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

UNIVERSAL Analyzers Inc.

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September 2025

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 – 22 yr anniversary this month
- 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. ***FUN FACT…GLOBALLY, THE CURRENT CEMS MARKET SIZE IS USD 3.27 Billion and is estimated to grow to USD 5.26 Billion by 2032. While North America has the highest share, CEMS are required in Asia Pacific, Europe, Middle East and South America…who knew?*** ***Got this from Stellar Market Research***

- 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 System".

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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Application Questionnaire

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

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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:

	Min	Max
Ambient 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? Yes No
(e.g. Simple Cycle Gas Turbine)

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

Distance to Analyzer: ft
Length of Sample Line: ft
Return sample to process? Yes, Pressure at Return Point: I.D. of Sample Line: in
Diameter of stack at Sample Location: in
Mating Flange Size: ANSI
Flange Spool length from stack/duct wall: in
Is there an Annulus? Yes, l: in x w: in x d: 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
Hastelloy
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.
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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**

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**

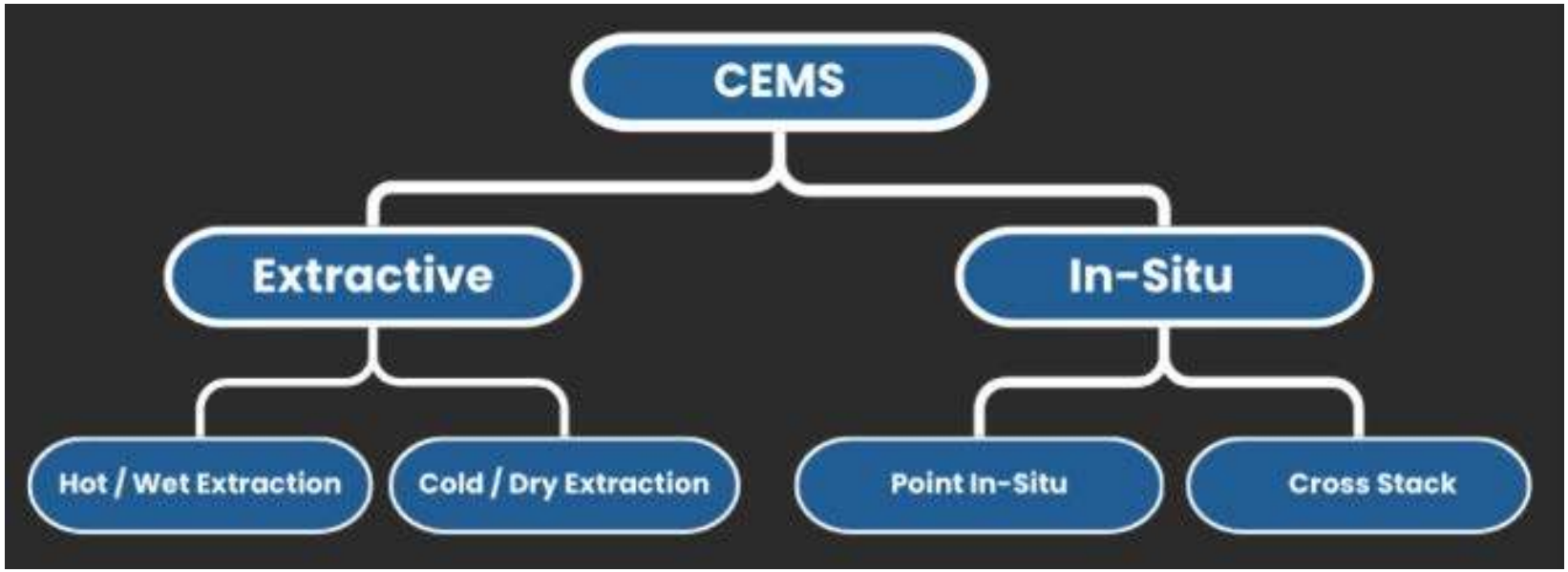
- Voltage, Maintain & Ambient temperature for the sample line
  - **Used for design of heat trace and insulation requirement**

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

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

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?)
  - Non-Metallic
  - 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”

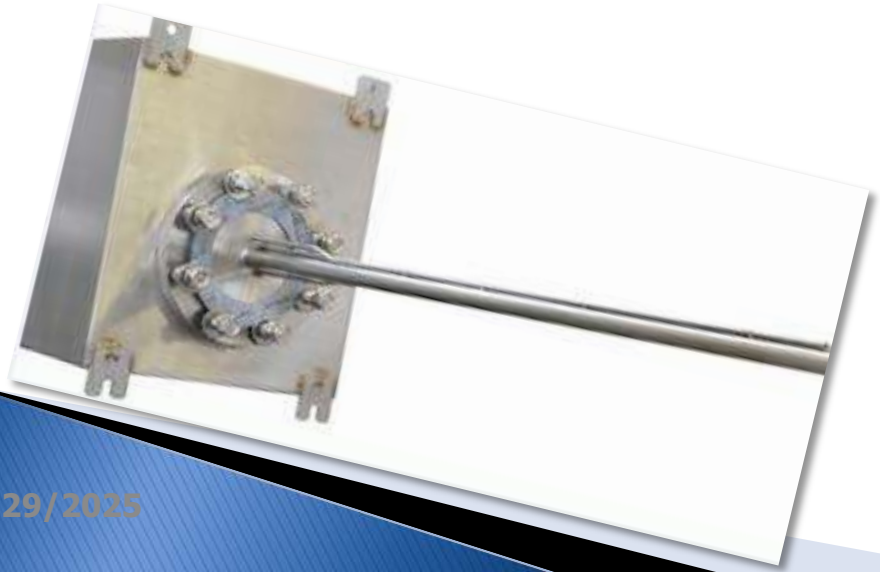
OR

“STRADDLED”

What happens when you don't specify the flange orientation …50/50 shot at getting it right…

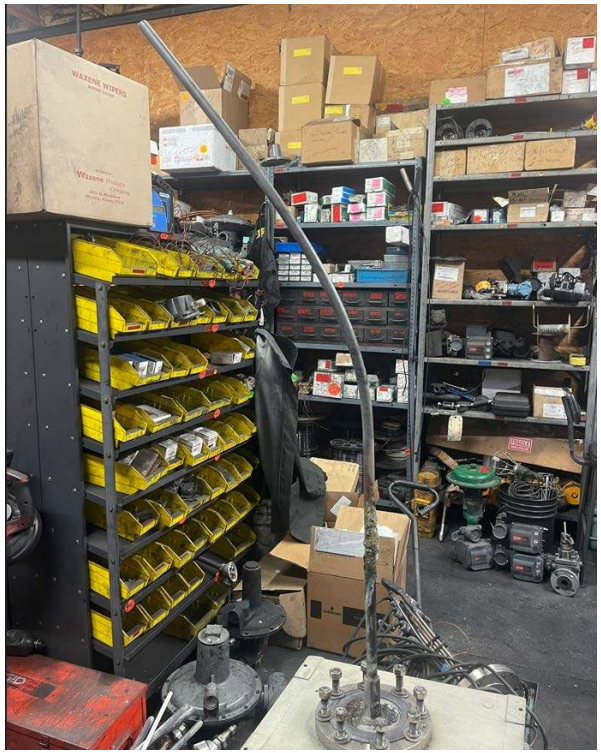
Common Probe Tube Material Selection

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



Example of Chemical Incompatibility

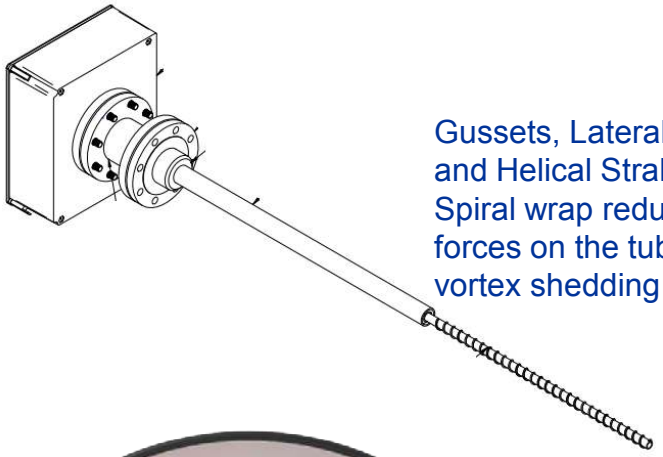
Example of Temperature Incompatibility



Too Long and/or Too Hot

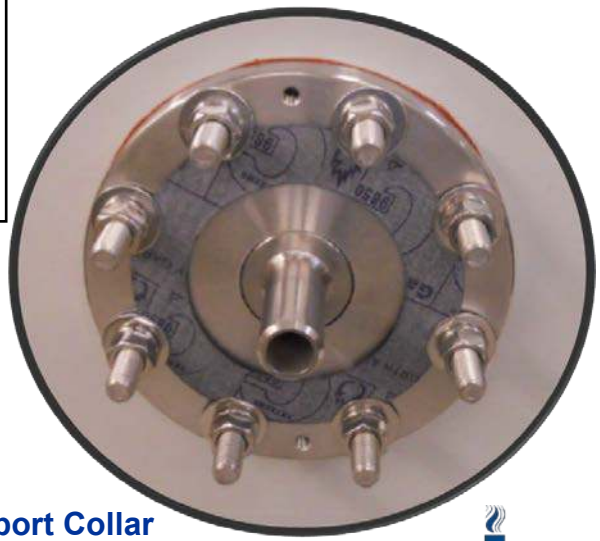
Standard and High Velocity Applications

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

Point of Connection Support



Probe Tube Support Collar

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

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

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

A typical system will include two multipoint probe tubes (each with a dedicated heated probe filter), two short heated sample bundles, and a two-point mixing/averaging module.

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

-Multi-point probe array's rarely considered up-front with a new CEMS

-Usually a requirement consideration as RATA numbers trend towards failure

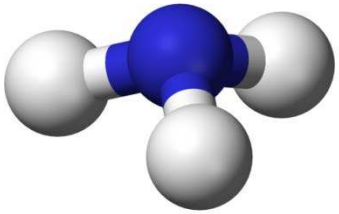
-Short stacks and not having proper mixing is one cause

-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…

Considerations for Dealing with and / or 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**
  - When to use?
  - Ammonia Slip (NOx differential)
  - SCR to convert NH3 to NO
  - 1250 - 1300°F for conversion

- **Ammonia Scrubber**
  - 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

Sample Probe – High Dust Load Option

- For Higher Dust Loading Applications - >5 g/m3
  Typical used but not limited to: Cement, Coal, Steel, FCC, SRU…
- 9” Stainless Steel Filter Element – 2µm
- Dual Accumulator Tanks For High-Efficiency Blow-Back
- Incorporates a Pneumatically Controlled Sample Line “Isolation Valve”
- Blow-Back - Inside Out
- Standard Stainless Steel NEMA Type Enclosure
- Easy To Remove Filter Element –No Tools Required

Dilution Probe Option

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 the 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 cals. Usually done with a Dilution Probe Controller Module

Sample Probes

Gas Coolers

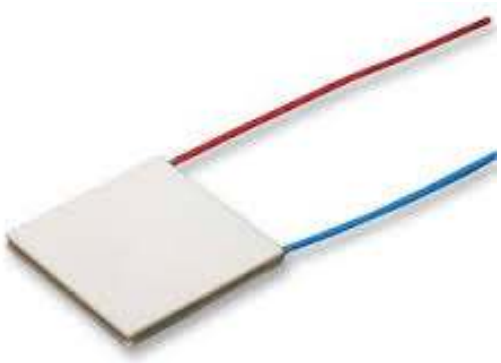
Sample Conditioning Systems

Function of a Gas Cooler and why!

- Remove the water vapor to a certain dew-point, typically 4-5°C without removing the water-soluble compounds from the gas stream.
- Water vapor can interfere with the measurement of your gas analyzer(s).
- Water vapor will can harm the analyzer
- Water will react with certain compounds
- Water can mix with particulates to form a “muck” and plug things
- Cold-Dry Systems are reported on a Dry basis
- Most analyzers DO NOT like water

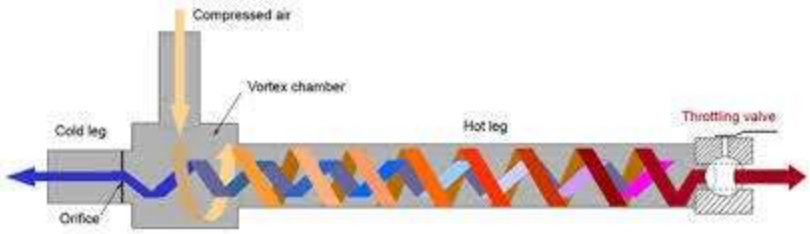
Types of CEMS style Gas Coolers

- **Thermoelectric**
  - Solid state Peltier effect cooler
  - No moving parts
  - CFC Free



- **Compressor**
  - Refrigeration type gas cooler
  - More cooling Power at high ambient conditions…> 90°F

- **Vortex**
  - Compressed Air cooler
  - No electricity required
  - Perfect for Hazardous Areas



Gas Coolers…How do they do what they do…

- They all do the same thing which is to chill the gas sample stream, lowering the dew-point and condensing out water and other condensable compounds down to a safe level for the analyzer(s)
- Standard outlet dew-points are typically 4-5 deg C
- Oddly, Southern California requires 37.5 deg C
- Oddly So Cal and the state of New Jersey both require that the gas stream sample temperature is measured…aka “NJ Option”!
- Whether thermoelectric, refrigeration or compressed air, they all chill a medium that chills a heat exchanger that chills the sample resulting in condensation and a dry sample, according to EPA protocols.

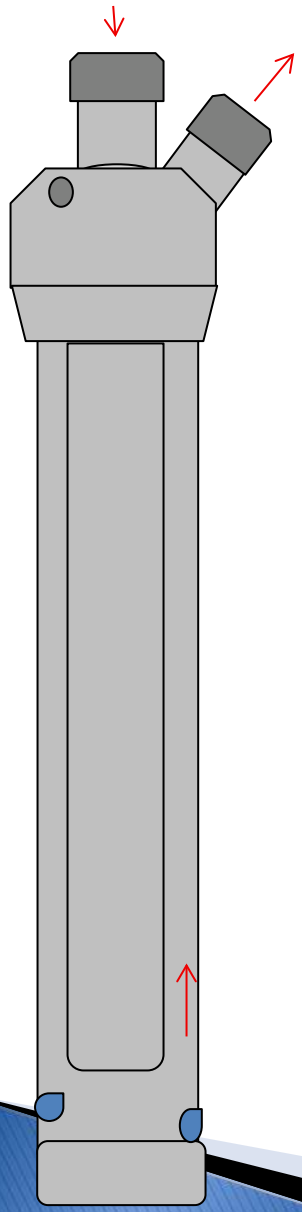
Gas Coolers…How do they do what they do…

- Some heat exchangers consist of a coil of tubing
  - Submersed in a water bath or wrapped around an aluminum block

- Others are tube within a tube design offering options for materials such as …

- Stainless Steel
- Glass
- Kynar
- Hastelloy
- Silconert Coated
- Teflon Coated

Example of a Tube in Tube Design



Gas Cooler Flow Path

- Tube within a tube design
- Inner tube isolated from outside chilled walls of heat exchanger
- Gas stays hot until it exits bottom of inner tube and flash dries
- Condensate forms and is continuously drained via a peristaltic drain pump or other
- Dry gas travels up annular space to sample output of heat exchanger
- Design is to minimize the contact of the condensate and the gases being measured (to prevent re-equalization of the liquid into the dry gas)
- Electro-polished exchangers minimize loss of water-soluble gasses such as NO_2 and SO_2

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ONE SIZE DOESN'T FIT ALL

500 series

1000 series

3000 series

One to four heat exchangers – One, two or more gas streams

Flow rates from 4 – 16 l/m STP

General Purpose or Hazardous Area

4°C or Sub-Zero temperature set point

1095E "Freezer Chiller"

1100 Vortex series

600 series

Freezer Chiller - Why?

- Standard gas cooler @ 4°C dew point still has ≈ 0.8% H_2O by volume
- Freezer chiller @ -25°C dew point removes H_20 down to ≈ 0.03% H_2O by volume
- SO_3 & H_2O react to form H_2SO_4
- Do not know of an SO_3 only scrubber
- Must remove as much H_2O as possible to minimize formation of H_2SO_4 which forms in gas cooler as an acidic aerosol.

Eliminate the Green Slime

Visual of the results of not applying the proper sample system to a High Sulphur Application
…could you imagine what the inside of the analyzer(s) looks like?

Sample Conditioning Systems
What is the real purpose …

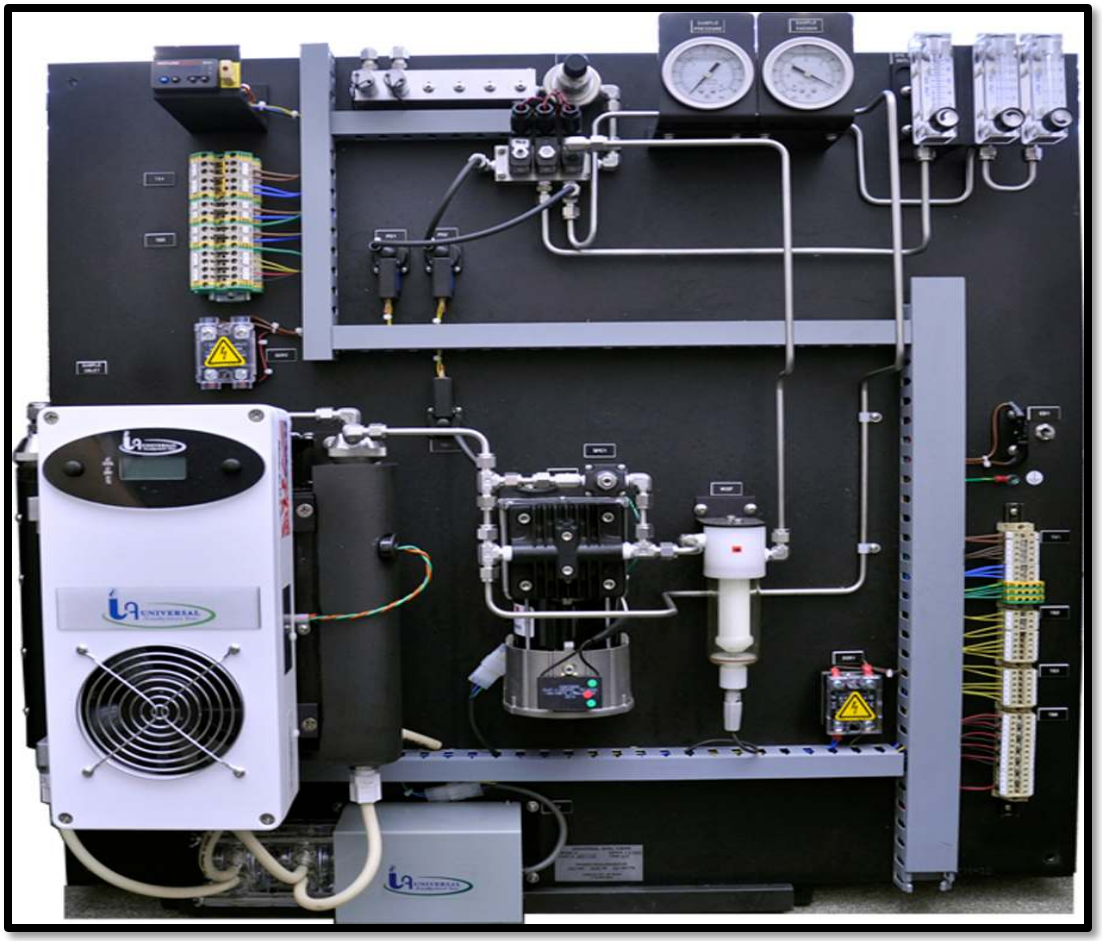
- Analyzer may not be compatible with pressure, temperature or moisture content of extracted sample.
- Prepare the sample for analysis without affecting relative concentration of components.
- Typically include some of the following:
  - Gas Cooler
  - Pumps (sample and peristaltic)
  - Flow meter(s)
  - Pressure & Vacuum gauges
  - Pressure regulator
  - Solenoid valves
  - Alarms
  - Temperature Controller

Designing Sample Systems / Common Concerns

1. How Many Sample Locations/Streams?
2. Will the Sample System be in a hazardous location?
3. What are the stream components?
    a. Moisture Content
4. How many analyzers and what is the desired response time?
5. Size Cooler
6. Plate, U-bracket, Drawer?
7. Will there be system and direct calibration?
8. What are the maximum possibilities of calibration gas?
9. What visual indicators are necessary?
10. What alarms need to be passed along?
11. Heated Sample Line control?

Sample Conditioning System on a wall mount panel

Sample System on a Wall Mount Panel



Sample Conditioning System In a 19” Rack Mount Drawer

Sample Conditioning System 19” U-Bracket

Portable Sample Systems

- One or two 5” heat exchangers
- One gas stream
- Flow rate options of 2.5 or 5 l/m STP
- Includes:
  - Gas cooler
  - Sample pump
  - Peristaltic pump
  - Flow meter
  - Water carry-over sensor
  - Digital temperature display
  - Stainless steel case
  - Carrying handle and feet
  - Approx: 16 kg

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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