of considerations for an Extractive Sampling System

- Particle size if it can be determined?
  - **Used to determine what the porosity sizing of the filters**

- How much water is present in vol %?
  - **Used to determine proper gas cooler sizing / capacity**

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Examples of considerations for an Extractive Sampling System

- Temperature, Pressure, Velocity & other compounds in the measured gas stream
  - **Used to determine material types, probe and sample line maintain temperatures & any extra probe tube support issues**

- How long should sample line be?
  - **Because we need to know**
  - **Measure twice**
  - **Buy exact or Buy long and trim in the field**

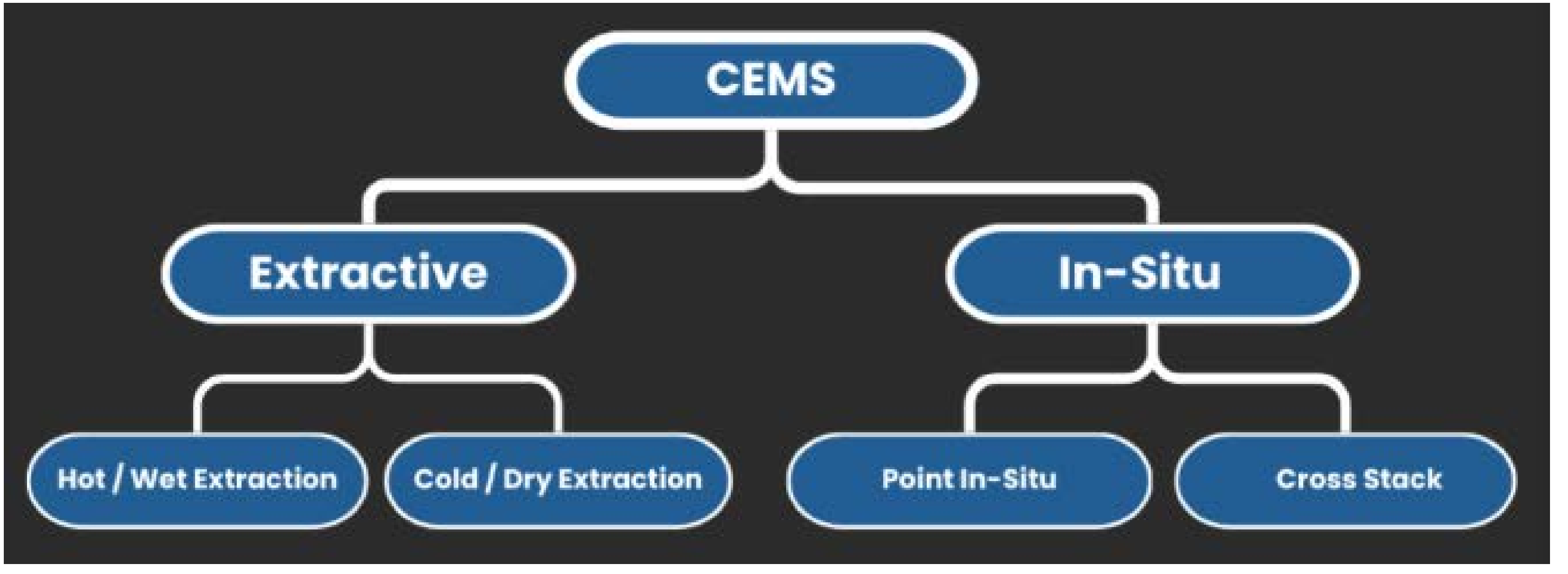
- Voltage, Maintain & Ambient temperature for the sample line
  - **Used for design of heat trace and insulation requirement**

Examples of considerations for an Extractive Sampling System

Hazardous Area Classification (HAZLOC) or General Purpose

- Used to determine heat trace type for sample lines
- Used to determine sample probe heater and gas cooler electronics
- If determined to be Hazardous, we need to take care to prevent the spark and arc that may cause an explosion…not a good thing!

…Lot's to Consider…



So, What's your Methodology of choice?

Sample Probes

Gas Coolers

Heated Sample Line

Sample Conditioning Systems

Accessories

A CEMS Sample Probe is not a probe is not a probe…

They are an engineered product with many options to consider

Types of gas sample probes …

- Extractive - Non-Dilution
- Extractive - Dilution
- Extractive - Low Dust Loading
- Extractive - High Dust Loading
- Extractive – Hazardous Area Classifications
- With NH_3 Converter for Ammonia slip measurement
- Multi-Point Probe Arrays
- Retractable

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Heated Sample Probes
The real purpose …

HEATED FILTER → ***MATING FLANGE*** → ***PROBE TUBE***

- Serves as a Heated Junction Between the Point of Measurement (stack nozzle) and the Heated Sample Line
- Keeps Gas Sample Heated and in a Gas Phase to prevent Cold Spots Avoiding Pre-Mature Condensate Drop Out, scrubbing and choking of the flow path
- Initial Point of Filtration
- Calibration gas inlet for daily cals – EPA compliance
- Provides proper representation of sample with properly engineered and placed probe tube … EPA recommends the tube end at 1 meter off the inside wall of the stack...is that the sweet spot?

SAMPLE PROBE CONSIDERATIONS AGAIN…LOTS TO THINK ABOUT

- Weather Protection Enclosure (NEMA or IP?)
  - o Non-Metallic
  - o Stainless Steel
- Interior enclosure heated and with insulation?
- Filter Temperature maintain…250°F .. 340°F .. 375°F??
- Temperature control (integrated thermoswitch or remote electronic control)?
- Flange Sizing / Flange Orientation?
- Heat Shrink Entry Seal for Heated Sample Line – SIZE?
- Probe tube length and material and reinforcement?
- Filter Porosity Size / Filter Material?
- Probe tip / Pre Filter?
- Blow Back … from shelter or directly at the probe housing?
- Hazardous or General Purpose?

SAMPLE PROBE MATING FLANGE

Need to specify size to properly mate to stack or duct flange

PLUS

Need to specify orientation
"TOP DEAD CENTER"

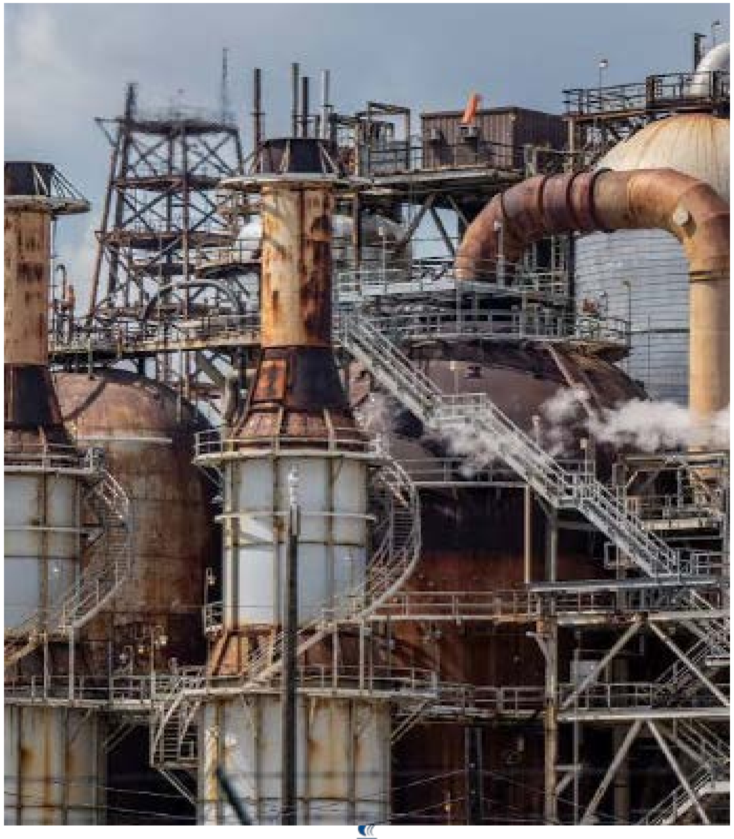
OR

"STRADDLED"

For General Purpose or HAZLOC

- **Most if not all of you work in plants where most or all of your electronics can be considered for General Purpose use and installations.**

- **There is another world out there…Refinery, Petrochem for example where it is imperative that they use electronics that do not spark or arc and blow things up.**



Class / Division Definitions

Class I **-** Contains flammable gases or vapors in quantities large enough to produce an explosion.

Class II **-** Is hazardous due to the presence of combustible dust in the air.

Class III **-** Contains easily ignitable fibers or flyings in the air. However, the quantities of fibers and flyings suspended in the air are not likely to be large enough to cause an explosion.

Division 1 - There is a high probability of an explosive atmosphere in normal operation. This can be for part of the time, up to all the time.

Division 2 - There is a low probability of an explosive atmosphere being present during normal operation.

*Group designations further define the types of gases, and dusts (A, B, C, D) (E, F, G)
*Example of an American certification would be:

- **Class I, Div 1, Groups A, B and C; Class II, Div 2, Groups F and G**

Probe for Hazardous Areas
Certified for the Area Class

FM APPROVED

FM, CSA, ATEX approved for Class I Division II areas
OR suitable for use in
Class I Division II areas with a Purge
OR
Custom configurations with site specific approval through our approval agency.

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5200 CONVAIR DRIVE
CARSON CITY, NV 89706

MODEL NO.
SERIAL NO.
VOLTS Hz
WATTS

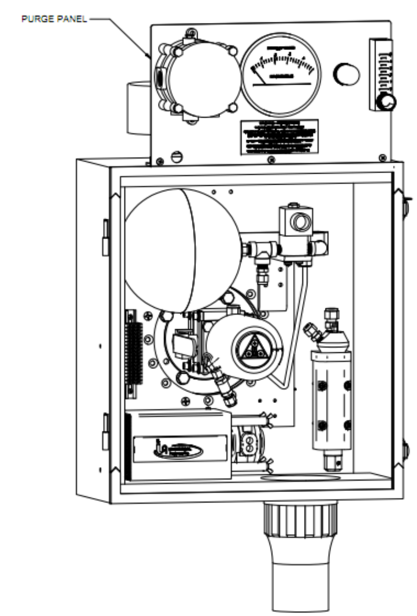
FM APPROVED
CLASS I DIV 2 GROUP A,B,C,D
MAXIMUM AMBIENT TEMPERATURE 93°C
TEMPERATURE RATING T3A

WARNING - EXPLOSION HAZARD -
SUBSTITUTION OF ALL COMPONENTS MAY IMPAIR
SUITABILITY FOR CLASS 1, DIVISION 2

AVERTISSEMENT - RISQUE D' EXPLOSION -
LA SUBSTITUTION DE COMPOSANTS PEUT
RENDRE CE MATERIEL INACCEPTABLE POUR
LES EMPLACEMENTS DE CLASSE 1, DIVISION 2

WARNING - EXPLOSION HAZARD -
DO NOT DISCONNECT EQUIPMENT UNLESS
POWER HAS BEEN SWITCHED OFF OR THE AREA
IS KNOWN TO BE NON-HAZARDOUS

AVERTISSEMENT - RISQUE D' EXPLOSION -
AVANT DE CONNECTER L' EQUIPMENT COUPER
LE COURANT OU S' ASSURER QUE L' EMPLACEMENT
EST DESIGNES NON DANGEREUX



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Probe for Hazardous Areas Utilizing a Purged Enclosure Makes it Suitable for the Area Class

- Additional components or any modifications to the standard, approved configuration void the pre-approval

Solutions include…

- Providing a Purged Enclosure which declassifies the internal components and makes it “suitable for the area classification…less expensive

- Doing a one-off Inspection and Certification performed by a NRTL such as FM, UL, Metlabs, Intertek, etc….more expensive

- Manufacture with all electrically rated components within the enclosure but no Purge or 3rd party inspection and Certification by a NRTL…less expensive

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Common Filter Size and Porosity

A common Filter Porosity (at least for my manufactured sample probes) is 2µm but others use anywhere from 2µm - 7µm

Natural Gas Fired Anything is what I consider low to moderate dust loading and 2µm is typically the best technical solution.

Other applications such as Coal Fired plants, Incinerators, RTO's, Steel, Refineries can be dirtier and while the 2µm may still be the best technical solution, for these, we should consider a larger surface area type filter element and a more aggressive blow back

Particle sizing should also be considered, and certain applications may be sub 2µm. With these applications, a lower porosity filter may be required….such as 1µm or even 0.1µm.

WHEN YOU NEED IT…YOU NEED IT

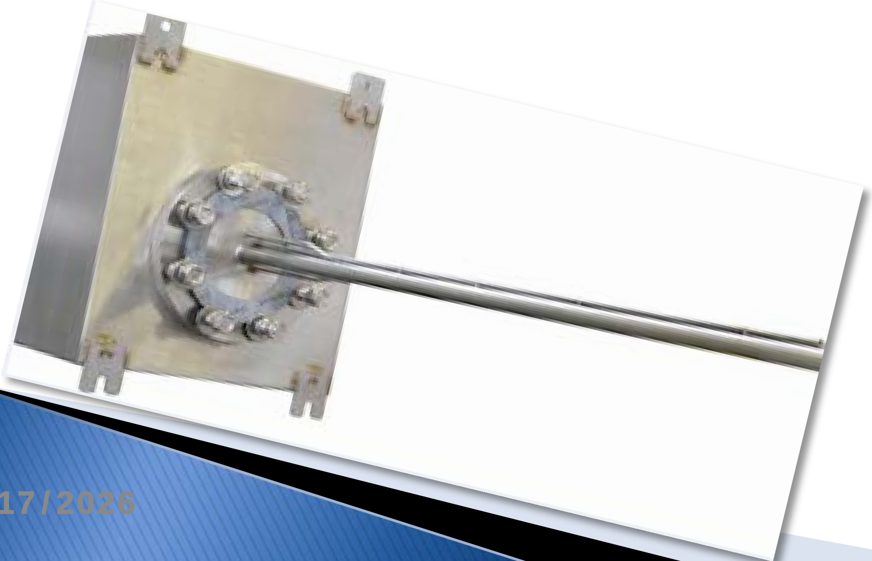
Choices

Ceramic …. SS
Hastelloy … Glass Fiber
Polyethylene … Teflon

Large and Larger Surface Areas

Common Probe Tube Material Selection

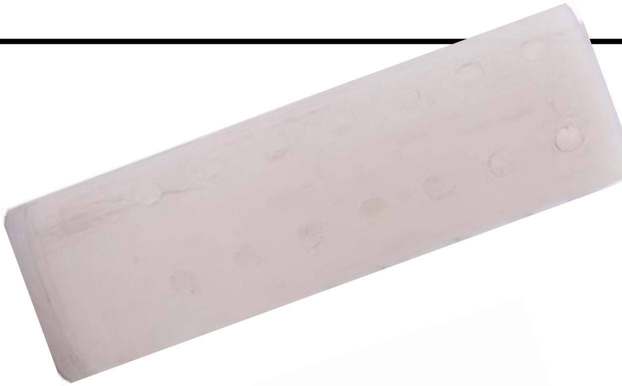
Probe Tube Material	Max Temperature
316 SS	1100ºF / 593ºC
Inconel®	1600ºF / 871ºC
Hastelloy® C276	1900ºF / 1037ºC
310 SS	2000ºF / 1093ºC
Hastelloy ® X	2150ºF / 1177ºC
Ceramic	2600ºF / 1427ºC

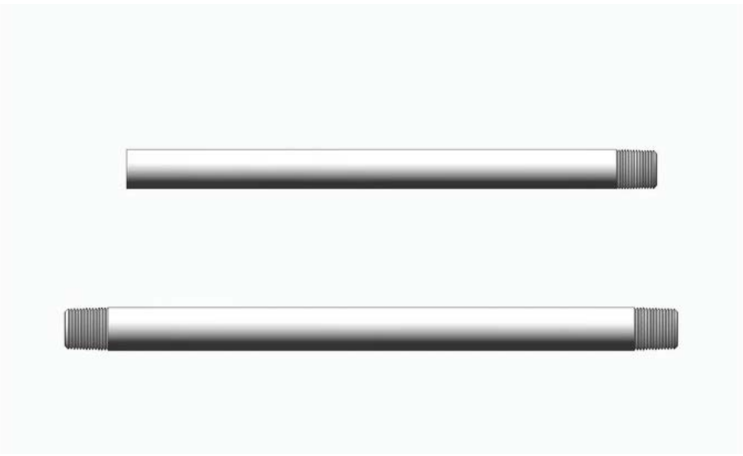


Common Probe Tube ADD-ONS

…WHEN YOU NEED THEM, YOU NEED THEM…

Probe tip Demister used after a wet scrubber when it is "raining in the stack"





Probe tip filters

LIP "Low Induction Particle" rejection. When the sample inlet velocity is low the probe pulls in fewer particles

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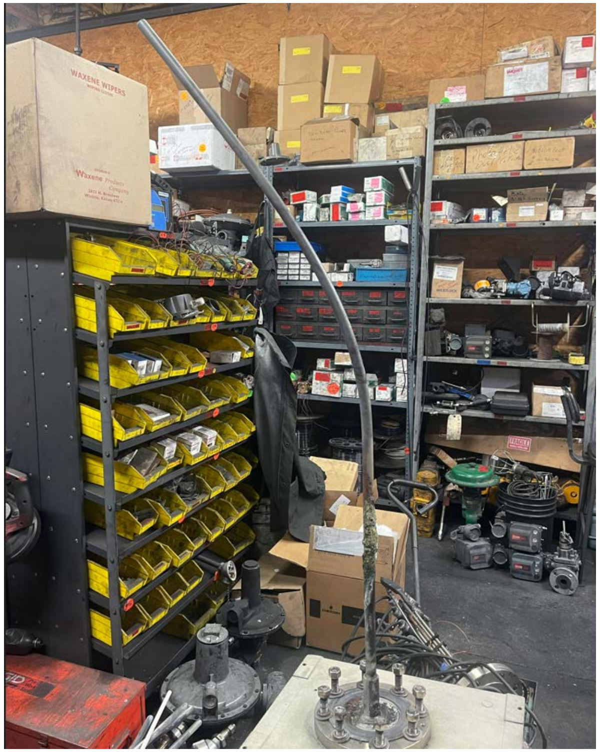
Example of Chemical Incompatibility

Example of Temperature Incompatibility



Too Long and/or Too Hot

And another example of what Temperature can do…

Simple Cycle Turbines are known for high exhaust temperatures…e.g. 900-1100 deg F…

At these temperatures, the Chromium protective layer breaks down, and Molybdenum Oxides can form on the surface of the very standard 316SS. Moly then reacts with the NH_3 / Oxygen to form NO…

We have also tried Hastelloy C276 which has better results but at the higher temperatures it to can also undergo a thermal oxidation…It's high content of Nickel plays a part in the reaction with Oxygen and Ammonia at elevated temperatures to again form NO…

It is the above reactions, as a for instance where we get these false high readings vs your real NO_x number

If the temperatures are low enough, we can put a barrier on the metal exposed to the exhaust stream…that is for instance SilcoNert. Issue is that the Silconert coating, in particular Silconert 2000 has a maximum operating temperature of +- 750°F.

We have found it best to use "Nickel Free Alloys" such as Hastelloy C22 or Inconel 625 for this reason.

Velocity should be another consideration as when specifying a sample probe, in particular the probe tubes on a

Turbine exhaust!

Standard Velocity Applications

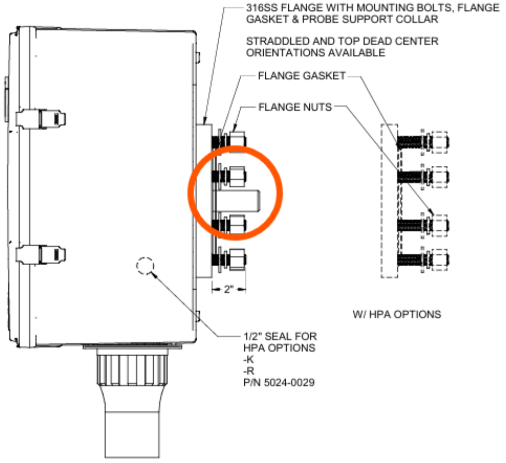
< 65 ft/sec

Point of Connection Support

Sch 40 Pipe

Sch 80 Threaded Connection

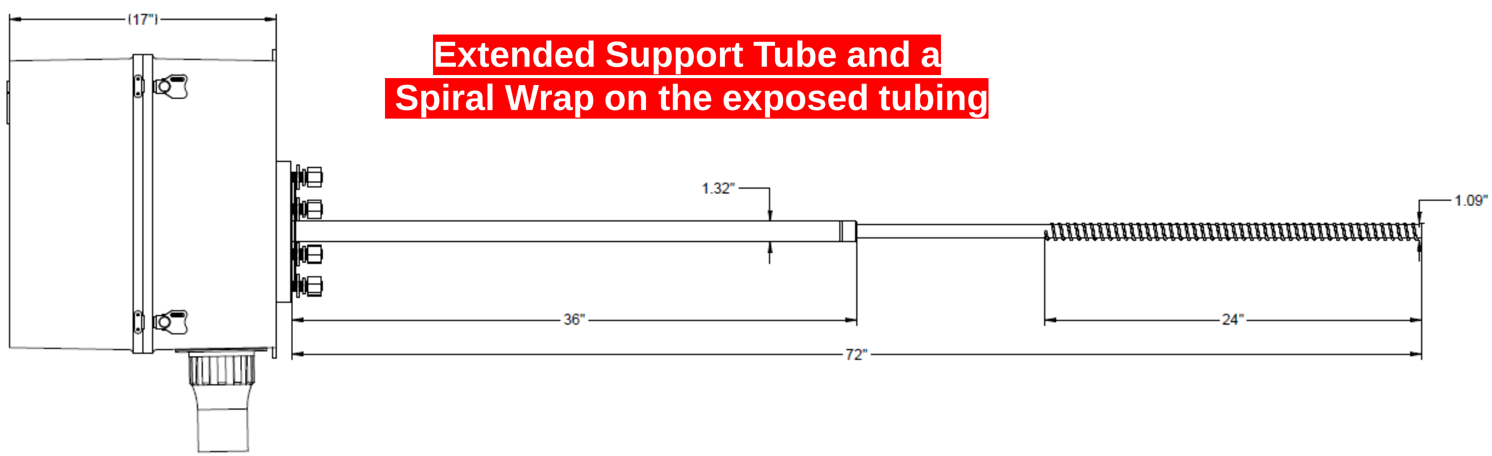
Probe Tube Support Collar



What I call a Hybrid "High Velocity Probe"

High Velocity Probe Tube
Duct / Exhaust Flows > 65 fps

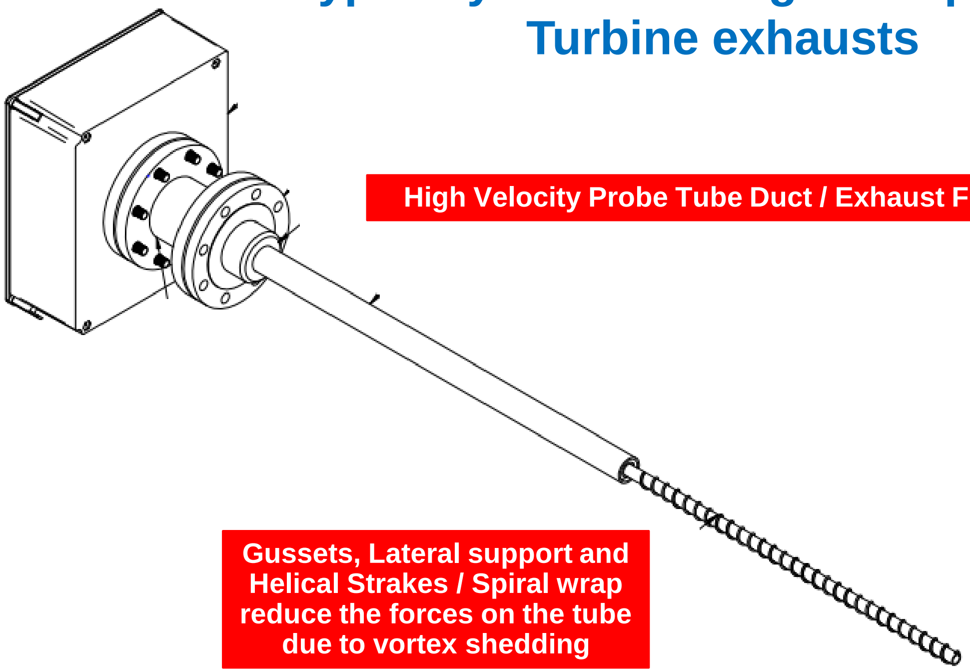
Extended Support Tube and a
Spiral Wrap on the exposed tubing



RIGHT SIDE VIEW

High velocity applications

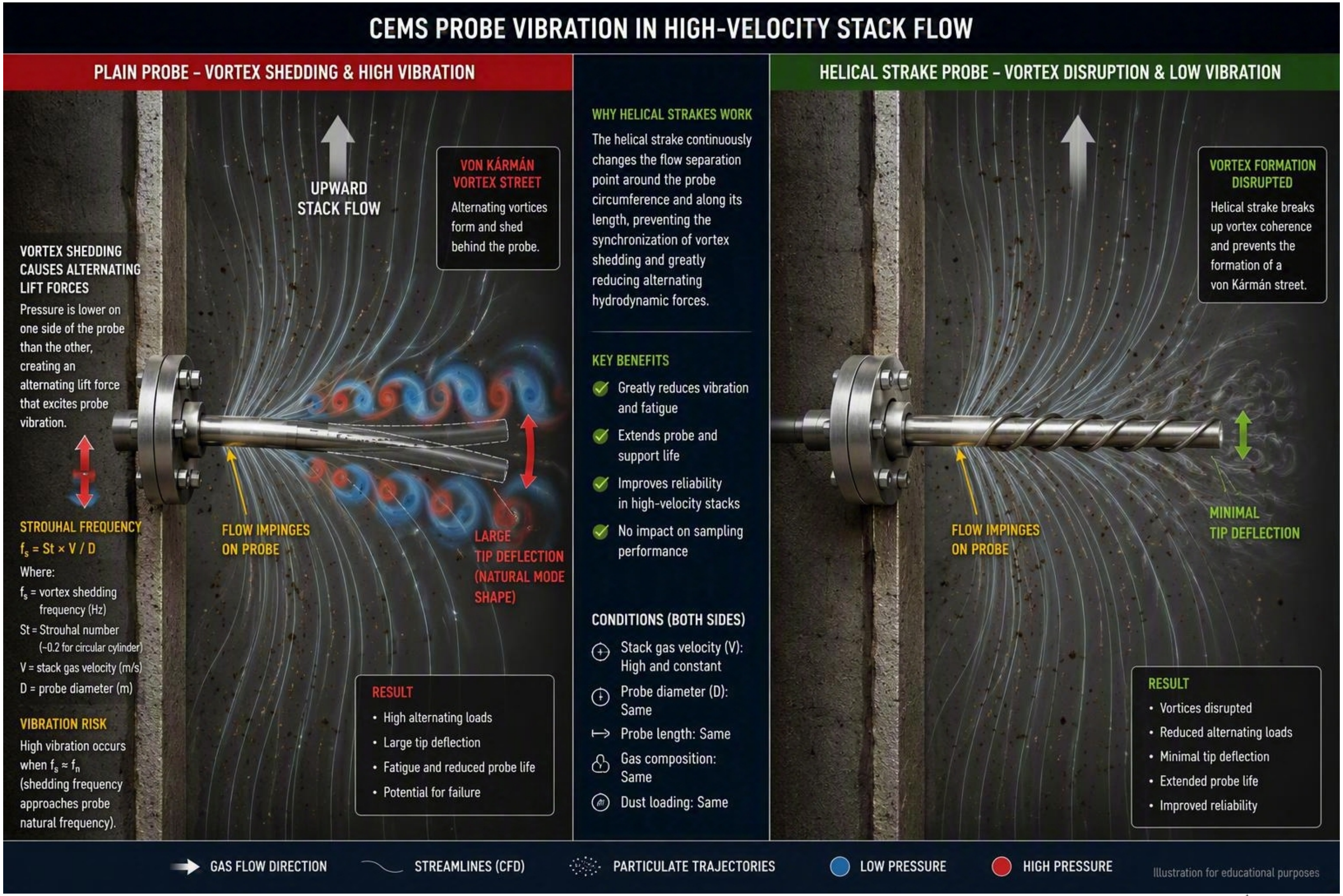
> 100 ft/sec
Typically found in larger Simple Cycle Turbine exhausts



High Velocity Probe Tube Duct / Exhaust Flows > 100 fps

Gussets, Lateral support and Helical Strakes / Spiral wrap reduce the forces on the tube due to vortex shedding

Probe tube Stress Graphic



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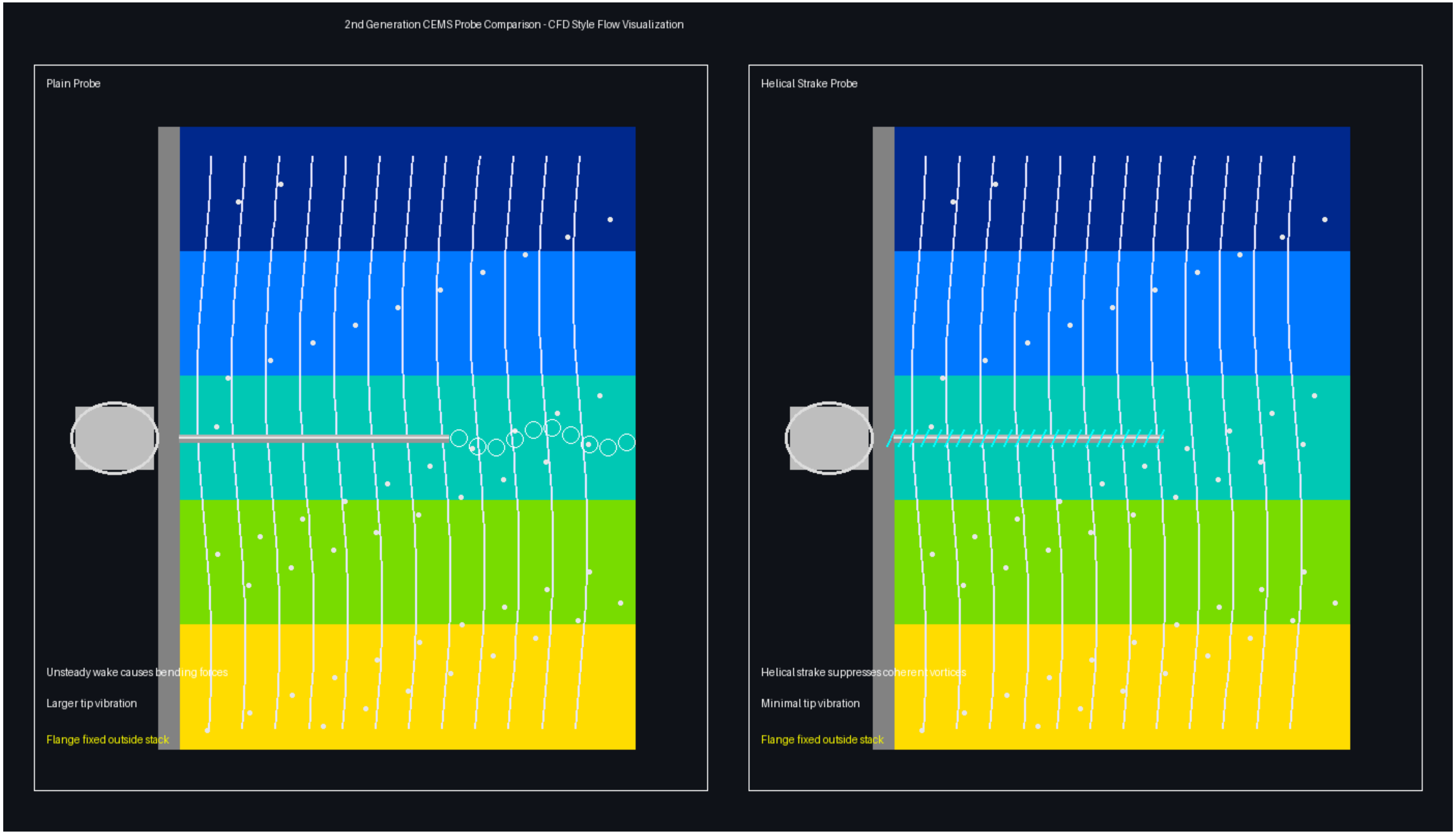
Probe tube Stress Cartoon



Probe tube Stress Video

Spiral Wrap / Helical Strakes – What are they?

Helical strakes are aerodynamic stabilizers used to reduce forces and deflections due to vortex shedding on structures such as stacks, tubulars, and chimneys. They consist of fins that spiral along the structure's length, disrupting vortex shedding and improving aerodynamic properties.

Everyday & Industrial Uses

Industrial Chimneys and Smoke Stacks:
You will often see these large metal spirals wrapped around the top one-third of tall factory chimneys. They keep the tall, slender vents from swaying violently during high winds

Car Antennas:
Have you ever noticed a tiny wire spiraling up your car's radio antenna? That is a miniature helical strake! It stops the antenna from whistling and vibrating when you drive fast down the highway

Thermowells:
These are protective tubes used inside chemical factories to measure heat. Tiny strakes are carved into them so they do not snap under the high-pressure flows of moving chemicals.

Another Probe Tube Option ----- Multi-Point

Multi-point probe tube arrays are used and excel as a useful solution for a cross-stratified stacks in scenarios where the user is attempting to measure relatively low pollutant/concentration levels

A Multipoint Probe Tube and Sampling System are designed to obtain a representative sample when there is stack stratification in a Continuous Emissions Monitoring System.

A typical system will include multipoint probe tubes (2 or 4) with heated probe filter(s), short heated jumper sample bundles, and a mixing/averaging module.

Another Probe Tube Option ----- Multi-Point

-Multi-point probe arrays were rarely considered up-front with a new CEMS … but times are a changing…

-Usually a requirement / consideration as RATA numbers trend towards failure

-Short stacks and not having proper mixing is one cause

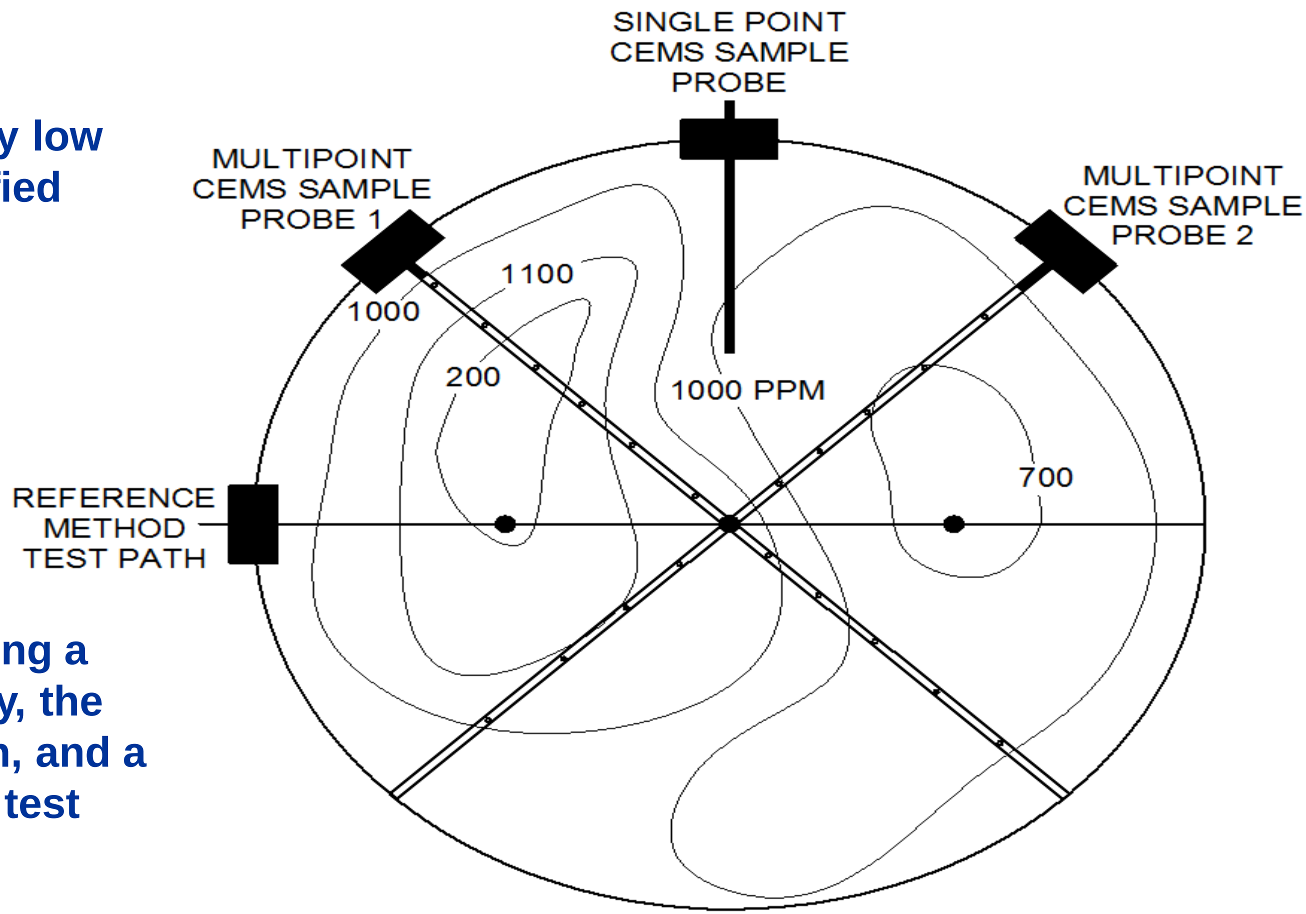
-Changing disturbances up stream contribute to deteriorating values (e.g. Catalyst getting old, ducting out of alignment)

-Ever changing measured values going lower and lower…fewer molecules to measure

-Multi-Point Probe tube array is a special, more costly consideration but can be the difference between passing and not…

Exaggerated Example of a Stratification Profile

Used to measure relatively low concentrations in a stratified gas stream.

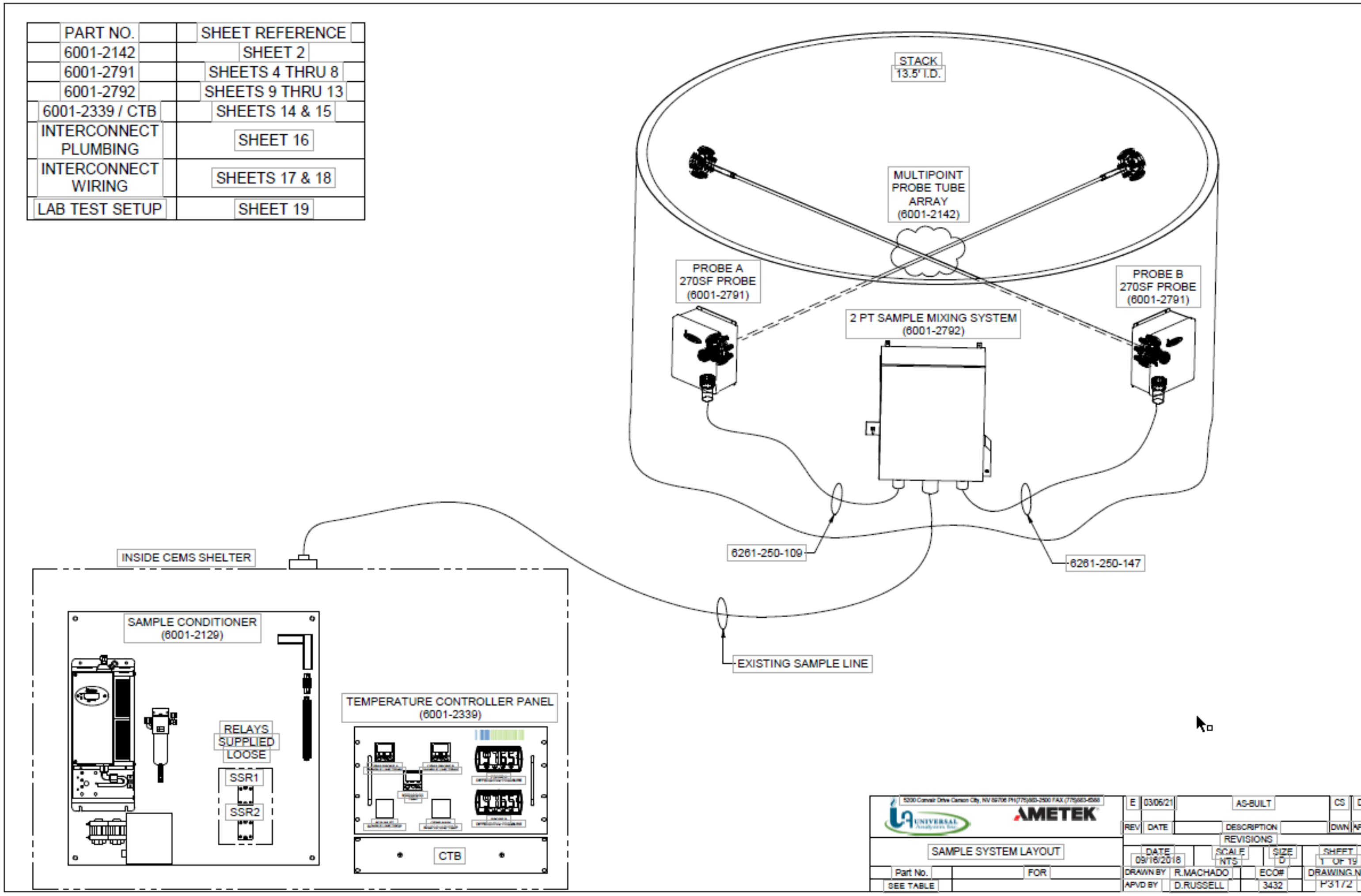


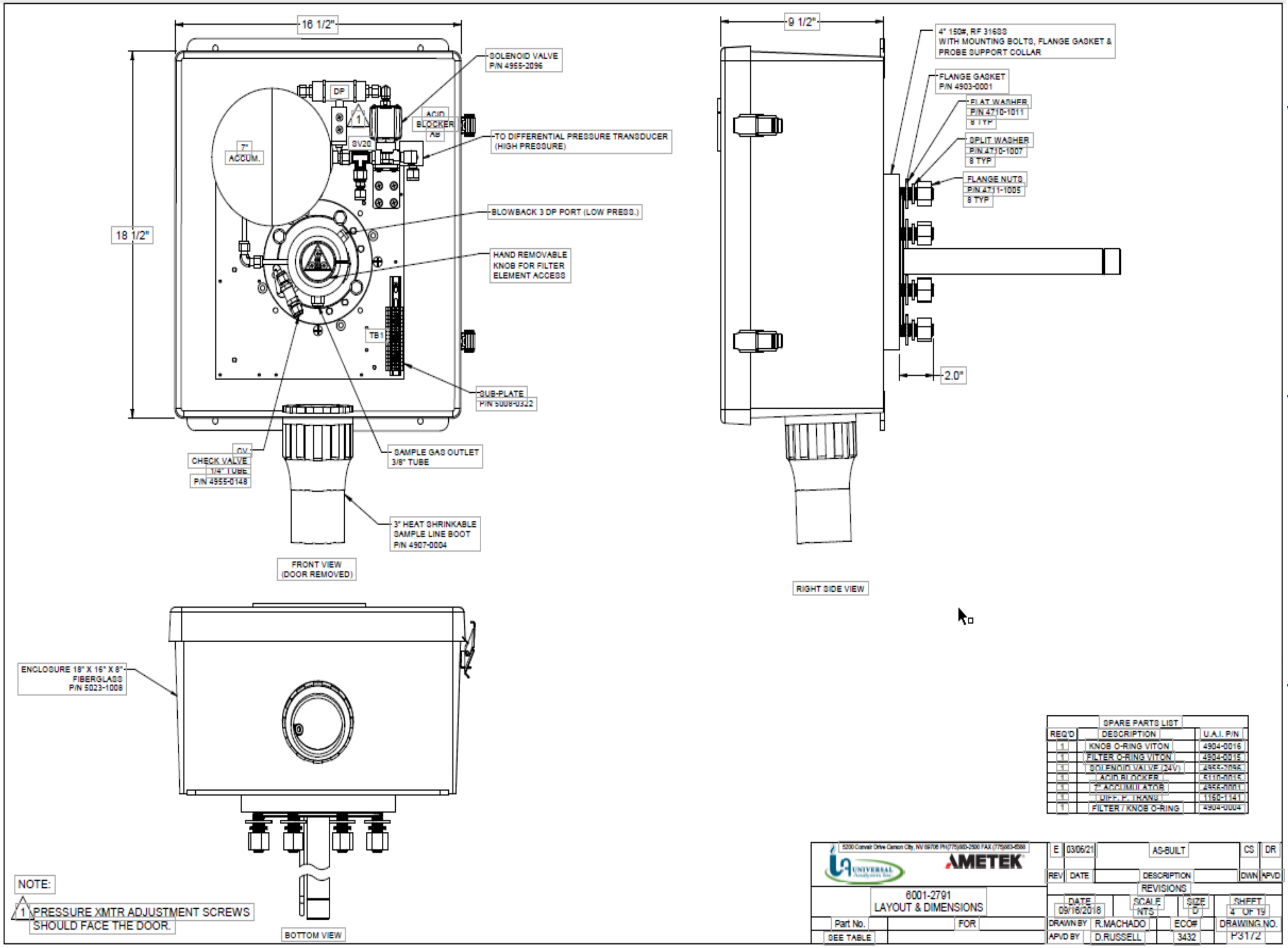
Stratification profile showing a multipoint probe tube array, the reference method test path, and a single point sample probe test point

Example
Stack i.d. 13.5ft.

2ea. Cross stack "criss-cross probe tubes

1ea. Heated / nested mixing/averaging enclosure with heated flow meters and manifold





Gas Sample probe with…

-Heated filter

-Blow back

-Mating flange

-Extra support welded to flange for long probe tube

-Heat shrink boot/entry seal for heated sample line

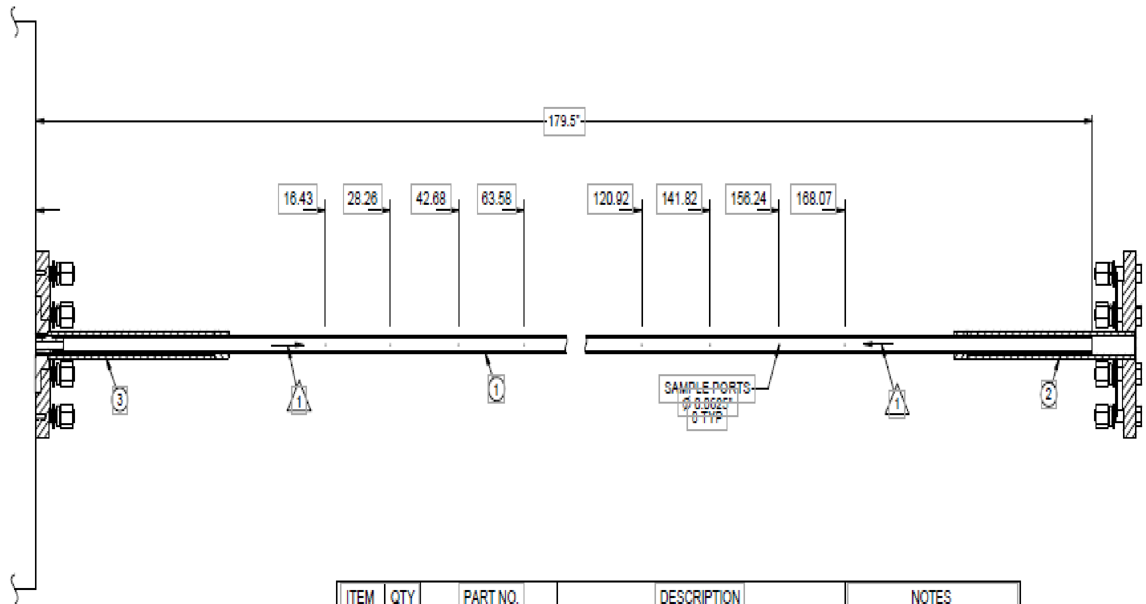
-Differential pressure connections and transducer to monitor health of the multi-point array

Multipoint Probe tube

-Can be Stainless Steel or Inconel or coated with Silconert Coating

-8 holes per tube usually to mimic traverse points from the stack test team

Flanges with extra in-stack support for the tube



ITEM	QTY	PART NO.	DESCRIPTION	NOTES
1	2	5155-1591	Multipoint Probe Tube, 316SS	(2) 5155-1591 + (2) 5155-1592 Make Up (1) 6001-2142.
2	2	5155-1592	1Ft. 316SS Probe Tube Support w/ 4" 150# Flange For Installation on Opposing Nozzle Flange	
3	2	6001-2238	270-SF w/ 1 Ft. Support & 4" 150# Flange, 316SS w/ Static Pressure Tube	

NOTES:

1. ALIGNMENT ARROW PROVIDED ON TOP AND BOTTOM OF PROBE TO HELP FACILITATE ALIGNMENT DURING INSTALLATION. FOR BEST RESULTS, INSTALL SUCH THAT THE SAMPLE PORTS ARE SIDEWAYS TO THE SAMPLE FLOW.
2. TWO PROBE TUBES AND TWO PROBE TUBE SUPPORTS FOR THE OPPOSING NOZZLE FLANGE WILL BE PROVIDED FOR INSTALLATION AT 90° FROM EACH OTHER.
3. SEE DWG P2279 FOR CONTROL PRINT FOR 6001-2142.

AMETEK

MULTIPOINT PROBE TUBE DETAIL

REV	DATE	DESCRIPTION	DWN	APVD
A	1/29/16	Initial Release	MW	DR

REVISIONS

DATE	SCALE	SIZE	SHEET
12/07/15	NTS	D	2 OF 16

Part No.	FOR	DRAWN BY	M. Walser	ECO#	DRAWING NO.
SEE TABLE		APVD BY	D. Russell	-	P2566

Another Example

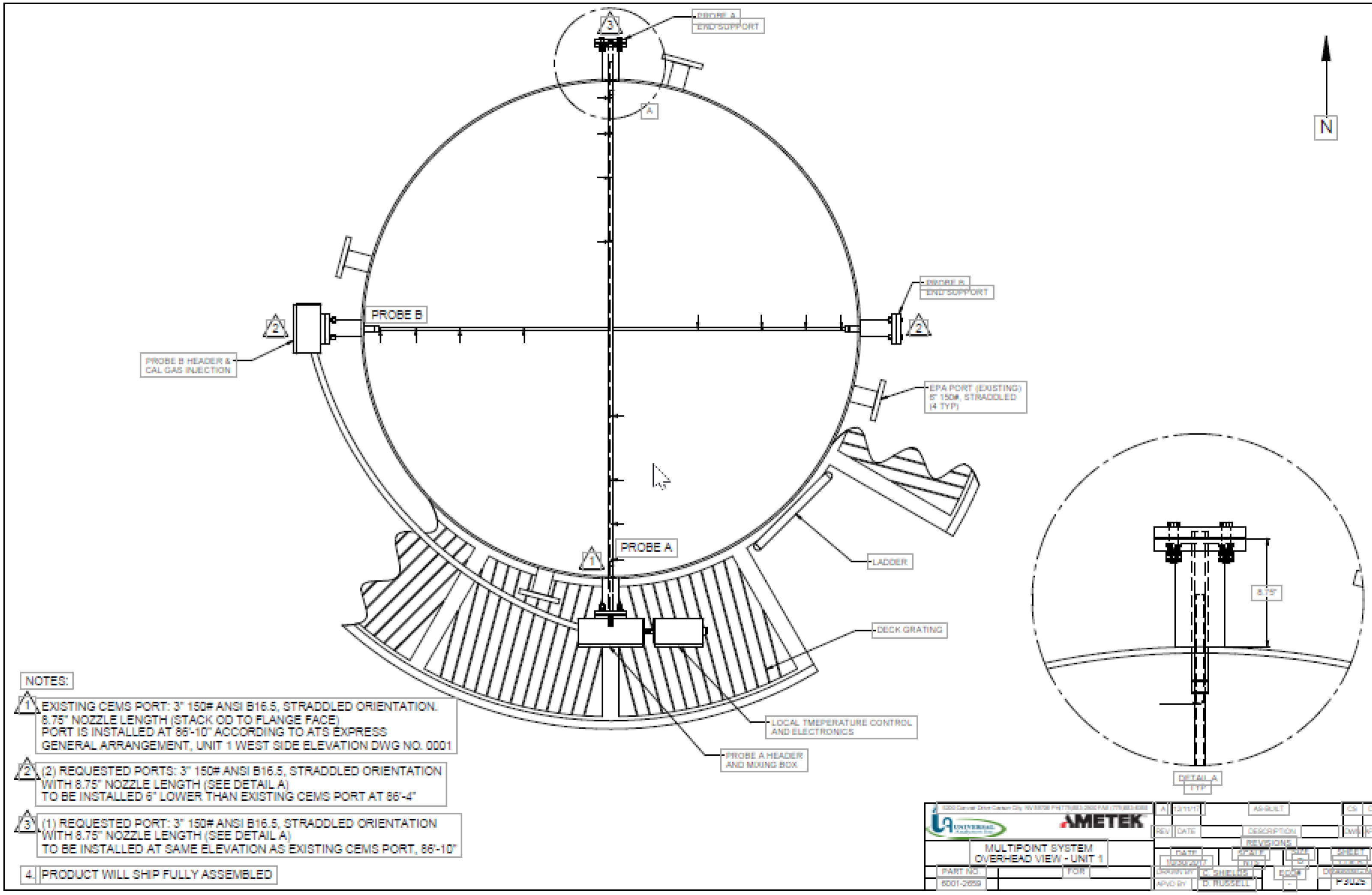
-approx. 7ft. Stack i.d.

-criss-cross probe array

-probe A enclosure is a combination heated filter, flow meter, mixing/averaging module

-probe B is a heated inter-connect

-short heated sample line connecting probe a-b



Application: It is used in stack testing and stationary source emissions monitoring (often in conjunction with methods like EPA Method 2 or local source test protocols like SCAQMD 511) to ensure a multi-hole probe extracts a **representative gas sample** across a stack or duct

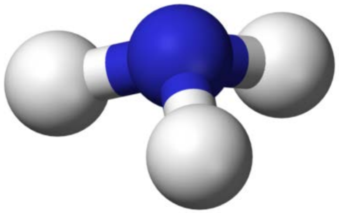
Compliance: All of our multi-point probe tube arrays must go through specific testing per EPA GD-031 and meet the **c**riteria required to verify the performance and flow variability of multi-hole gas sample probes. Probes must demonstrate that their flow rates and sampling characteristics meet specific limits defined in the guidance before they are approved for regulatory emission testing.
It is Extensive and required along with a documented report.

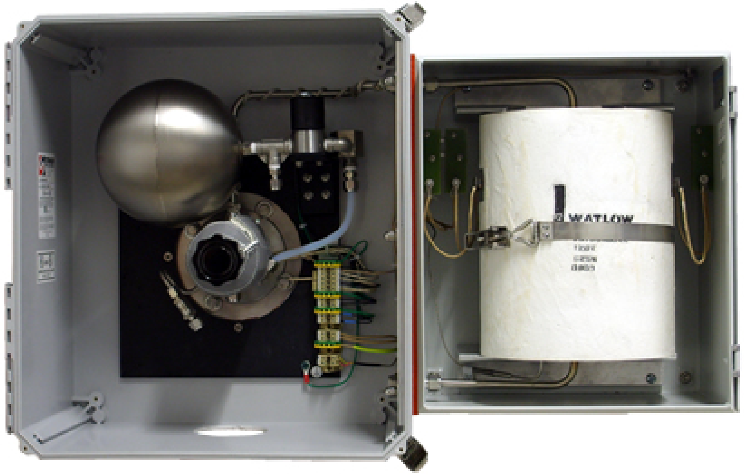
Whether it is cross-stack multi hole array with (2) individual probe tubes or (4) individual probe tubes around the circumference of the stack, testing must be performed in shop to assure compliance.

With the current Data Center activity, there are lots of Simple Cycle Turbines with shorter stacks and the potential for stratification being ordered.

Multi-Point Probe Tube arrays considering High Velocity exhaust rates are being spoken about a lot these days.

Another Probe add-on considerations – Measuring Ammonia





- Measure Ammonia with a Tunable diode Laser (TDL)
- Alternately calculate with the EPA's archaic work sheet
- **Alternately use a NOx differential Methodology**

- **Ammonia Converter at the probe for NOx differential**
  -

- **Ammonia Scrubber to Deal with Ammonia Salts from Slip**
  - Ammonia reacts with acid gases to form salts…
  - e.g., Ammonium Sulfates, Ammonium Nitrates
  - Salts plug off filters, clog sample lines, get to pump heads, etc.

- Common solution…
  - Scrub with media that is impregnated with Phosphoric Acid
  - Can be heated if installed upstream of a gas cooler
  - Typically located downstream of a gas cooler - un-heated version

And yet another type of CEMS Sample Probe…A Dilution Probe …Typical but not exclusive for Coal Fired Power Plants…

Dilution Probe Controller

- Application usually dirtier than clean burning natural gas fired turbines.

- Uses compressed air and a critical orifice to dilute the sample

- Sample System is reduced to providing clean instrument air as the motive air for an eductor, reading vacuum to assure sonic flow through the eductor and then regulating pressure and flow to the analyzer(s). Temperature control for the probe and calibration gases for daily validation.

Usually done with a Dilution Probe Controller Module

UNIVERSAL Analyzers Inc.

A Probe is not a probe is not a probe…

While this was brief, I hope I shared some food for thought. Please reach out if you have any specific questions that I didn't cover or if you have a nagging CEMS Sample System issue and often think to your self…

…"there's got to be a better way!"

THANK YOU FOR YOUR TIME!!!
…AND A BIG THANKS TO CISCO…SHANE, WALT AND THE TEAM FOR ALLOWING ME THE OPPORTUNITY TO ADDRESS Y'ALL!...

BOB BERTIK
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