An Introduction to Stack Sampling

Air and Climate Business Unit Environment Division
SUMMARY

- Safety and Stack Sampling
- Anthropogenic and Natural Sources of Air Pollution
- Secondary Air Pollution
- Particulate and Gaseous Pollutants
- Industrial (Stationary) Source Testing  
  (how, why, when, where)
- Future Direction of Source Testing
Safety Aspects of Stack Sampling

- Safety is an over-riding consideration at SRC.
- Many safety factors come into play when conducting stack sampling – safety regulations at each site - orientation site specific safety items.
- SRC conducts a tailgate meeting prior to the start of each day while stack sampling.
Safety Aspects of Stack Sampling

- Fall arrest, tie off points, working on roofs, scaffold or permanent platforms around the stack. Platform safety – ladder safety, hoisting considerations.

- Weather conditions of wind, rain, snow are considered.
Pollutant Emission Sources

www.nature.nps.gov
Secondary Air Pollutants
Health and Air Pollution

Health effects of pollution

- Air pollution
  - Headache
  - Fatigue
  - Nerve damage
  - Lead
  - Particulate matter
  - Ozone
  - Volatile organic compounds

- Respiratory illness
  - CO
  - SO₂
  - NOₓ

- Cardio-vascular illness
  - Gastroenteritis

- Cancer risk
  - Nausea
  - Skin irritation

- Water pollution
  - Bacteria
  - Parasites
  - Chemicals

- Soil contamination
  - Pesticides

healthtipsinsurance.com
Particulate Pollutants

- Size of airborne particulate expressed as aerodynamic diameter (ad) (µm).
- Unit density 1 gm/cm³, spherical.
- Terminal velocity of particulate in the atmosphere is dependent on size.
- Ranges from 0.1 - 30 cm/sec for unit density spherical particulate with ad of 1 – 100 µm respectively.
Particulate Size and Deposition In Humans

"an elevation of UFP count by 9748/cm³ has been associated with an increase in cardiovascular mortality of approximately 3% within 4 days in Erfurt, Germany"  


Particulate Suspension in the Environment
Particulate Suspension Time

- 2.5 µm particle (50% suspended) after 10 hr travels 100 km in 10 km/hr wind.
- 10 µm particle (50% suspended) after 10 hr travels 6.5 km in 10 km/hr wind.
- 100 µm particle (50% suspended) after 10 hr travels 0.1 km in 10 km/hr wind.
Why Perform Stack Sampling

- Determine concentration (mg/drm$^3$), emission rate (kg/h) and/or intensity (gm/tonne) or (gm/GJ of NOx energy production) from a stationary source.

- If the production rate and process stream are constant and the air pollution control devices are operating correctly, the emission rate of pollutants should be constant.

- Annual stack testing at an Industrial site should give representative results year over year.
Stack Sampling Train for Particulate
Method 5 Sampling Train
The General Stack Sampling Train

- Probe, nozzle, pitot tubes, thermocouples
- Hot box houses the filter
- Cold box houses the impingers (various liquids)
- Umbilical cord attaches the sampling train to the control console
- Control console and operator
- Isokinetic Sampling (particulate)
The Control Console
Sample Nozzle

- Sharp tapered edge important for sampling
- Nozzles come in a variety of materials for different heat conditions within the stack
Isokinetic Sampling Considerations

Selective sampling due to nonisokinetic conditions.
### Recommended Maximum Temperatures

<table>
<thead>
<tr>
<th>Material</th>
<th>Max Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless Steel</td>
<td>650°C (1200°F)</td>
</tr>
<tr>
<td>PFA Fittings</td>
<td>177°C (350°F)</td>
</tr>
<tr>
<td>Borosilicate Glass</td>
<td>480°C (900°F)</td>
</tr>
<tr>
<td>Inconel</td>
<td>980°C (1800°F)</td>
</tr>
<tr>
<td>Quartz</td>
<td>900°C (1650°F)</td>
</tr>
<tr>
<td>Viton® O-Rings</td>
<td>260°C (500°F)</td>
</tr>
<tr>
<td>Graphite Ferrules</td>
<td>980°C (1800°F)</td>
</tr>
<tr>
<td>Glass Filled PTFE</td>
<td>315°C (500°F)</td>
</tr>
<tr>
<td>Hastelloy C276</td>
<td>980°C (1800°F)</td>
</tr>
</tbody>
</table>
Stack Sampling Methodology


- U.S. Code of Federal Regulations Protection of the Environment 40 Part 60 outlines Methods 1 to 320 which deal with all types of sampling protocols for particulate, gases, radionuclides and other pollutants.
Requirements on a Circular Stack

Details of a Circular Stack with Specifications:
- **Eyebolt**: Port 10.1 cm (4 in.) dia.
- **Ports**: Male threaded nipple.
- **Platform Extension**: 1.5 m (5 ft.)
- **Electric Outlet**: 110/120 Volts (15-20 Amps)
- **Top Rail**: To swing upwards and over 180°
- **Ladder with Safety Harness or Bird Cage**

Additional Note:
- Stacks with I.D. less than 1.2 m (4 ft.) do not require platform extension. However, the 1.2 m (4 ft.) top rail-guard in front of ports with or without platform extension shall be hinged to swing upwards and over 180 degrees when necessary.

**Sampling Facilities on Circular Stacks**
Figure A-1  Minimum Number of Traverse Points for Particulate Sampling
Prescribed Sampling Points

Environment Canada
Particulate Sizing Devices
Sizing of Particulate

SEM image of particulate after the cyclone before the scrubber
Techniques for Sizing Particulate

Physical Diameter vs. Aerodynamic Diameter

- Physical diameter is obtained through laser sizing results
- Aerodynamic diameter is obtained using an inertial impactor, such as the Pilat Mark III
- Separates into size ranges of submicron up to \(\sim 15 - 20 \mu\text{m}\), depending on flow rate through the impactor
FIG. 27-12 Effect of fuel-air ratio on flue-gas composition for a typical U.S. natural gas containing 93.9% CH₄, 3.2% C₂H₆, 0.7% C₃H₈, 0.4% C₄H₁₀, 1.5% N₂ and 1.1% CO₂ by volume. Perry’s Chemical Engineers’ Handbook Seventh Ed.
Gaseous Sampling Methods

- Wet chemical techniques for SO$_2$, NO$_x$, HCl, NH$_3$, Cl$_2$ involves absorption into appropriate solution.

- Instrumental gas analyzers using electrochemical sensing technology - need to remove water from the stack prior to detection.

- Fourier Transform Infrared (FTIR) analysis of stack gases (not for H$_2$, Cl$_2$, O$_2$, N$_2$ etc.)
US EPA Method 8 for SO$_2$ and H$_2$SO$_4$
US EPA Method 7 for NO$_x$
FTIR Instrument
## Random Errors and Stack Sampling

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Variable</th>
<th>Standard Deviation, σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_o$</td>
<td>Calibration Constant for orifice, $\frac{ft^3 , lb}{min , lb\text{-mole} , in , Hg , \frac{1}{\circ R}^{1/2}}$</td>
<td>0.01</td>
</tr>
<tr>
<td>$D_N$</td>
<td>Nozzle diameter in inches in</td>
<td>0.001</td>
</tr>
<tr>
<td>$M_d$</td>
<td>Molecular weight of stack gas on a dry basis, $lb_m/\text{lb\text{-mole}}$</td>
<td>0.1</td>
</tr>
<tr>
<td>$P_m$</td>
<td>Absolute pressure upstream of the orifice inches-Hg</td>
<td>0.05</td>
</tr>
<tr>
<td>$T_m$</td>
<td>Absolute temperature upstream of the orifice, $\circ R$</td>
<td>2</td>
</tr>
<tr>
<td>$\tau$</td>
<td>Sampling time interval, minutes</td>
<td>0.01</td>
</tr>
<tr>
<td>$(\Delta H)_{setting}$</td>
<td>Error associated with setting required orifice pressure drop, inches-$H_2O$</td>
<td>0.02</td>
</tr>
<tr>
<td>$(1-B_{wo})$</td>
<td>Proportion by volume of dry gas in the stack gas stream, dimensionless</td>
<td>0.01</td>
</tr>
</tbody>
</table>
Magnitude of the seven components from random errors in stack sampling

<table>
<thead>
<tr>
<th>Error Term</th>
<th>Magnitude</th>
<th>% of Total Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross-sectional Flow Area of Duct, ( \frac{\sigma_{A_s}}{A_s} )^2</td>
<td>0.000148</td>
<td>5.5</td>
</tr>
<tr>
<td>Mass of Particulate Matter, ( \frac{\sigma_{M_p}}{M_p} )^2</td>
<td>0.000148</td>
<td>1.4</td>
</tr>
<tr>
<td>Average Stack Velocity, ( \frac{\sigma}{(U_{s_{avg}})} )^2</td>
<td>0.0031</td>
<td>30.1</td>
</tr>
<tr>
<td>Stack Gas Moisture Content, ( \frac{\sigma_{B_{wo}}}{B_{wo}} )^2</td>
<td>0.000067</td>
<td>0.65</td>
</tr>
<tr>
<td>Average Stack Gas Temperature ( \frac{\sigma}{(T_{s_{avg}})} )^2</td>
<td>0.00082</td>
<td>8.0</td>
</tr>
<tr>
<td>Absolute Stack Gas Pressure ( \frac{\sigma_{P_s}}{P_s} )^2</td>
<td>0.000000286</td>
<td>Negligible</td>
</tr>
<tr>
<td>Total Gas Sample ( \frac{\sigma}{(V_{m_{ref}})/(V_{m_{ref}})} )^2</td>
<td>0.0056</td>
<td>54.4</td>
</tr>
<tr>
<td>Totals</td>
<td>0.0103</td>
<td>100</td>
</tr>
</tbody>
</table>
Future Directions of Stack Testing

- Automated Method 5 analysis
- Additional applications for FTIR measurements
- Real time air pollution measurements using optical sensing
Questions?
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