Secrets of Successful Source Emission Test Programs

November 4, 2021

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STACK TESTING 101

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Agenda

- ➢ Source emission testing overview
- ➢ General source testing goals and objectives
- ➢ Source emission testing category review
  - Volumetric flow rate measurements
  - Isokinetic test methods
  - Gaseous compound
  - Instrumental real-time testing
- ➢ Key source test program elements
- ➢ Common source testing program pitfalls

Source Emission Testing can be best defined as:

"*Quantifying pollutant emissions from a stationary air emission point source*"

- Point sources can range from a 2-inch ID process vent to a 20 foot or larger diameter utility boiler stack.
- Some of the pollutants commonly tested include:
  - particulates (filterable, condensible, PM-10, PM-2.5)
  - volatile organic compounds (VOCs)
  - acid gases (HCl, HF, HNO3, H2SO4)
  - SOx, NOx, CO, THC, NH3
  - semivolatile compounds
  - aldehydes and ketones
  - toxic metals

Why Test?

1. To evaluate or demonstrate compliance with a State or Federal emission standard
2. To audit a continuous emission monitoring device
3. To evaluate the emission impacts of a process modification
4. To generate data in support an emissions inventory or permitting activity, or
5. To evaluate the performance of a pollution control device

Source emission testing can:

➢ Accurately quantify target pollutant emissions providing quality data for compliance and engineering projects.

Source emission testing can't necessarily:

➢ Identify all unknown pollutants in a gas stream. Need to have some information on process parameters, raw materials, exhaust gas constituents, etc. to select appropriate test methods.

Typical Source Testing Program

- ➢ Scope of work and pollutant target list are developed (preliminary testing)
- ➢ Testing protocol is submitted (if required by client or regulatory agency)
- ➢ Field testing conducted
- ➢ Data reduction performed
- ➢ Test report prepared
- ➢ Compliance demonstrated

Sample Journey

- **Collection**
  - Initiation of Chain of Custody
- **Transportation**
  - Different samples, different requirements
- **Receipt at laboratory**
  - Verification of Chain of Custody
- **Sample Analysis**
  - Extraction/Recovery, preparation, analysis & reporting

Source Testing Project Costs

Depends primarily on number of sources tested, target pollutants, and degree of off-site analytical work and process stream modifications (*e.g*. waste feed spiking) needed.

- Costs can range from $1,500 for a simple opacity monitoring test to over $1MM for a large hazardous waste trial burn.
- Typical testing project fees range from $7,000 to $30,000.
- Average Alliance test program fee in 2020 was ~ $12,000.

Source Emission Test Method Categories

- Fortunately, regulatory agencies (*e.g.* USEPA and CARB) along with industry trade groups (*e.g.* NCASI) have established detailed, validated source test methods for specific pollutant types.

- These test methods can be divided up into four general categories –
  - Volumetric flow rate
  - Isokinetic, multi-point sample collection
  - Single-point, nonisokinetic (constant sample rate)
  - Instrumental – realtime, on-site analysis

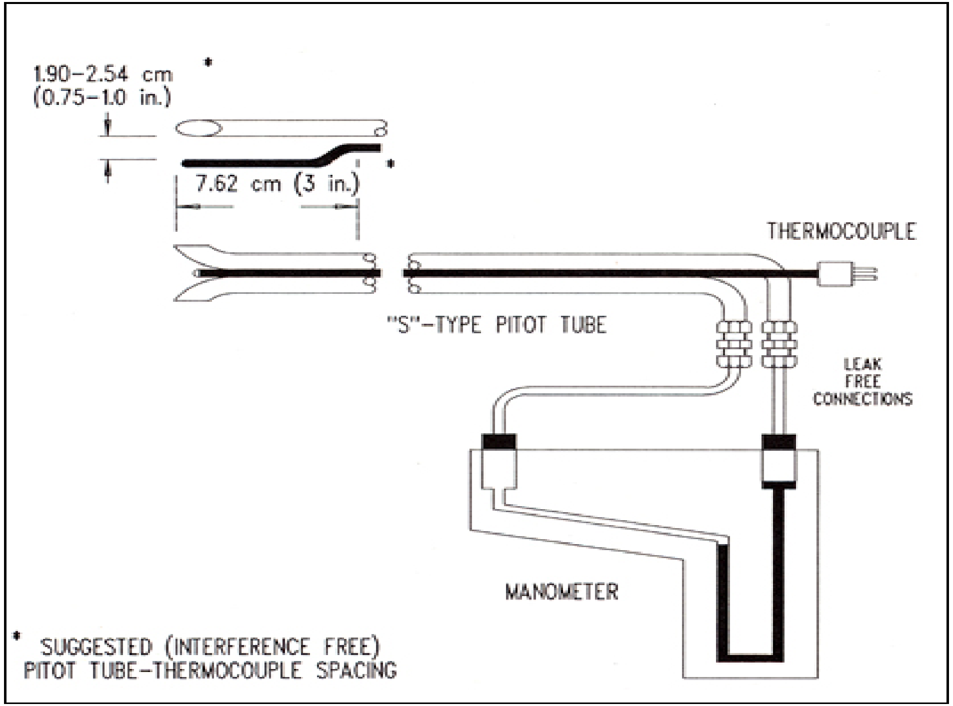
Specific Methods

PARAMETER	TEST METHOD	PARAMETER	TEST METHOD
Volumetric Flow Rate	EPA Methods 1-4	Dioxin / Furan	EPA Method 23
Oxygen / Carbon Dioxide	EPA Methods 3, 3A & 3B	Total Hydrocarbons	EPA Methods 25, 25A-E
Particulate Matter	EPA Methods 5, 5A-5I	Hydrogen Halides & Halogens	EPA Methods 26 & 26A
Sulfur Dioxide	EPA Methods 6 & 6C	Metals	EPA Method 29
Nitrogen Oxides	EPA Method 7E	Total Vapor Phase Mercury	EPA Methods 30A & 30B
Sulfuric Acid Mist	EPA Method 8, 8A & CTM- 013	Mercury	EPA Methods 101 & 101A
Visible Emissions	EPA Methods 9 & 22	Mercury-Hydrogen Streams	EPA Method 102
Carbon Monoxide	EPA Methods 10, 10A & 10B	Beryllium	EPA Methods 103 & 104
Hydrogen Sulfide	EPA Method 11	Vinyl Chloride	EPA Method 106
Lead	EPA Method 12	Arsenic	EPA Method 108
Total Fluoride	EPA Methods 13A, 13B, 14 & 14A	PM2.5/PM10	EPA Method 201A
Reduced Sulfur Compounds	EPA Methods 15 & 15A	Condensable Particulate Matter	EPA Method 202
Total Reduced Sulfur	EPA Methods 16, 16A, 16B & 16C	Total Enclosures (PTE / TTE)	EPA Methods 204, 204A-F
In-Stack Particulate Matter	EPA Method 17	Total Chromium	EPA Method 306
Volatile Organic Compounds	EPA Method 18	Methanol	EPA Method 308
Emission Rates (F-Factor)	EPA Method 19	Formaldehyde	EPA Method 316, 320 & 323
NOX - Gas Turbines	EPA Method 20	Hydrochloric Acid	EPA Method 321
VOC Leaks	EPA Method 21	FTIR (Organics / Inorganics)	EPA Methods 318, 320 & 321

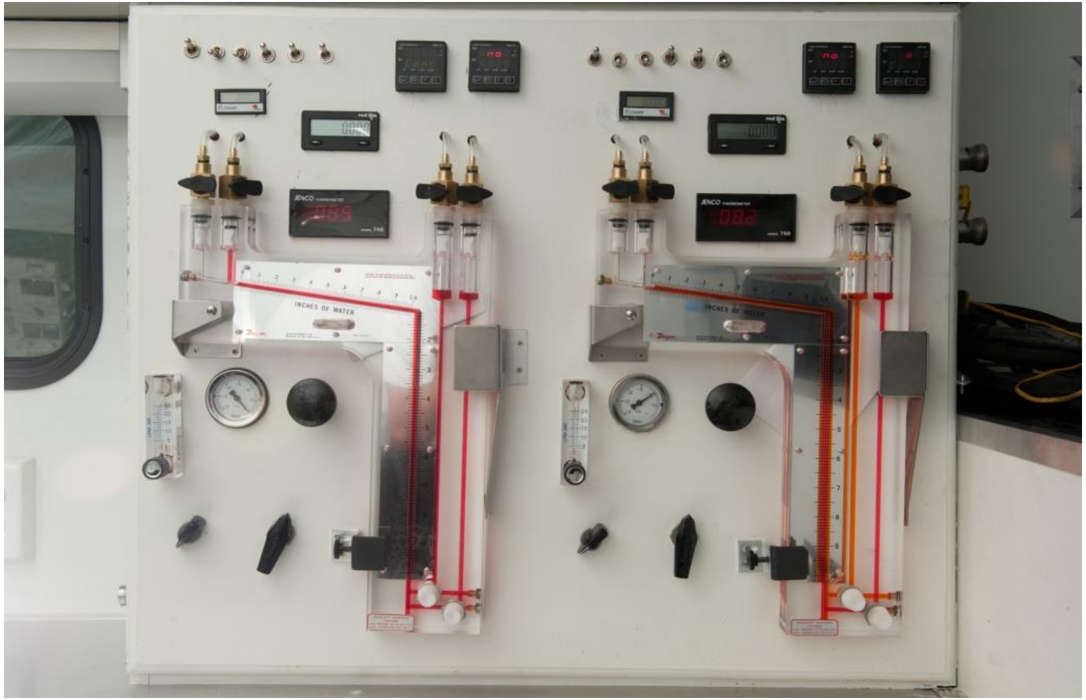
1 - Volumetric Flow Rate Test Methods

- Measuring the volumetric flow rate of a gas stream is included in most source testing programs.
- It is used to relate pollutant concentrations to mass emissions rates (lb/hr)
- The following test equipment are used to evaluate flow velocity
  - S-type or Standard pitot tubes (USEPA Methods 1 and 2)
  - Hot wire anemometers
  - Vane anemometers
  - Ultrasonic flow meters
  - Orifice meters
  - Flow measurement head is traversed across duct to account for velocity stratification

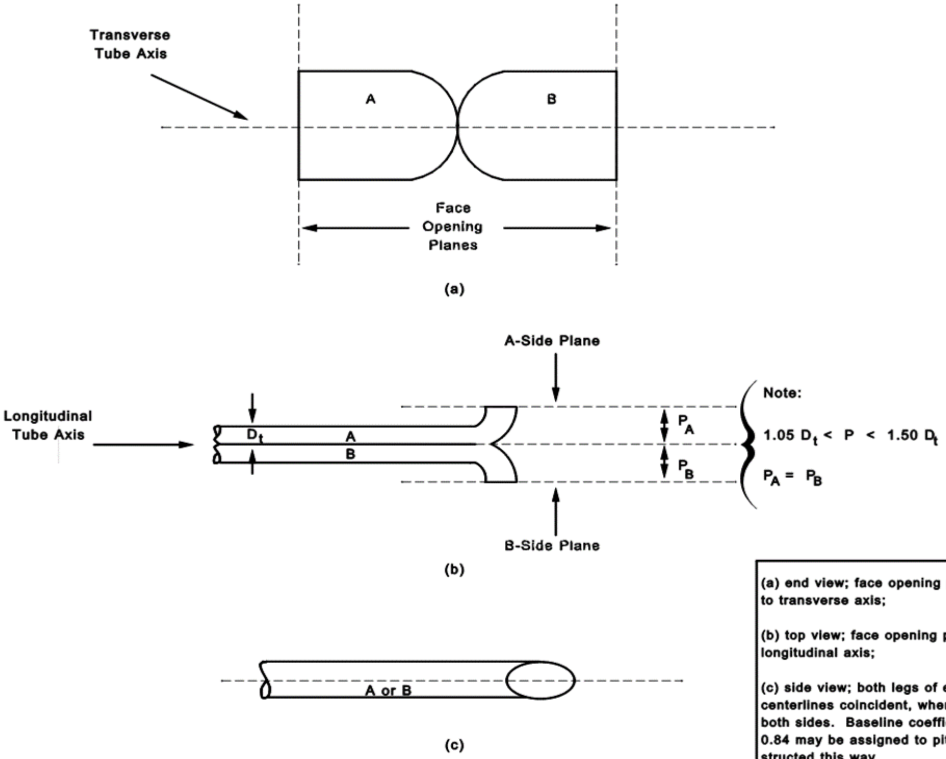
S-Type Pitot Tube Schematic



Flow Measurement Incline Manometer



Pitot Tube Tip

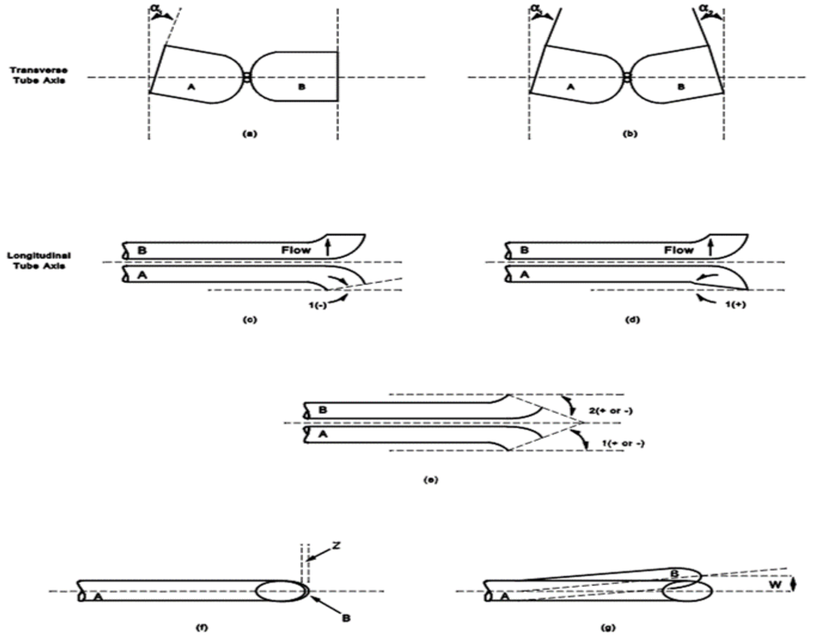


(a) end view; face opening planes perpendicular to transverse axis;

(b) top view; face opening planes parallel to longitudinal axis;

(c) side view; both legs of equal length and centerlines coincident, when viewed from both sides. Baseline coefficient values of 0.84 may be assigned to pitot tubes constructed this way

Pitot Tip Alignment

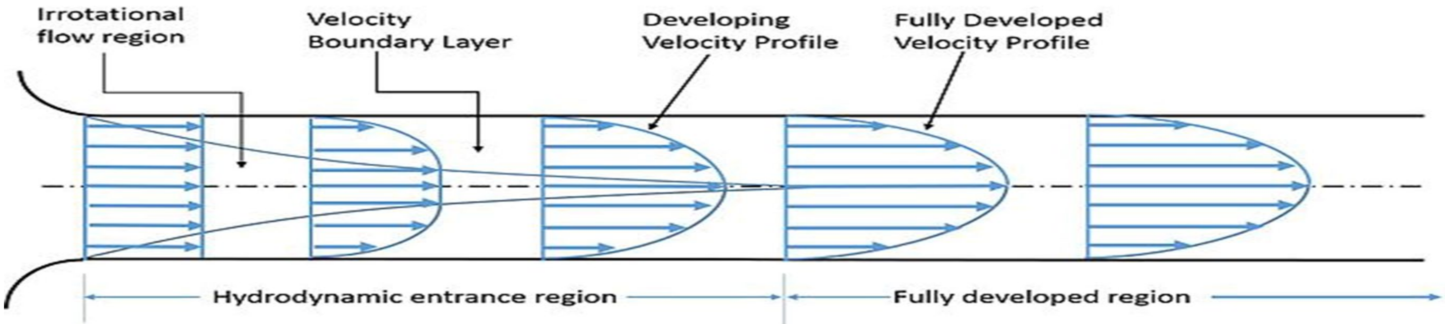


The types of face-opening misalignment shown above will not affect the baseline value of Cp(s) so long as α_1 and $\alpha_2 \le 10$, and < 5, z < 0.32 cm (1/8 in.), and w < 0.08 cm (1/32 in.) (reference 11.0 in Section 16.0).

Exhaust Stream Flow Profile Evaluation

- Important that the flow profile at the test location be a laminar as possible for volumetric flow rate measurements and isokinetic sampling
- USEPA Method 1 criteria states the average yaw angle must be less than 20 Deg. from vertical or flow is considered “Cyclonic” and site is not acceptable
- 3D flow measurement probes must be used for flow profile testing if test location does not meet USEPA Method 1 location criteria
- Traditional isokinetic testing cannot be conducted in cyclonic gas streams
- In certain circumstances the sample nozzle can be rotated to the flow angles at the various traverse points
- Flow straighteners are commonly used to reduce cyclonic flow conditions

Exhaust Stream Flow Profile Evaluation, Con't



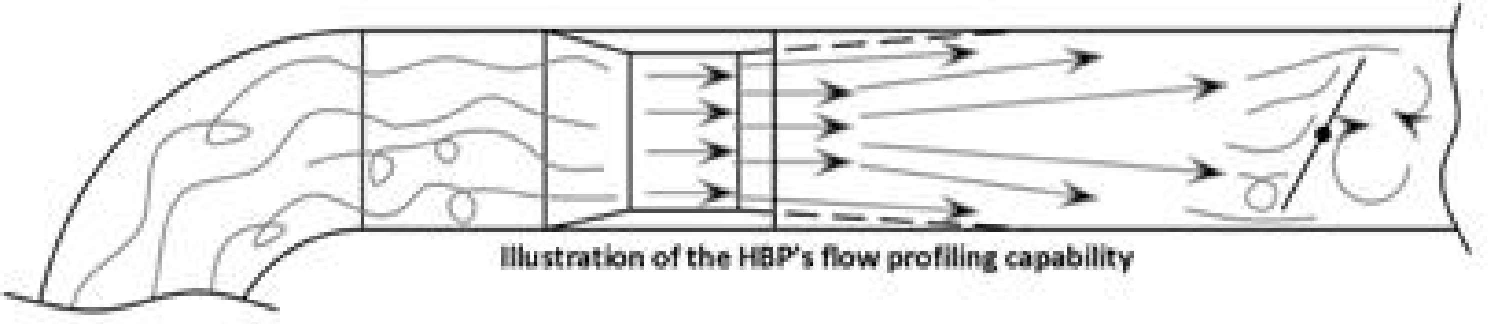


Illustration of the HBP's flow profiling capability

Pitot Tube Velocity and Flow Rate Equations

- Stack Gas Velocity (ft/sec) = K x pitot tube coefficient x $(\Delta P)^{½}$ x $(T_s/P_s \times M_s)^{½}$
- Stack gas Molecular Weight = 0.44 x (%CO_2) + 0.32 x (%O_2) + 0.28 x (%N_2 + % CO)
- Stack Gas Flow Rate (dscf/min) = 3600 x (1-Bws) x Vs x Stack Area x (T_{STD} x Ps/Ts x P_{STD})

  Where:

  ΔP = pitot tube differential pressure (in H_2O)

  K= Conversion constant

  T_s = Stack Temperature (Deg. R)

  P_s = Stack Pressure = (In Hg)

  M_s = Stack gas molecular weight

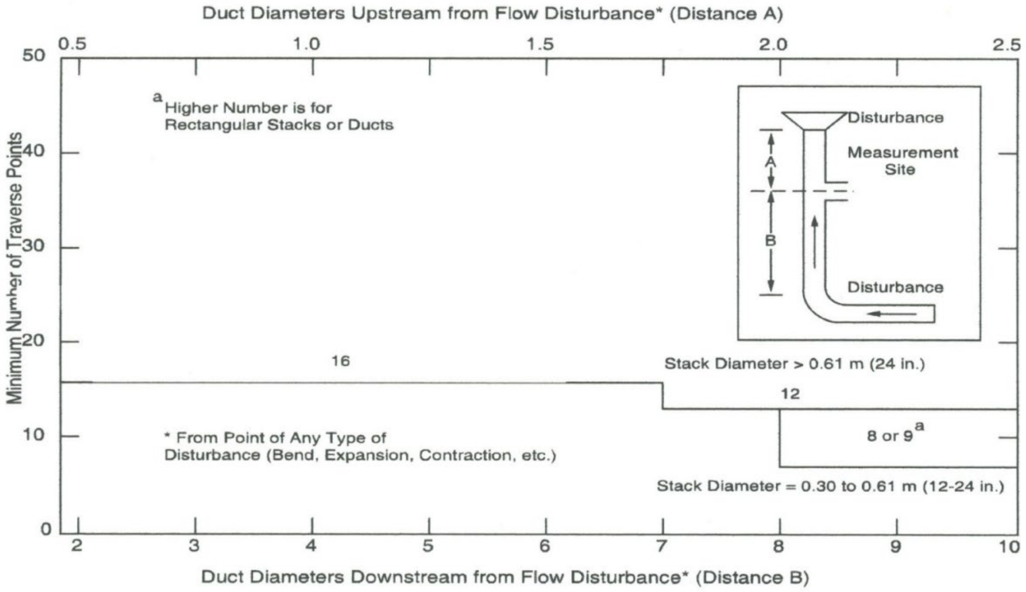
  B_{ws} = Stack gas moisture content (percent by vol.)

  T_{STD} = Standard temperature (460 Deg. R)

  P_{STD} = Standard pressure (29.92 in Hg)

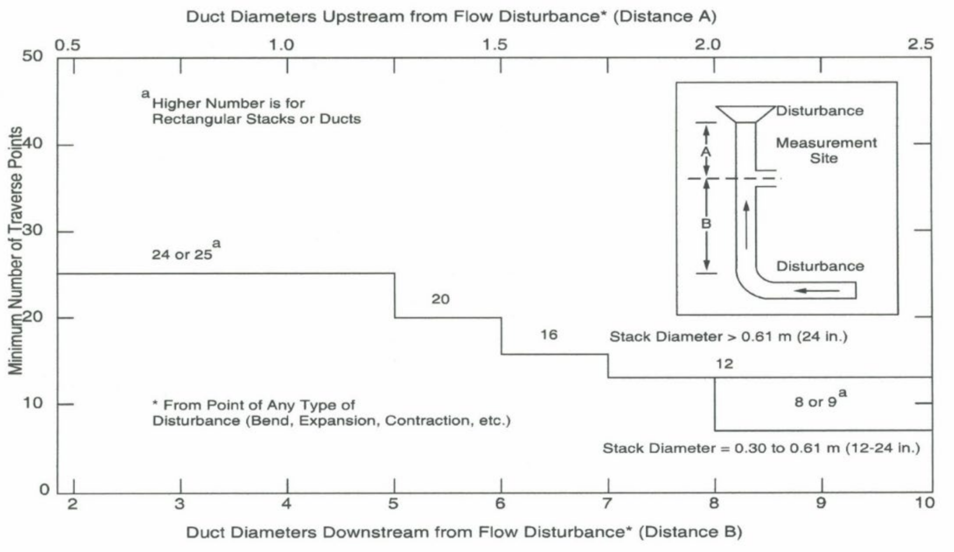
USEPA Method 1: Figure 1-2

Minimum number of traverse points for velocity traverses



USEPA Method 1: Figure 1-1

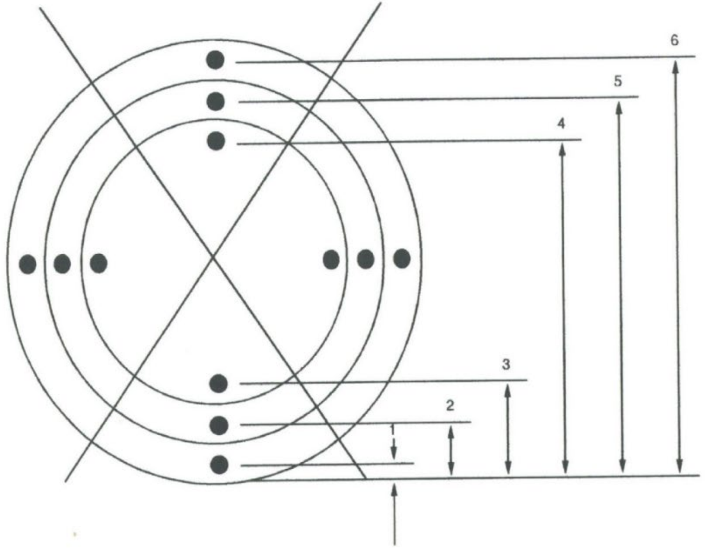
Minimum number of traverse points for particulate traverses



USEPA Method 1: Figure 1-3

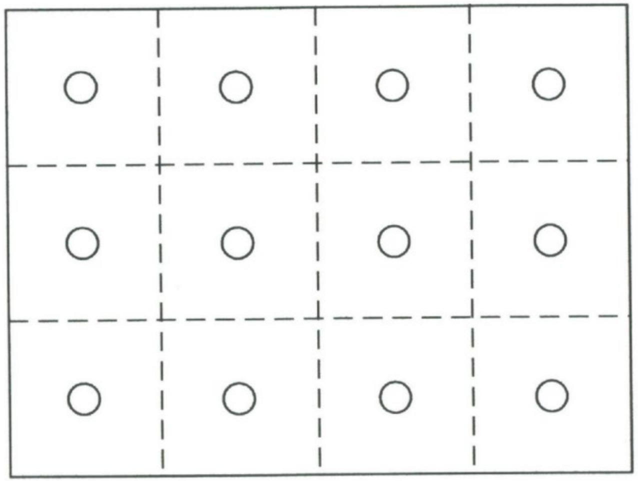
Circular stack cross section divided into 12 equal areas

Traverse Point	Distance % of diameter
1	4.4
2	14.7
3	29.5
4	70.5
5	85.3
6	95.6



USEPA Method 1: Figure 1-4

Rectangular stack cross section divided into 12 equal areas



2 - Isokinetic Test Methods

Alliance

- Isokinetic methods are used to sample for pollutants in a solid or aerosol state at stack temperature. These methods maintain a sample rate that is equal to the velocity of the sample stream.
  - Particulate or particle-bound pollutant captured on filter media
  - The “same velocity” sample rate is important so that the collected sample is not biased due to varying particle sizes.
  - Sample nozzle diameter and sample rate are selected to achieve an isokinetic sampling condition given specific stack gas conditions
  - This sample velocity/rate is maintained through-out the test run regardless of charges to stack flow rate
  - Sample velocity/rate criteria for the majority of isokinetic methods is 90-110% stack flow rate

Isokinetic Test Methods, con't

- Sample nozzle is traversed across duct to account for particle stratification
- Commonly used Isokinetic test methods:
  - USEPA Reference Method 5 (particulates)
  - USEPA Reference Method 23 (PCDD/DF)
  - USEPA Reference Method 29 (metals)
  - USEPA Reference Method 201A (PM-2.5 and PM-10)
  - CARB Method 429 (PAH)
  - SW846 Method 0050 (HCl/Cl_2)
- USEPA Methods 1-4 which measure stack gas flow rate are conducted in conjunction with above methods

Isokinetic Test Methods, con't

- % Isokinetic Sample Rate $= \dfrac{100 \times T_s \times [(V_m \times Vol_c)/T_m \times (P_{bar} + \Delta H/13.6)]}{60 \times P_s \times A_n \times V_s}$

- Sample Volume (dscm) $= \dfrac{V_m \times \text{Meter Gamma (Y)} \times T_s \times (P_{bar} + \Delta H/13.6)}{T_m \times P_s}$

- Pollutant Concentration (mg/dscm) $= \dfrac{\text{Pollutant Mass (mg)}}{V_{m(STD)}\ (m^3)}$

- Pollutant Emission Rate (lb/hr) = Pollutant Conc. (mg/dscm) x volumetric flow rate (dscm/min) x 60 x K

Particulate Matter 101

- Types of Particulate Matter
  - Filterable PM (FPM)
  - Filterable PM_{10} (FPM_{10})
  - Filterable $PM_{2.5}$ ($FPM_{2.5}$)
  - Condensable PM (CPM)

  - PM_{10} (FPM_{10} plus $FPM_{2.5}$ plus CPM)
  - $PM_{2.5}$ ($FPM_{2.5}$ plus CPM)

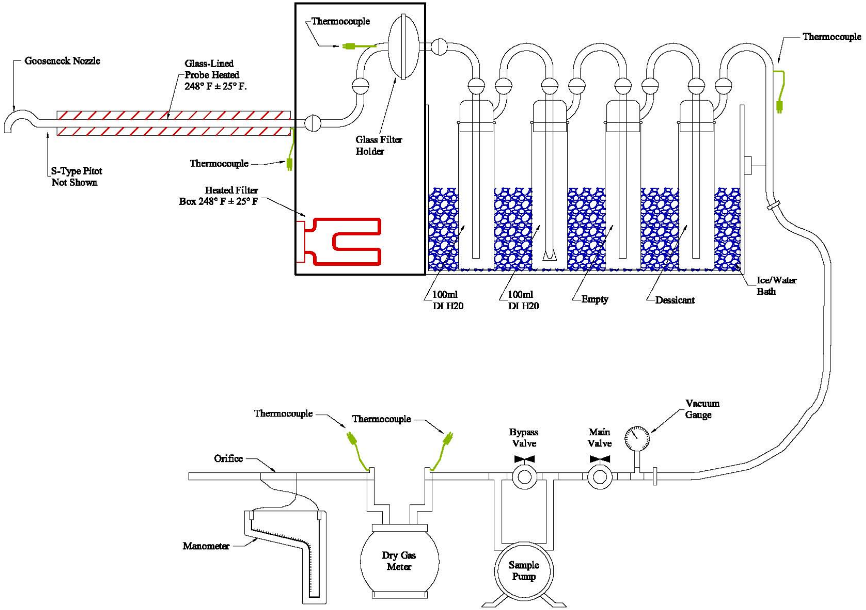
Particulate Matter 101, con't

- Particulate Matter is defined by Method
  - Filterable PM - Filtration Temperature
    - In-stack
    - 248ºF or 320ºF
  - Condensable PM - Back half Train Operating Temperature
    - 65 - 85ºF
    - As close to 85ºF as possible

Particulate Matter Test Methods

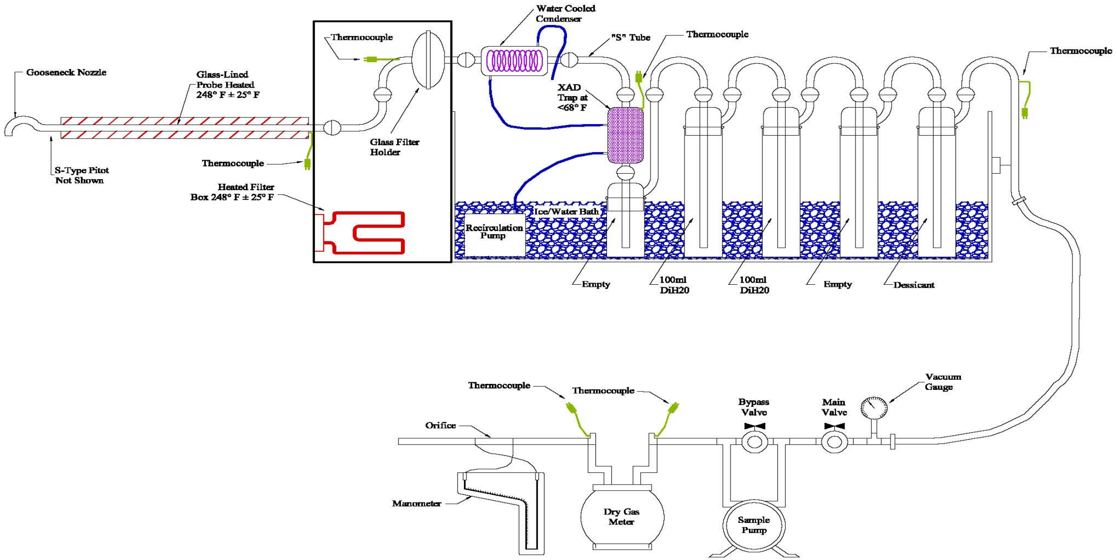
- EPA RM 5 or 17
  - PM
  - FPM
- EPA RM 201A
  - FPM_{10}
  - $FPM_{2.5}$

Isokinetic Sample Train Schematic



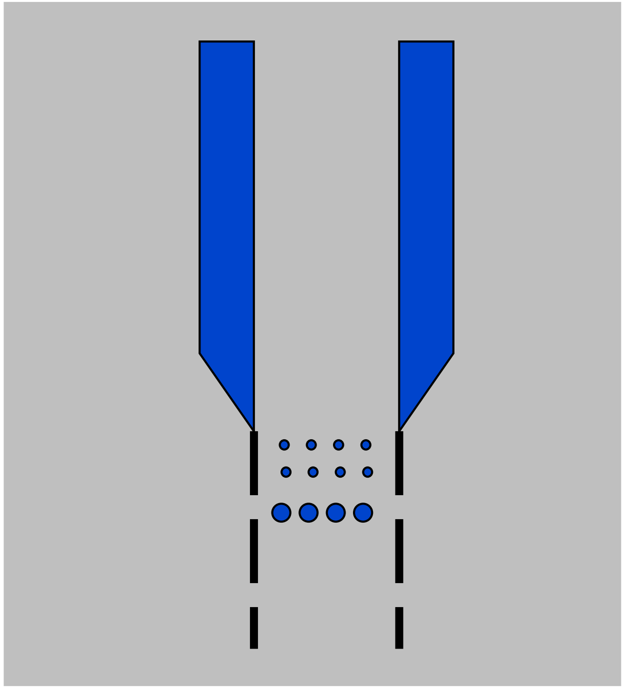
USEPA REFERENCE METHOD 5 - PARTICULATE MATTER

Isokinetic Sample Train Schematic



USEPA REFERENCE METHOD 23 - DIOXINS & FURANS

Isokinetic Sampling - 100% Isokinetic



Allowable: 90-110%

{100 ±10%}

8 lbs small

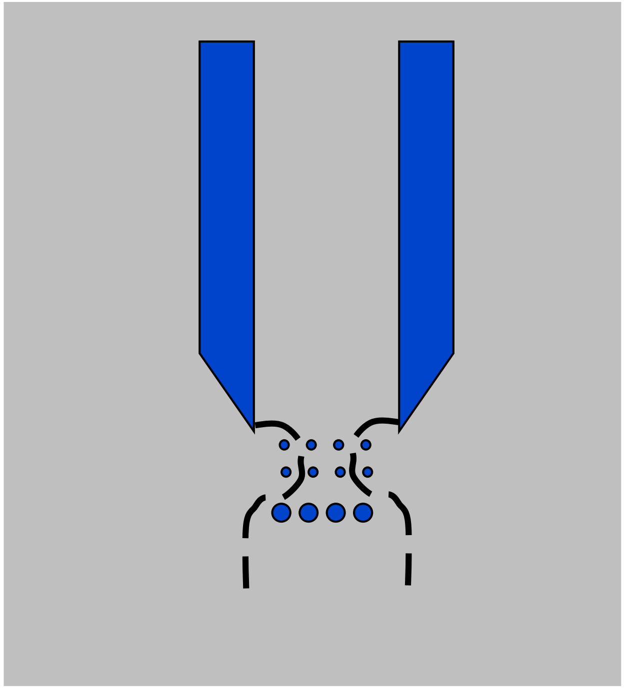
4 lbs large

12 lbs total collected

1 ft^3 of gas

12 lbs/ft^3

Isokinetic Sampling – 50% Sub-isokinetic



4 lbs small

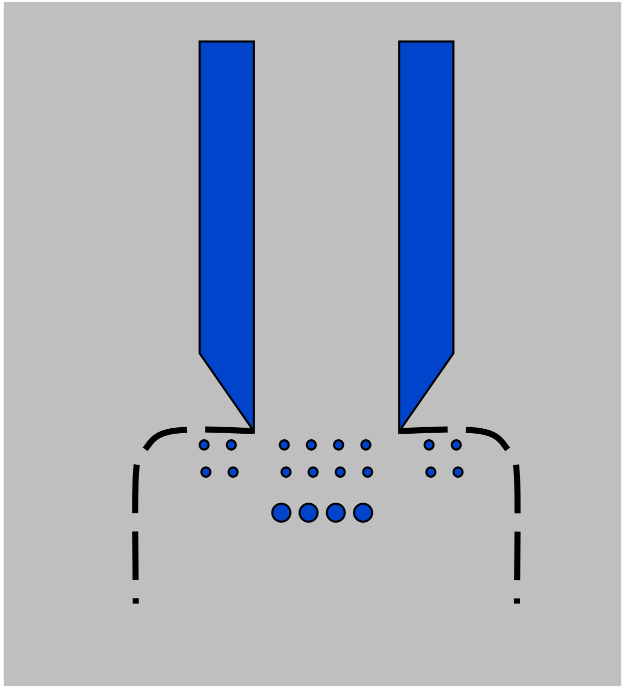
4 lbs large

8 lbs total collected

0.5 ft^3 of gas

16 lbs/ft^3 (high bias)

Isokinetic Sampling - 150% Super isokinetic



12 lbs small

4 lbs large

16 lbs total

1.5 ft^3 of gas

10.67 lbs/ft^3 (low bias)

3 - Single Sample Point, Nonisokinetic Test Methods

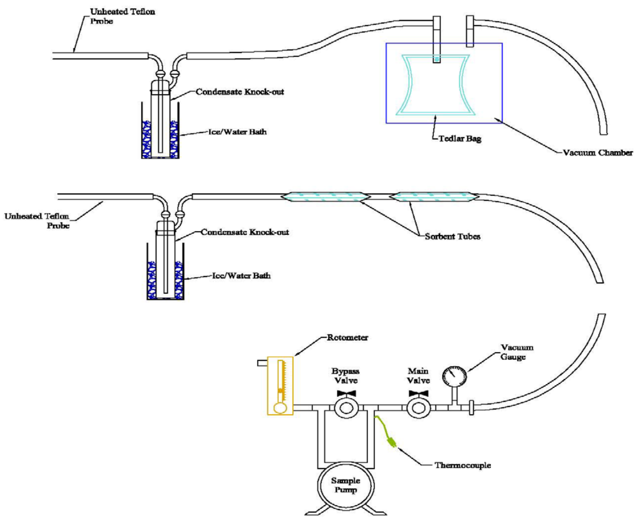
- Single point nonisokinetic test methods are used to sample pollutants in the gaseous or vapor state where isokinetic particle effects can be discounted.
  - Samples are adsorbed onto a solid sorbent media or absorbed/reacted in a solution
  - Sampling is usually conducted at a single point in the duct or stack as pollutants are assumed to be in gaseous state and not stratified
  - Sample rate varies with pollutant, concentration, collection media type
  - Samples are typically analyzed off-site, however on-site analysis can be conducted depending on complexity of the analysis and need for realtime data.

Single Sample Point, Nonisokinetic Test Methods, con't

Alliance

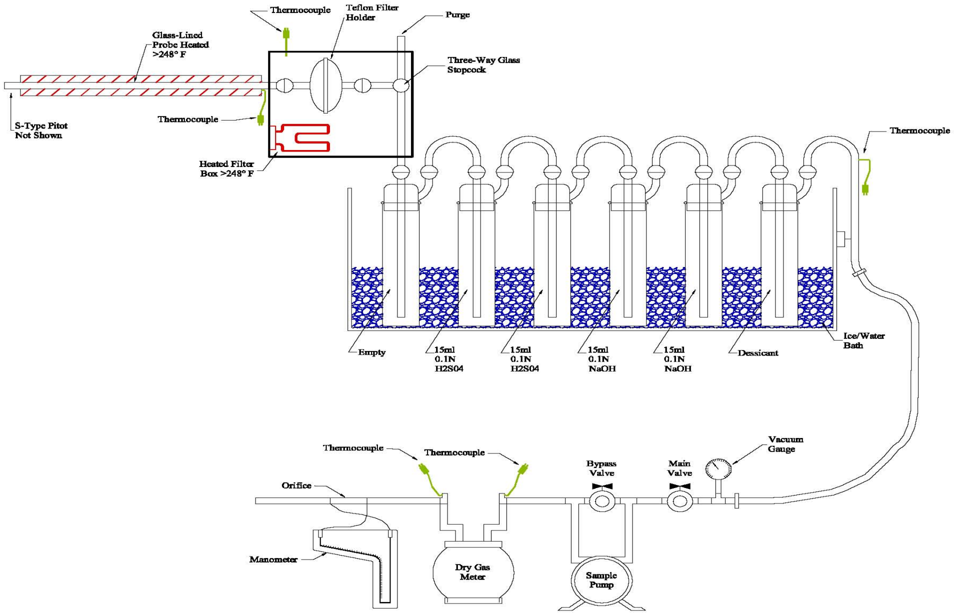
- Example of single point test methods include:
  - USEPA Reference Method 6 (SO2)
  - USEPA Reference Method 7 (NOx)
  - USEPA Reference Method 18 (VOCs)
  - USEPA Reference Method 26 (HCl/Cl_2)
  - USEPA Reference Method 308 (Methanol)
  - SW846 Method 0051 (HCl/Cl_2)
- USEPA Methods 1-4 which measure stack gas flow rate are conducted separately from the above methods

Single Point, Nonisokinetic Sample Train Schematic



USEPA REFERENCE METHOD 18 - VOC by GC

Single Point, Nonisokinetic Sample Train Schematic



USEPA REFERENCE METHOD 26 - HYDROGEN HALIDE AND HALOGENS

4 - Instrumental Test Methods

- On-site instrumentation is used to obtain real-time emissions data
- Sampling is conducted at a single point or multi-point traverse depending on stratification levels.
- Sample is gaseous, so isokinetic particle effects can be discounted.
- Commonly used on-site analytical procedures include:
  - Chemiluminescence (NOx)
  - Pulse Fluorescence (SO2)
  - Nondispersive infrared (CO, CO2)
  - Electrochemical and paramagnetic(O2)
  - Flame ionization (Total organics)
  - Gas chromatography and FTIR (speciated VOCs)

Instrumental Test Methods, con't

- Single point test methods include:
  - USEPA Reference Method 6C (SO2)
  - USEPA Reference Method 7E (NO_x)
  - USEPA Reference Method 10 (CO)
  - USEPA Reference Method 25A (total hydrocarbons)

- USEPA Methods 1-4 which measure stack gas flow rate are conducted separately from the above methods

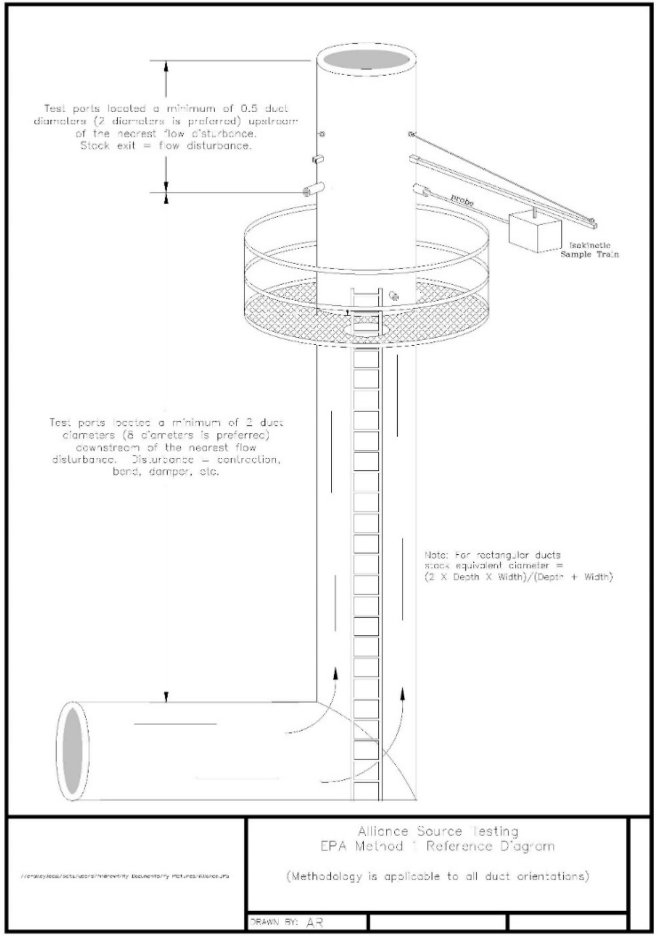
Key Source Emission Testing Program Elements

- Proper planning is key to a successful source emission test program
  - Define testing objectives
  - Identify target pollutants
  - Select appropriate methods for the target parameters
  - Identify process conditions to be tested
- Select source testing contractor carefully
  - Ensure contractor has experience in selected methods and source type
  - Don’t use cost as primary selection criteria
  - Get references and experience profiles

Key Source Emission Testing Program Elements, Con't

- Establish clear project timeline with field test, result, and deliverable schedule clearly defined
- Test plan is not always required, but it is recommended to document test program objectives, methods, process operating conditions, QA/QC procedures, and report format/content
- Review facility safety requirements and procedures with all program participants
- Conduct pretest if time and budget allows
- If pretesting is not possible, verify historical test data, stack port locations, flow profile – These parameters can change over time!

Key to a successful source emission test: Plan, Plan, and then Plan some more!

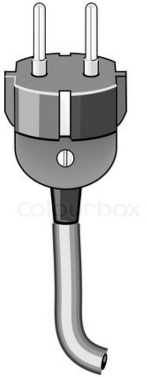

Test ports located a minimum of 0.5 duct diameters (2 diameters is preferred) upstream of the nearest flow disturbance. Stack exit = flow disturbance.
probe
Isokinetic Sample Train
Test ports located a minimum of 2 duct diameters (8 diameters is preferred) downstream of the nearest flow disturbance. Disturbance = contraction, bend, damper, etc.
Note: For rectangular ducts stack equivalent diameter = (2 X Depth X Width)/(Depth + Width)
Alliance Source Testing
EPA Method 1 Reference Diagram
(Methodology is applicable to all duct orientations)
DRAWN BY: AR

Site Safety

- Is there a safe means available to access the test ports (i.e. ladder, stairs, man lift, elevator)?
- Is there a safe location to conduct testing (i.e. platform, scaffolding, man lift)? Does it meet OSHA criteria and is it in good condition?
- Can the area below test location be isolated/secured?
- How high are the handrails? Are handrails cut?
- Any site specific safety issues (heat stress, high noise levels, respiratory concerns)?
- Work area conditions compromised due to plant operations (forklift traffic, overhead cranes)?

Electrical Power Availability

- How close is power supply to the mobile laboratory staging location?
- Is 480V power available? 240V power? 120V power?
- Can generators be used as an alternative to plant power?
- Is 120V power available on the stack or in close proximity to the sampling location?



Stack Set-up and Access

- Is the stack vertical or horizontal?
- Height to test ports from ground?
- Is the stack circular or rectangular?
- Stack diameter (circular) or width/depth (rectangular)?
- Are cyclonic flow conditions anticipated?

Stack Set-up, con't

Test Ports

- Are test ports installed? How many?
- Are they located 90 degrees apart or in center of equal areas?
- What are the diameters of the test ports?
- What are the port collar lengths?
- What is the height of the test ports?
- Are monorail supports present? D-rings?

Questions & Discussion

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Thank you for Attending!

A recording will be available in 3-4 days. You will receive an email once it's posted to our site.

Have a safe & healthy day!