



**Multipoint Probes to Mitigate
Stratification
CEMTEK Users Meeting**

September 28th, 2016



M&C supplies World Class Custom Designed Probes, Manifold Systems, Sample Tubes, Coolers, Analyzers, Samplers, Smart Controllers, Custom Sample Conditioning Panels, and Multipoint Probes for over 30 years.

**US Headquarters
Ventura, CA**

**New Product Development Center
Reno, NV**



M&C Technology Group—Embracing Challenge

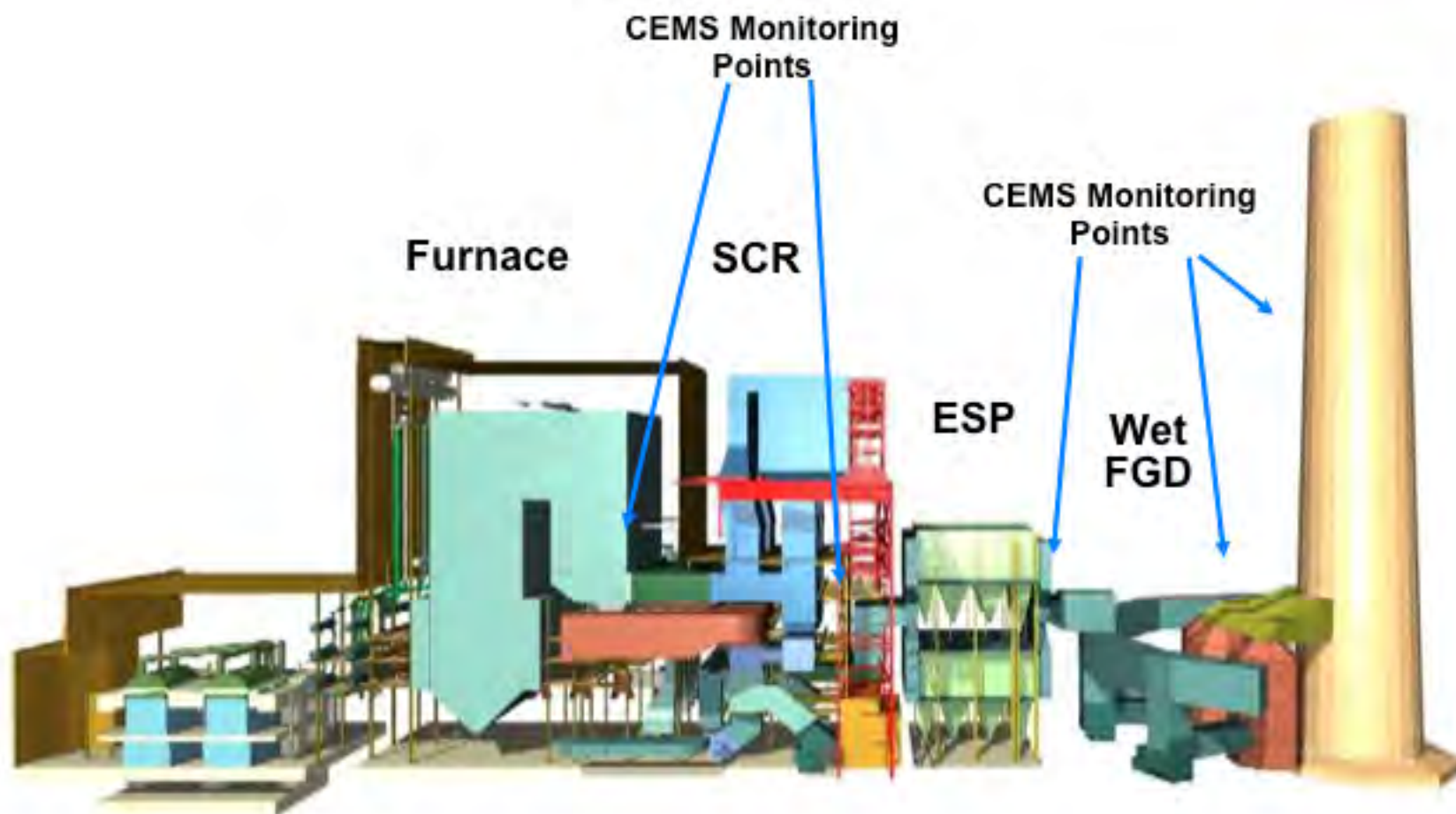


Presentation Overview

- Why Use a Multipoint Probe
- Regulatory History
- Gas Laws
- Probe Selection Criteria
- Anatomy of a Multi Point Probe
- Performance Testing, QA, Maintenance



Typical CEMS Power Plant Monitoring Points



Why Use a Multipoint Probe?

Top 10 Reasons

10. **Samples multiple points which allows more precise results than a single point probe**
9. **Allows more accurate sampling when SCR operating conditions change**
8. **CAN SAMPLE FROM IRREGULAR SHAPED STACKS**
7. **SCR seals eventually fail causing NH₃ distribution across the Grid to Change-This change of NH₃ will affect NO_x emissions!**
6. **The Stack Testers Van samples by traverse across the stack in an “X” type configuration which may not match up with single point probe**

Why Use a Multipoint Probe?

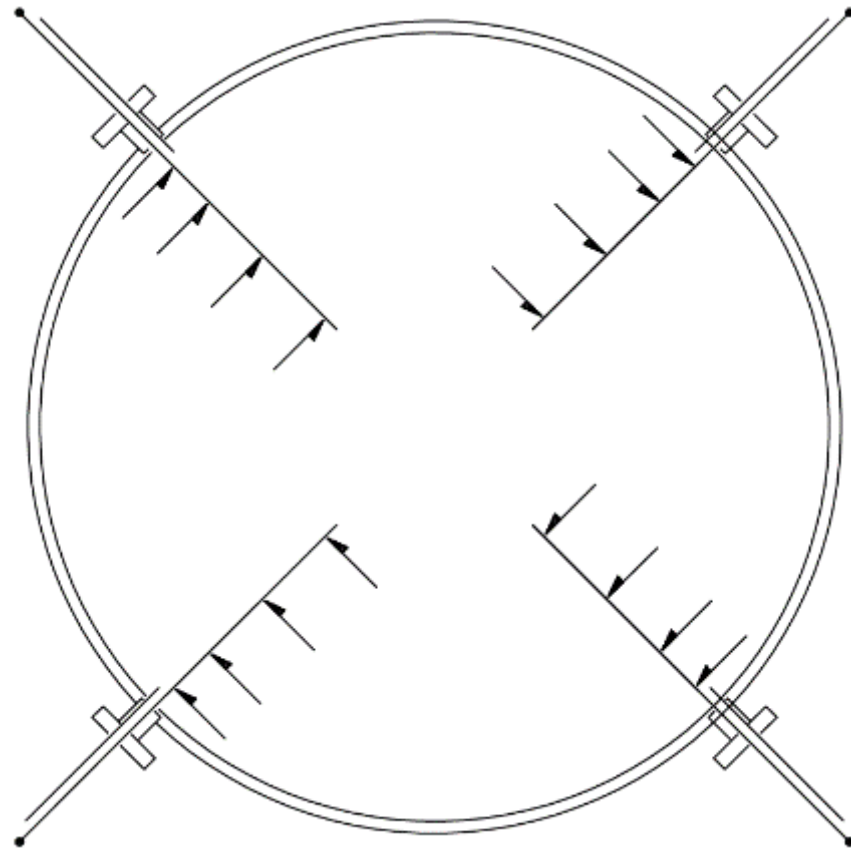
Top Ten Reasons

5. **CO configuration in a plant changes, NOx changes**
4. **Aging plants stack emissions characteristics change**
3. **PROACTIVE PLANT POLICY TO GET THE BEST SAMPLE**
2. **Its in your Permit-District requires you to.**
1. **You Fail your RATA**

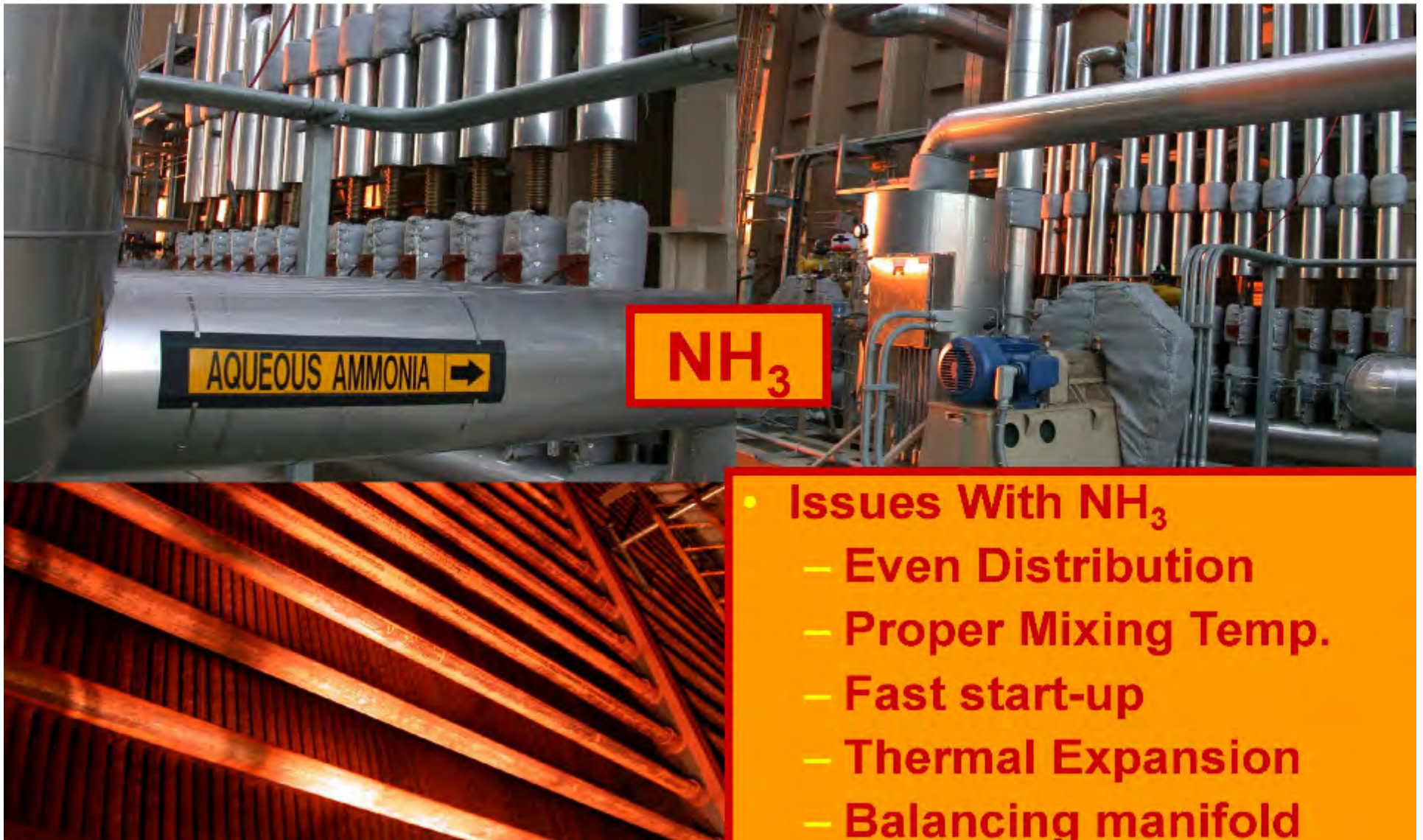


#10 Multipoint Probe 4 Point Stack

**Cross Stack Example with 4
Insertion Points**



9 Changing SCR Conditions



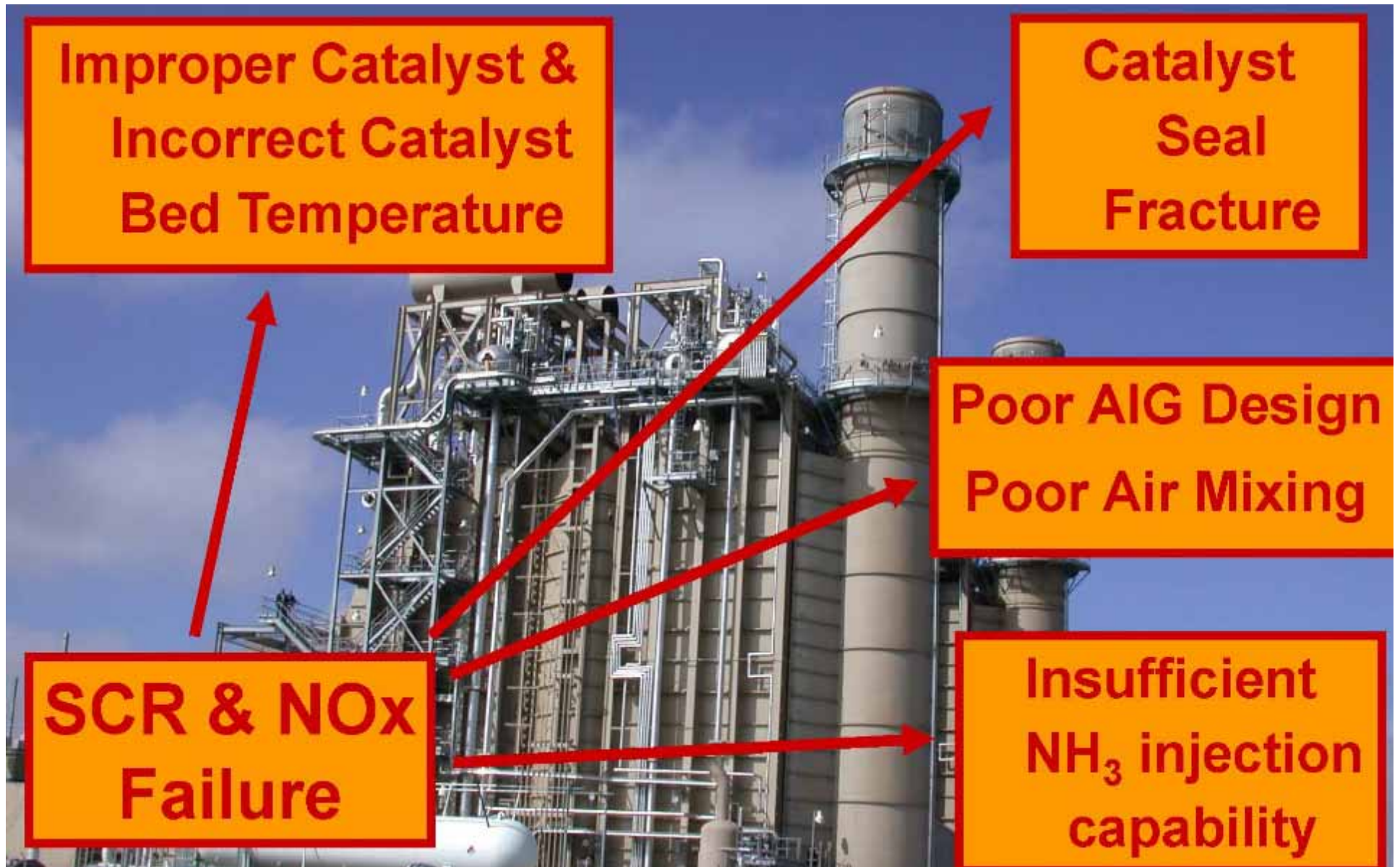
- **Issues With NH_3**
 - Even Distribution
 - Proper Mixing Temp.
 - Fast start-up
 - Thermal Expansion
 - Balancing manifold



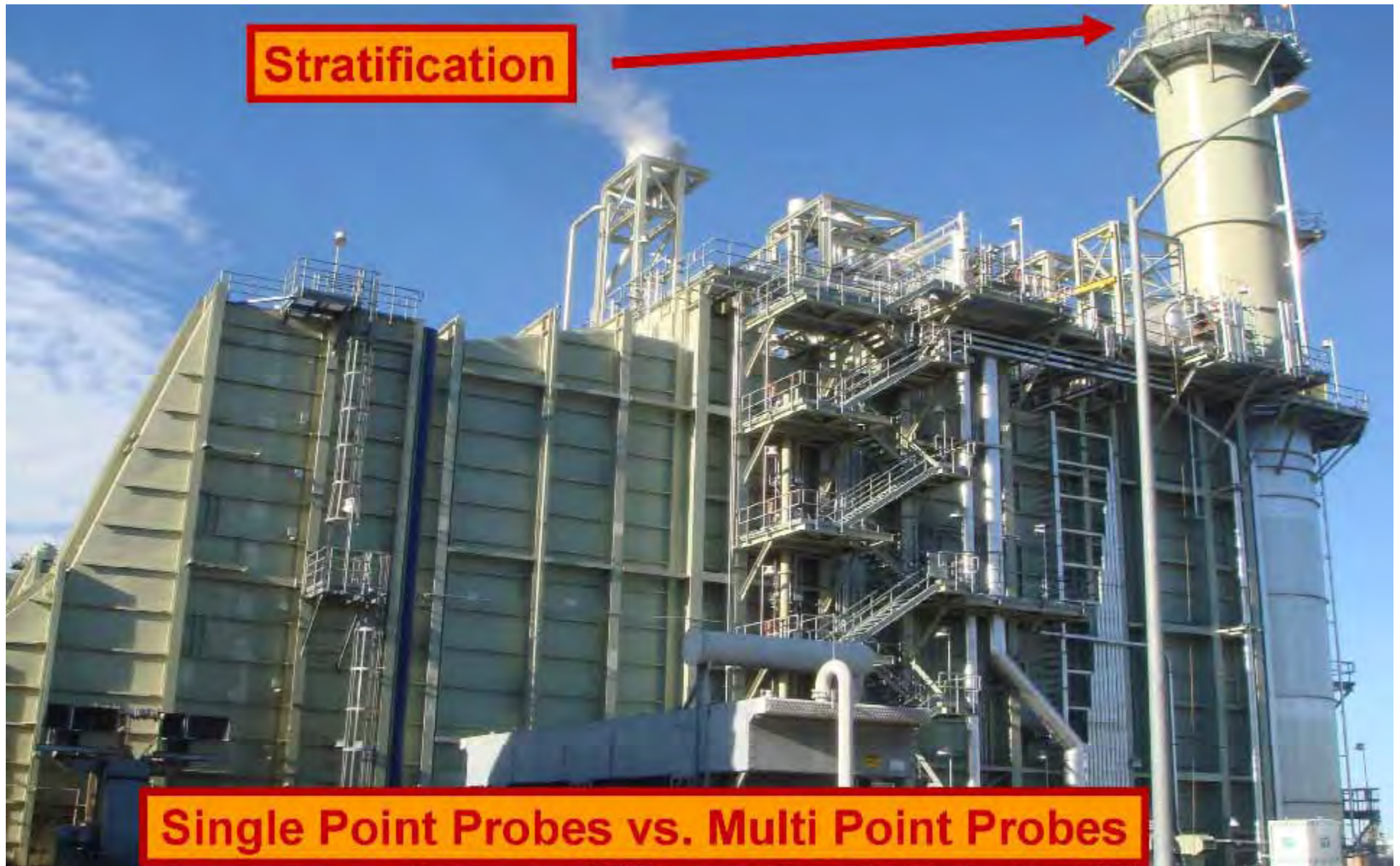
#8 Square Stack with Multipoint Array



#7 SCR & NO_x Failure



#6 Stack Tester Traverse Sampling finds Stratification at Stack



#5 CO Catalyst Issues



#4 Aging Plant --Stack Characteristics Change

**Gas Turbine
Inlet & Outlet NO_x**



#3 Proactive Plant Policy-Avoiding Excess Emissions Events



**What Constitutes
Excess Emission
Events (>2ppm
NO_x) and
Breakdown?**

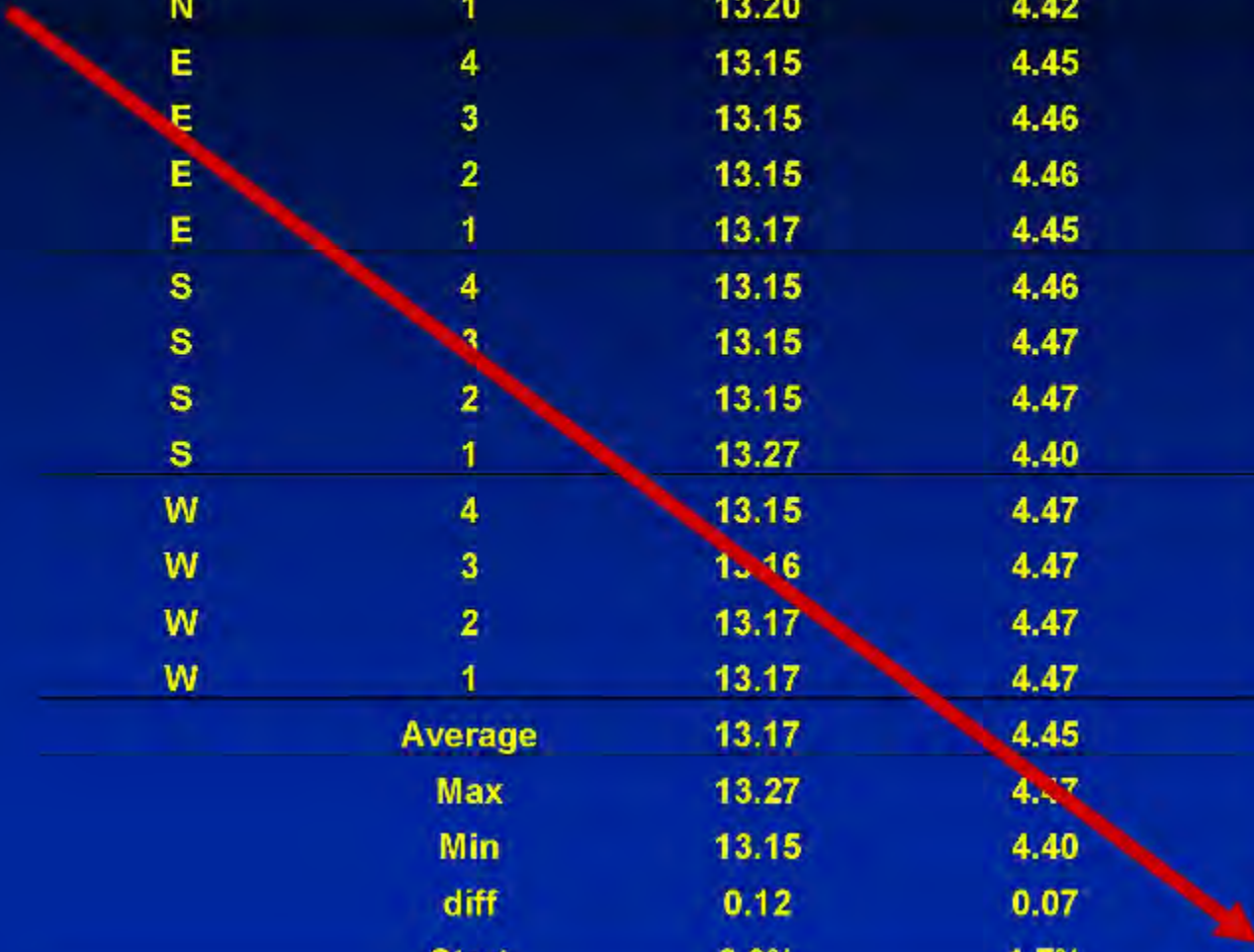
#2 It's in Your Permit

- **TITLE V OPERATING PERMIT APCD2006-TVP-XXXXXX**
- **Issued To:**
- Solar Turbines Inc.
Site ID: APCD1976-SITE-xxxxx
- **Site Address**
- 100 Anywhere Road San Diego, CA 92123
- **Mailing Address**
- P.O. Box 60609 San Diego CA 92186
- **Responsible Official:** John Wayne, President; Paul Mc Cartney, Director
Packaging Systems
- **Facility Contact:** Marilyn Monroe, Manager EHS **Permit Information**
Contact: Sharon Osbourne
- Issued by the San Diego County Air Pollution Control District on This Title V
Operating Permit expires on .
- Signed by:
John doe, P.E., Chief of Engineering



#1 You Fail Your RATA

Port	Point	O2	CO2	NOx	CO
N	4	13.19	4.42	1.99	-0.42
N	3	13.19	4.42	1.93	-0.43
N	2	13.20	4.42	1.86	-0.43
N	1	13.20	4.42	1.86	-0.43
E	4	13.15	4.45	1.79	-0.43
E	3	13.15	4.46	1.68	-0.45
E	2	13.15	4.46	1.61	-0.44
E	1	13.17	4.45	1.64	-0.45
S	4	13.15	4.46	1.67	-0.44
S	3	13.15	4.47	1.62	-0.45
S	2	13.15	4.47	1.65	-0.46
S	1	13.27	4.40	1.71	-0.46
W	4	13.15	4.47	1.54	-0.47
W	3	13.16	4.47	1.61	-0.47
W	2	13.17	4.47	1.63	-0.48
W	1	13.17	4.47	1.63	-0.48
Average		13.17	4.45	1.71	-0.45
Max		13.27	4.47	1.99	-0.42
Min		13.15	4.40	1.54	-0.48
diff		0.12	0.07	0.45	0.06
Strat		0.9%	1.7%	26.3%	-12.7%





Regulatory History

EMTIC GD-031

Allowed for **Different sized holes** that are **only balanced** at **tested flow rate/ambient conditions** (temperature) and would behave differently while in service in some cases.

One of Reference Meters specified in test protocol **Required Very High Pressure Drop** and would **interfere** with **as built conditions** on **standard CEM System Flow Rates**

SCAQMD Supplemental Guidelines

Allowed for alternate flow meters to allow test apparatus to not interfere with standard CEM System Flow Rates Required Array Sample Line to be assembled, hot and utilized.



Checklist for Multi-Point Probe Acceptance & Quality Assurance Testing for SCAQMD

- Brief description, summary, **critique of testing precedes** documented results.
- Multipoint probe is configured and **tested exactly as it will be assembled on proposed stack/duct** sampling location including properly-sized sample/vacuum pump, valves, rotameters, required AP or vacuum gauges, flow meters, etc. (a simple drawing of this configuration, as tested is provided)
- A **drawing** or representation showing **the probe(s) dimensions and location of points** with **respect to mounting flange** or other point of reference is included.
- **Total flowmeter specs** (type/make/model/serial no./flow range) and current calibration (if applicable) are included.
- **Point flowmeter specs** (type/make/model/serial no./flow range) and current calibration (if applicable) are included.
- **Sample/Vacuum pump specs** (type/make/model/volume) are included.
- All **vacuum meter/flowmeter/rotameter readings during test are recorded** and included, as well as **temperature/pressure corrections**, if applicable. **Current calibrations for all applicable metering devices** are also included.
- **All raw readings and data sheets**, as well as **calculated/summarized information** is included.
- An **example calculation, using actual data from this test** is included.
- All **reported deviations** are with respect to **the sum total of all points on all probes** (not each individual probe).
- All **applicable pages of the report** are **annotated as to company, data, time, personnel, run**; or otherwise identified to tie the report together.



Gas Laws-How Emissions are Affected

Standard Temperature and Pressure (STP) and Ideal Gas Laws

Fluid flow rates and the volumes of liquids and gases are highly dependent on Temperature and Pressure.

Standard Ambient Temperature (**25C-77F**) and Pressure (**1 atm**) are utilized with gas analyzers

Gases are made up of molecules in constant random motion

Pressure—is a result of **gases colliding and hitting walls of stack**, which are perfectly elastic (no loss of kinetic energy)

Temperature—proportional to the average kinetic energy of **gases**



Gas Laws

Ideal Gas Law

$$PV = nrT$$

Boyle's Law –assumes constant temperature

Charles Law-assumes constant pressure

Guy-Lussac's Law-assumes constant volume

or

“Real” Gas Law

$$PV = ZnRT$$

Allows for the compressibility of gas

Analyzer companies allow for this compressibility factors when developing the programs and factors to calculate results



Flow Related Forces from Gas Flow

Lookup tables in: PINK	
Enter composition percent values below	
N2	69.7 (Don't enter N2. It's calculated to make 100%)
O2	15.4
CO2	4
H2O	10
Air	0.9
Temp °F	830
Temp °R	1290
Stack Press, PSI	13.9
Exhaust Density:	lb/cu ft 0.0285
Flue Vel, FPS	183
Viscosity (**Sutherland Formula) [lb-ft-sec/ft²]:	7.47E-07
** for dry air. Hey, it's close!	
Enter Characteristic Diameter	For probe tubes NRE calc, use tube OD
	For pipe/stack flow NRE calc, use ID or equiv diameter
Characteristic Dia, ft	0.0417
	Probe Tube O.D.s (in Feet)
	1.5" PIPE 0.156
	1" PIPE 0.11
	3/4" PIPE 0.0875
	1.25" PIPE 0.136
	1" TUBE 0.0933
Reynold Number:	NRE 9.04E+03
Probe Tube Force Calculations	
Tube Length, ft.	10
Probe Projected Area:	sq. ft. 4.17E-01
Von Karman Force, lbs:	Fk lbs force 1.05E+01
Fk From Penys. Given Ck=1.7 for tubes	
Von Karman Frequency, f:	834
Penys; Valid for 500<NRE<10^5	
Drag Force, Fd	Bennet and Meyers
	given Cd = 1.4 for cyl with NRE<10^4
	(For other NRE, enter appropriate Cd)
Cd	1.4
	Fd lbs force 8.64E+00
Resultant Force	lbs force 1.36E+01
Resultant Moment, for strength calcs	ft-lbs 6.00E+01



Analyzer Bias's from Pressure

Analyzers are sensitive to the pressure of the gas in the measurement cell.

In calibration mode, a high gas flow rate from the calibration gas cylinder can pressurize the cell and lead to subsequent sample measurement biases.

In spectroscopic absorption instruments, (NDIR) the gas concentration measured is related to the number of molecules in the light path.

If the pressure is increased, the density of the sample gas is increased.

The number of molecules in the light path increases correspondingly, even though their true concentration remains the same.

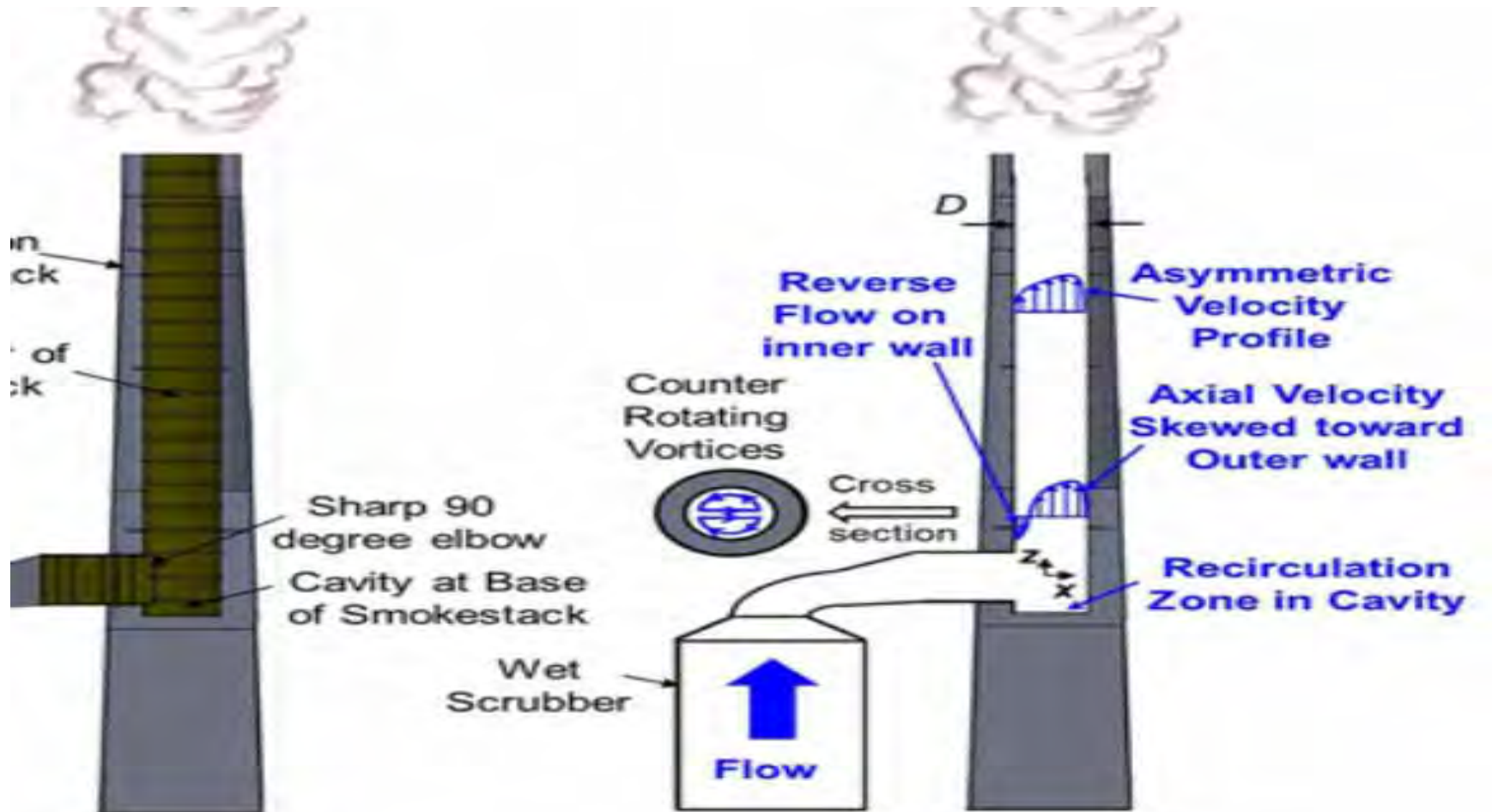
Gas flow rate into the measurement cell must be the same in both calibration and sampling modes.

Most gas manifolds are maintained to exhaust at a fixed pressure, the flow rates in both the calibration and sampling modes should be set so that this pressure is not exceeded.

https://www.epa.gov/sites/production/files/2015-05/documents/chapter_6_sources_of_bias_in_the_gas_analyzer.pdf



What Causes Stratification in a Stack





Probe Selection Criteria

- What are the characteristics of the stack-height, size, interior, dimensions, sample locations, area classification?
- Any temporal variations (stratification) in the stack?
- Sample residence time?

From this information the type of probe-traditional, dilution or multipoint can be selected. The correct engineered probe will be designed for your application.



Probe Selection-Its Complicated cont.

What gases are being measured & at what ppm levels?

Reactive & other gases and temperature in stack are critical!



NO₂

Dew Point, water vapor in stack?

Acid dew point-high SO₂ may require acid mist catchers,
additional filters....



CO₂

Stack Hazard class-Probe needs to be engineered to fit classification

-Class 1 Div 2...

Impact of final optimal configuration upon CEMS QA/QC plan



Multipoint Design Criteria

- Probe design is based on stack dimensions and conditions
- Stacks that are < 80 feet typically have flow disturbances in close proximity to sampling range (silencer can cause issues)
- Shorter stacks commonly have temporal variation
- Shorter stacks make the engineering of a multipoint probe more challenging due to shorter residence time, and shearing stress on the sample tubes
- M&C has engineered multipoint probes for stacks <80 feet



Probe Selection Criteria

- Is the sample gas “dirty”, with particulates, oil, or other contaminants ?
- How wet is the sample (dew point)?
- What temperature is the stack where gas will be sampled?
- What gases are being measured and at what ppm?
- What other gases/acids will be present, which may cause sampling & measurement issues or require additional components..... Filters?



Multi Point Probe Design

-Its Complicated

Stack coordinates, round or square, height (upstream/downstream distance from flow disturbances (method 1)

The **stack temperature**, **flow**, **pressure** and **residence time** are critical in designing the correct probe for your application.

- Mechanical Strength of probe required for high velocity and temperature.
- Prepare the correct flow rates and residence time and submit test procedure for approval from district

What **fuel** is used-**oil**, **coal**, **natural gas**, **waste**, **biofuels**, **Biomass**, **Digester Gas**, **trash**, **tires...**

- The **fuel contaminants & Particulates/dust loading** will also effect the probe design in selecting the correct filters, shields, separators, acid mist catchers, blow back....



Using the Correct Probe is Critical



NOx measurement at sub 5 ppm is challenging

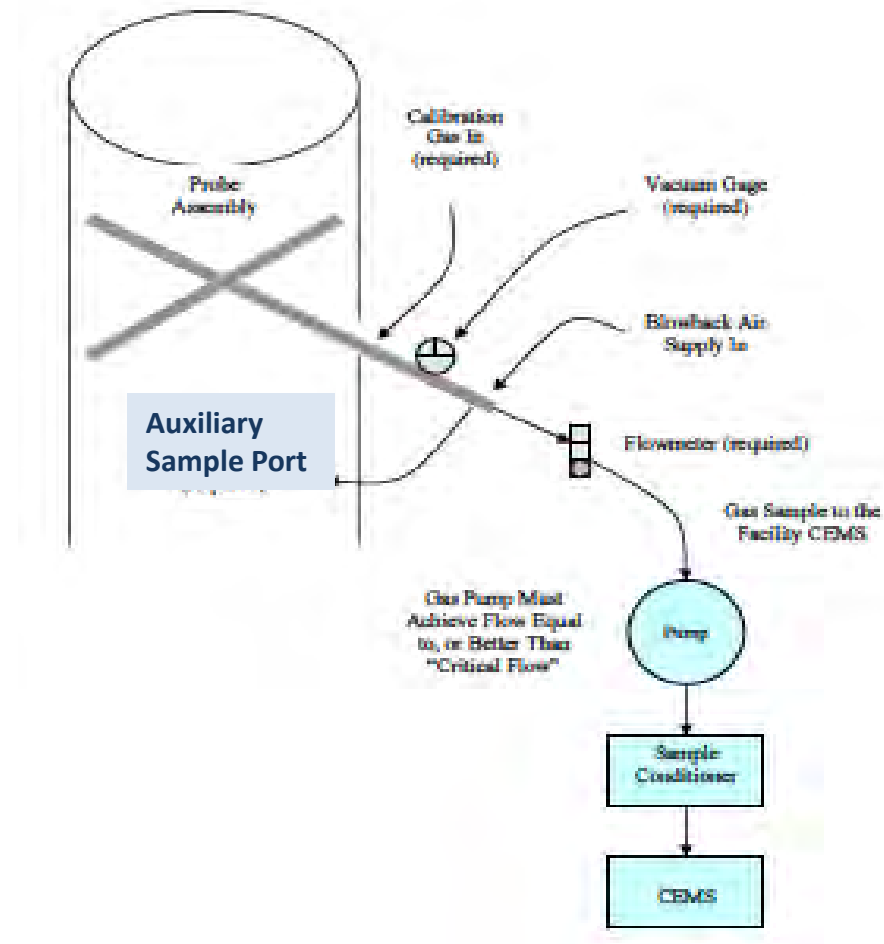
Sample Extraction is the Key to Good Measurement

The probe is the most critical component that can be controlled, in getting a representative sample.

Multipoint Probes ensure a representative sample due to their design to sample across the stack at multiple points. More sample points mean a better sample of the gases to be measured even when the sample conditioning vary.

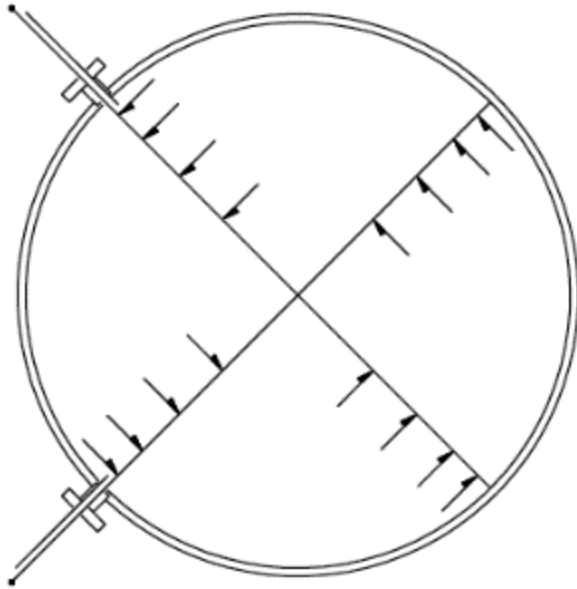


Typical Multi-Point Probe Configuration Basic & Required Components





Multipoint Probe 2 Point Stack



Cross Stack Example with 2 Probe Insertion Points

Each multipoint probe is custom engineered based on the individual stack characteristics.



Anatomy of a Multipoint Probe

- Probe Tubes or barrel
- Heated /unheated filters
- Probe controller
- Accumulator tank for blow back
- Mixing chamber
- Probe housing dependent on area classification
- Flange





Sample Tubes for Various Applications

Gas sampling requires an extension tube to properly extract sample from a specific point in the gas stream. The correct configuration of tubes and material is critical.

Examples:

Screw-in Tubes

Flange-Welded Tubes

Multipoint Tubes

Stainless

Hastelloy

Silcoat or Sulfinert

Teflon

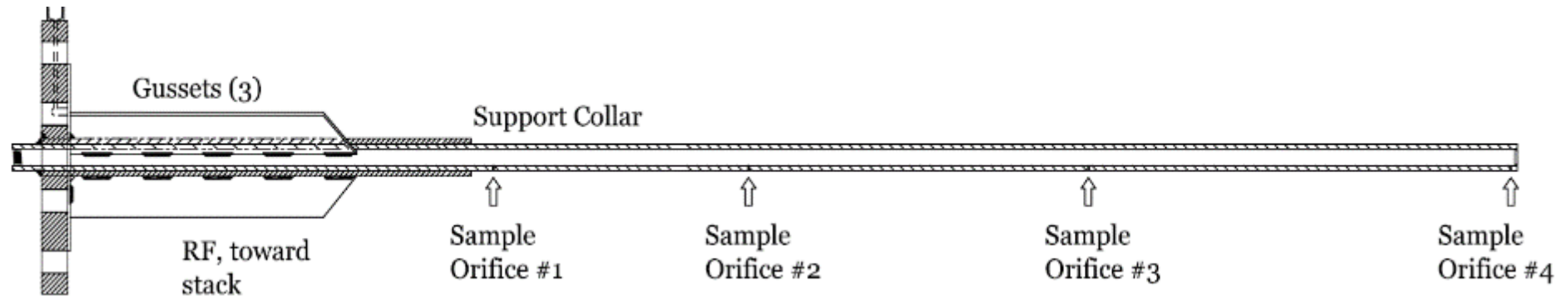
Sintered Tubes



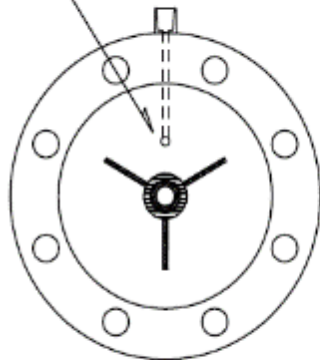
The sample tube material is based on the application. Temperature of sample, actual gas sampled, other gases present, width of stack, stratification, all play a critical role in tube or array design.



Cantilever Probe Tube



Static Pressure Port



4" 150# ANSI
Raised Face (RF)
Flange

Cantilever Probe Tubes

(4) Sample Orifice per Tube. Sample Orifice Locations
Determined by EPA Method 1 for
Stack Dia ____", ____" Ports, ____" Offset
Orifice Size(s): ____

(#) Ea. Required Per Stack. (16 Total Points In Array)

Materials:

Support Tube:

Sample Tube:

Support Structure:



Sample Tube Material Choices



Options for Low dust loading $<2 \text{ g/m}^3$

SP2000/SS stainless steel up to 600°C

SP2000/T teflon up to 160°C

SP200/TI titanium up to 400°C

SP2000/HC hastelloy up to 900°C



Factors to Consider for Filter Selection

Corrosive or *Aggressive* Sample Constituents

Heated Or Unheated Filter

What *Gases* Are To Be *Monitored*?

Downstream *Component* Operating *Temperature*, *Filter Heater*

Downstream *Component* Operating *Pressure*, *Pressure Regulator* and/or *Relief Valve* Required

Sample *Dewpoint* (Acid, Hydrocarbon, or other), *Separator* and/or *Membrane* Required

Spectral *Interference In Sample*, *Adsorption Material*

Area Classification

Flow Requirement



Heated filter



Probe tube prefilter



Accumulator Tank



Accumulator Tank



Accumulator Tank in Uninsulated
probe housing



Mixing Chamber





Probe Housing



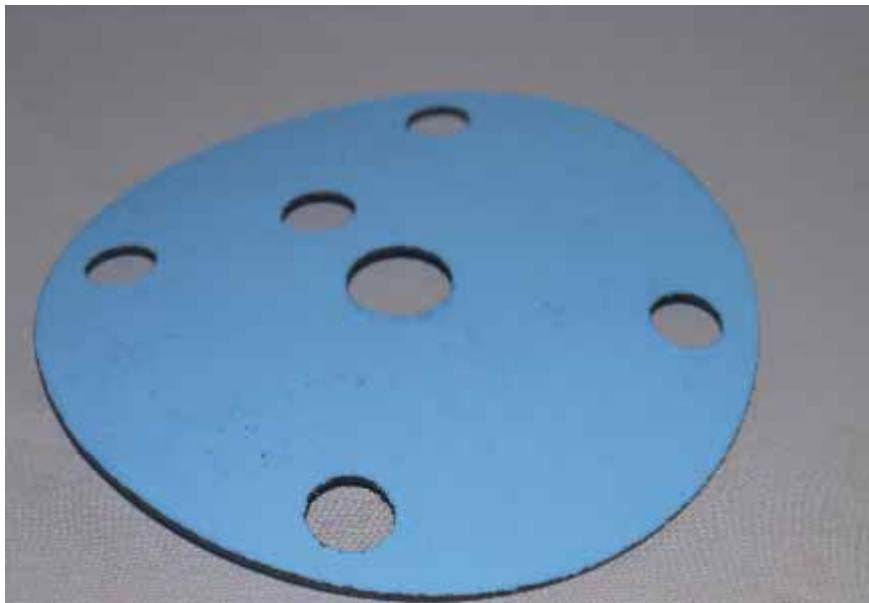
Insulated Housing



Uninsulated Housing

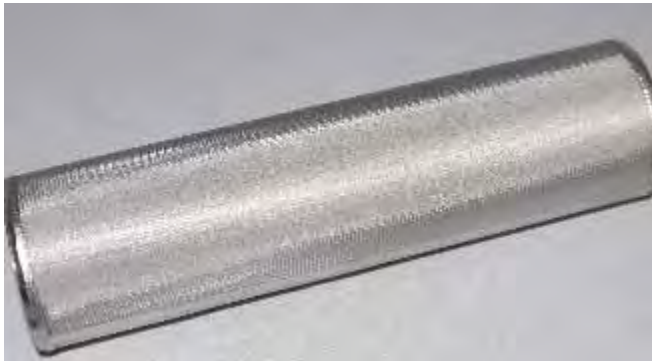


Flanges





Filters, Separators, Shields



Shield



Heated Filter



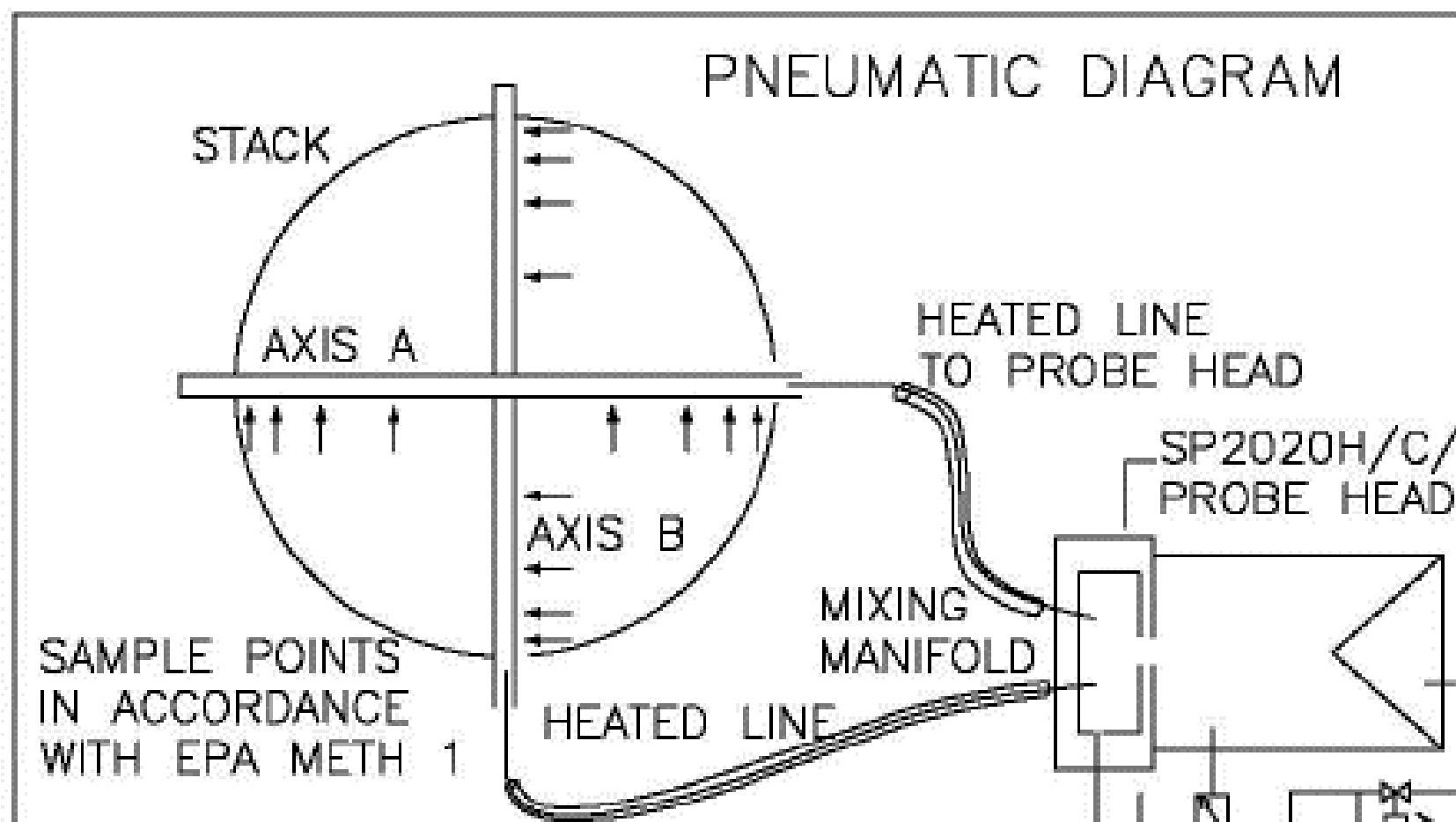
Separators



Shield



Multipoint Probe with Mixing Manifold





Multi Point Probes/Arrays/Manifolds

Arrays are **custom designed** for stacks with **gaseous stratification**, or a **variation in contaminant** and/or **diluent gas concentration** with **temporal variation** (inconsistent stack flow). SCAQMD has been requesting multi point arrays for new applications.

The array consists of a number of sample extraction points or holes on one or more probes, configured to equally cover the proposed stack or duct cross sectional area of interest. The probe(s) are manifolded together to a high volume, positive displacement sample pump, must have flow and vacuum meters to monitor probe performance, as well as an audit Port.



Stream selection Manifold for SCR tuning in stratified flow

Arrays are common in applications <10 ppm NO_x, in SCAQMD



Probe Placement in Stack is Critical

Method 1— Sample and Velocity Traverses for Stationary Sources

Method 1 will provide guidance for the selection of **sampling ports** and **traverse points** at which sampling for air pollutants will be performed. Two procedures are provided a simplified and alternate. Acceptable for gas streams flowing in **ducts, stacks or flues**.

Not Applicable for conditions where:

-the flow is cyclonic or swirling

-a stack is smaller than 12 in. in diameter, or 113 in.² in cross-sectional area



Probe Placement in Stack is Critical

Simplified Procedure

Sampling or flow velocity site located at least **eight stack or duct diameters downstream** and **two diameters upstream** from any flow disturbance (bends, expansion or contractions in the stack or visible flame)

- 12 traverse points required circular/rectangular >24 inch stacks

- 8 traverse points required circular 12 to 24 inch stacks

- 9 traverse points required rectangular 12 to 24 inch stacks



Calculates (8) traverse point locations across circular stack		
Mount probes (traverses) on two axis at 90° to complete traverse		
Calculation per 40CFR part 60, Method 1		

Point #	Location (from wall)	Location (from flange face)
1	4.48	16.48
2	14.7	26.7
3	27.16	39.16
4	45.22	57.22
5	94.78	106.78
6	112.84	124.84
7	125.3	137.3
8	135.52	147.52

Performance Testing Criteria

With flow being critical to the operation of a multi-point probe, the total flow rate of which the probe is certified or will be the minimum allowable volumetric flow rate for the CEMS to operate.

Performance Criteria for Acceptable Operation is Dictated by Statistical Criteria Specified in EMTIC GD-031

Array Differential Pressure is also recorded during test procedure and the as tested differential pressure can be monitored on a periodic basis to insure that the multi-point probe is operating in a balanced flow condition during field operations.



Performance Testing

Bench Testing is required in accordance with EPA/EMTIC Guidance Document (GD)-031 Evaluation Procedures for Multi-Hole Sample Probes

Assures that high-volume sample pumps can provide constant & equal flow to all points of the probe array

Test Measures Total & Individual Point Flow with:

- each individual sample point being within 10% of the overall flow average
- the sum of all individual point flows must be within 10% of the overall flow

Formal notification of CEMS initial approval or Probe recertification must be received by AQMD before the multi-point probe is installed.



Probes: Correct Design is Necessary

Probe **Filter is not correct for application**-too much particulate

Probe has **cold spots, poor temperature controller**—results in moisture in sampled gas and loss of sample gas in moisture

Probe **Mounted Incorrectly** or **installed in wrong place in stack**-does not meet method 1 requirements, non representative sample

Blowback not setup correct-need properly sized tank

Stratification in stack **causes poor sampling**-need multipoint probe

Array setup incorrectly-**various configurations custom engineered**



Quality Assurance

The following must be addressed in the QA document for the Multi-point probe

1. Periodic system Blowback
2. Visual inspection for corrosion, plugging, leaking
3. Periodic Pump/Conditioning system PM (by vendor, or visual problems see 2)
4. Total flow & vacuum readings must be periodically recorded
5. Periodic AQMD audit of probe performance (by AQMD or 3rd party)

Multi-point probes with reference method audit ports can not be used as a QA RM CEMS/ Audit tube can not be used to validate performance of the probe to acquire a representative gas sample, since any errors (leaks, point bias) would be Mirrored by both CEMS



Good Maintenance Practices

- Check probe prefilter, if plugged replace
- Check probe temperature
- Check flow through to the sample
- Confirm CEMS operation by daily calibration
- Check Calibration and zero gas cylinders, pressure >200lbs.



The M&C Difference

- M&C Tech Group has worked with SCAQMD when Multi Point Probes were originally designed to meet the correct sampling guidelines.
- Design for each Multipoint Probe is custom to users application.
- M&C communicates and supports customers every step of the process from design to RATA .
- Over 15 years experience with every Multi Point Probe units, with all passing their RATA.
- Multi Point Probe support continues after certification.



Thanks for Listening Questions ?

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M&C Technology Group—Embracing Challenge