Stack Monitoring
Stack Sampling

Stack sampling or source sampling may be defined as a method of collecting representative samples of pollutant laden air/gases at the place of origin of pollutants to determine the total amount of pollutants emitted into the atmosphere from a given source in a given time.
The purpose of stack sampling is to determine emission levels from plant processes to ensure they are in compliance with any emission limits set by regulatory authorities to prevent macro environmental pollution.
Stack Sampling

Stack sampling is used for the assessment of the following:

1. To determine the **quantity and quality of the pollutant** emitted by the source.

2. To measure the **efficiency of the control equipment** by conducting a survey before and after installation.

3. To determine the **effect on the emission** due to changes in raw materials and processes.

4. To compare the **efficiency of different control equipments** for a given condition.

5. To **acquire data** from an innocuous individual source so as to determine the cumulative effect of many such sources.

6. To **compare with the emission standards** in order to assess the need for local control.
Stack Sampling

Source sampling is carried out in a process ventilation stack to determine the emission rates/or characteristics of pollutants.

Planning the study:
- Familiarity of the process and operations to determine the time of cyclic operations, peak loading that might cause variations in the characteristics.
- Method of sampling
- Method of analysis of samples
- Sampling time because certain industries undergo cyclic changes
- Amount of sample required
- Sampling frequency
Stack Sampling

Representative sample:
• Sample collected must truly represent the conditions prevailing inside the stack.

The important considerations for accurate representative sample collection include:
• Accurate measurement of pressure, moisture, humidity and gas composition
• The selection of suitable locations for sampling
• Determination of the traverse point required for a velocity and temperature profile across the cross section of the stack and sampling for particulate matter
Schematic Diagram of Sampling Train
Stack Sampling

Sampling System:

Stack sampling is carried out by diverting a part of the gas stream through a sampling train of which a general arrangement is shown below.

1 Nozzle 2 Sampling probe 3 Particulate collector 4 Gas collector 5 Gas flow meter 6 Flow control valve 7 To vacuum pump


Stack Sampling

The train consists of a nozzle placed in the gas stream, a sampling probe through which the sample is drawn at different traverses, particulate and gas collection devices, a flow measuring device and a prime mover such as a vacuum pump or an ejector.

Nozzle: It is at the end of the probe is sharp edged, pointing inward from the outside edge and the traversing probe is made of stainless steel with glass or Teflon lining.
Stack Sampling

Â For Sampling hot gases whose temperature are above 400 °C, these probes are provided with a circulating coolant system to prevent combustion of particulate materials inside the probe and to prevent the temperature from exceeding the maximum allowable temperature of filtration materials.

Â Devices: Collection of particulates: Filtration, wet or dry impingement, impaction, electrostatic and thermal precipitation

Â Collection of gases: Absorption, adsorption, freeze out

Â Flow measurement: Use rotameter or orifice meter or dry gas meter if the information on the total volume of the gas sampled is required.
Iso kinetic Sampling

Particulates sampling

Â Isokinetic stack particulate sampling is conducted to obtain a representative particulate stack sample independent of particle size.

Â To achieve this, the gas stream entering the collector should have a velocity (speed and direction) equal to that of the gas stream just ahead of the sampling port of the collector.
Iso kinetic Sampling

Â Webster's dictionary defines ISO as denoting equality, similarity, uniformity.

Â Kinetic is defined as due to motion.

Â Isokinetic sampling is an equal or uniform sampling of particles and gases in motion within the stack.

Â Isokinetic source sampling is achieved when the velocity of gas entering the sampling nozzle is exactly equal to the velocity of the approaching gas stream. This provides a uniform, unbiased sample of the pollutants being emitted by the source.
Different conditions...

1. Sample collection Velocity (V) > Stack gas velocity (W)
2. Sample collection Velocity (V) < Stack gas velocity (W)
3. Sample collection Velocity (V) = Stack gas velocity (W)
Super-ISOKINETIC Condition

(V) > (W)

Å If the collection velocity is **too high** heavy particles fail to adhere to the flow lines and end up **by-passing the probe**, thereby **under-estimating** large particles.
Sub-ISOKINETIC Condition

$(V) < (W)$

Å If the sample collection velocity is too low heavy particles can enter the probe even if the flow line on which they were located passes by the probe.

Å Thus too many large particles are collected.
ISOKINETIC Condition

\( (V) = (W) \)

When conducting isokinetic sampling all particles flowing toward the intake opening are equally collected.
Reference Method for Source Testing: Measurement of Releases of Particulate from Stationary Sources

- **Method A**: Determination of Sampling Site and Traverse Points
- **Method B**: Determination of Stack Gas Velocity and Volumetric Flow Rate
- **Method C**: Determination of Molecular Weight by Gas Analysis
- **Method D**: Determination of Moisture Content
- **Method E**: Determination of Particulate Releases
- **Method F**: Calibration Procedure for S-Type Pitot Tube, Dry Gas Meter and Orifice Meter
Minimum requirement of a stack monitoring equipment

- **Particulate Sampling:**
  2 – 30 lpm collection on **thimble** type filter up to 0.3 micron rating

- **Gaseous sampling:**
  0.2 – 3 lpm collection in a set of Borosilicate glass **impingers**

- **Rotameter:**
  Rotameters: 0 to 60 lpm for particulate monitoring and 0 to 3 lpm for gaseous monitoring.

- **Filter Holder:**
  Fabricated from SS 304 tube suitable to hold either cellulose filtration thimble or glass micro fibre thimble
• **Nozzles**:  
  A set of 3 stainless steel nozzles

• **Digital clock**:  
  0-60 minutes, 1 second readout with start and stop switches

• **Impinger Sampling Train**:  
  2 No. of 240 ml capacity and 3 No. of 120 ml capacity borosilicate glass impingers with Ball socket joints accommodated in ice tray, made out of FRP, placed on the rear side of instrument panel with a provision of keep ice

• **Vacuum Pump**:  
  Monoblock Rotary Vane type, oil lubricated, 0.5 HP single phase motor (230V) with more than 50 lpm free flow capacity
• **Thermocouple:**
Thermocouple sensor shall be provided with analog or digital dial gauge capable of measuring temperature from 0 to 600°C covered with stainless steel or mild steel casing with acid resistant treatment.

• **Manometer:**
To measure differential pressure

• **Pitot tube:**
Pitot tube shall be modified “S-type” fabricated from SS 304 or equivalent grade. The construction feature should be as per United States Environmental Protection Agency (EPA) regulation, Method 2, Given in Figures 1.1 and 1.2 (A) ii. The construction feature shall be such that the coefficient of the pitot tube is above 0.95.
Method A: Determination of Sampling Site and Traverse Points

Â Applicability
Â Principle
Â Location of Sampling Site
Â Determination of Traverse Points
Â Location of Traverse Points
Â Confirmation of Cyclonic and Reverse Flow
Applicability

• This method is applicable to flowing gas streams in stacks or ducts.
• The method is not applicable as written when one or more of the following conditions exist:
  1. Stack or duct diameters less than 0.30 m (1.0 ft);
  2. non-circular or non-rectangular stacks or ducts; and
  3. Sampling site less than two stack or duct diameters downstream from a flow disturbance, or less than 0.5 stack or duct diameter upstream from a flow disturbance.
  4. cyclonic flow
  5. reverse flow
Location of Sampling Site

Select a site in a straight section of stack located at least eight stack diameters downstream and two stack diameters upstream of any flow disturbance such as a bend, expansion, contraction, visible flame, junction, or stack exit.

Size of sampling point: 7-10 cm
Determination of Traverse Points

When the sampling site is located at least eight diameters downstream and two diameters upstream from a flow disturbance, the required minimum number of traverse points for a circular or rectangular cross section is determined from Table A-1.
Table A-1: Minimum Number of Traverse Points for Sampling Sites that Meet the Eight- and Two-diameter Criteria

<table>
<thead>
<tr>
<th>Stack or Duct Diameter (m)</th>
<th>Required Minimum Number of Traverse Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Circular Duct</td>
</tr>
<tr>
<td>&gt; 0.61</td>
<td>12</td>
</tr>
<tr>
<td>0.30 to 0.61</td>
<td>8</td>
</tr>
</tbody>
</table>
### Minimum no. of Traverse point for sampling sites

<table>
<thead>
<tr>
<th>Inside Dia. of Stack (m)</th>
<th>Number of Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.D &lt;= 0.3</td>
<td>4</td>
</tr>
<tr>
<td>0.3 &lt;= I.D &gt;= 0.6</td>
<td>8</td>
</tr>
<tr>
<td>0.6 &lt;= I.D &gt;= 1.2</td>
<td>12</td>
</tr>
<tr>
<td>1.2 &lt;= I.D &gt;= 2.4</td>
<td>20</td>
</tr>
<tr>
<td>2.4 &lt;= I.D &gt;= 5</td>
<td>32</td>
</tr>
</tbody>
</table>
Determination of Traverse Points

When the eight- and two-diameter criteria cannot be satisfied, the minimum number of traverse points is determined either from Figure A-1 for particulate sampling or from Figure A-2 for velocity measurement.
Figure A-1: Minimum Number of Traverse Points for Particulate Sampling

**Figure Description:**
- **X-axis:** Duct diameters downstream from flow disturbance (Distance B).
- **Y-axis:** Minimum number of traverse points.
- The graph shows the relationship between the distance downstream from the flow disturbance and the minimum number of traverse points required. The relationship is non-linear, with different numbers of traverse points required for different duct diameters.
- The graph includes a legend indicating different numbers of traverse points for various duct diameters:
  - 24 or 25 for duct diameters of 2 to 4.
  - 20 for duct diameters of 5.
  - 16 for duct diameters of 6.
  - 12 for duct diameters of 7.

**Additional Information:**
- Use Table A-1 for sites that meet the eight- and two-diameter criterion.
Figure A-2: Minimum Number of Traverse Points for Velocity Measurement
Location of Traverse Points on Circular and Rectangular Cross Sections Divided into Twelve Equal Areas
# Location of Traverse Points in Circular Stacks

<table>
<thead>
<tr>
<th>Traverse Point Number on a Diameter</th>
<th>Percent of Stack Diameter from Inside Wall to Traverse Point</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of Traverse Points on a Diameter: 2 4 6 8 10 12 14 16 18 20 22 24</td>
</tr>
<tr>
<td>1</td>
<td>14.6  6.7  4.4  3.3  2.5  2.1  1.8  1.6  1.4  1.3  1.1  1.1</td>
</tr>
<tr>
<td>2</td>
<td>85.4  25.0  14.7  10.5  8.2  6.7  5.7  4.9  4.4  3.9  3.5  3.2</td>
</tr>
<tr>
<td>3</td>
<td>75.0  29.3  19.4  14.6  11.8  9.9  8.5  7.3  6.7  6.0  5.5</td>
</tr>
<tr>
<td>4</td>
<td>93.3  70.5  32.3  22.6  17.7  14.6  12.5  10.9  9.7  8.7  7.9</td>
</tr>
<tr>
<td>5</td>
<td>85.3  67.7  34.2  25.0  20.1  16.9  14.6  12.9  11.6  10.5</td>
</tr>
<tr>
<td>6</td>
<td>95.6  80.6  65.8  35.5  26.9  22.0  18.8  16.5  14.6  13.2</td>
</tr>
<tr>
<td>7</td>
<td>89.5  77.4  64.5  36.6  28.3  23.6  20.4  18.0  16.1</td>
</tr>
<tr>
<td>8</td>
<td>96.7  85.4  75.0  63.4  37.5  29.6  23.0  21.8  19.4</td>
</tr>
<tr>
<td>9</td>
<td>91.8  82.3  73.1  62.5  38.2  30.6  26.1  23.0</td>
</tr>
<tr>
<td>10</td>
<td>97.5  88.2  79.9  71.7  61.8  38.8  31.5  27.2</td>
</tr>
<tr>
<td>11</td>
<td>93.3  85.4  78.0  70.4  61.2  39.3  32.3</td>
</tr>
<tr>
<td>12</td>
<td>97.9  90.1  83.1  76.4  69.4  60.7  39.8</td>
</tr>
<tr>
<td>13</td>
<td>94.3  87.5  81.2  75.0  68.5  60.2</td>
</tr>
<tr>
<td>14</td>
<td>98.2  91.5  83.4  79.6  73.9  67.7</td>
</tr>
<tr>
<td>15</td>
<td>95.1  89.1  83.5  78.2  72.8</td>
</tr>
<tr>
<td>16</td>
<td>98.4  92.5  87.1  82.0  77.0</td>
</tr>
<tr>
<td>17</td>
<td>95.6  90.3  85.4  80.6</td>
</tr>
<tr>
<td>18</td>
<td>98.6  93.3  88.4  83.9</td>
</tr>
<tr>
<td>19</td>
<td>96.1  91.3  86.8</td>
</tr>
<tr>
<td>20</td>
<td>98.7  94.0  89.5</td>
</tr>
<tr>
<td>21</td>
<td>96.3  92.1</td>
</tr>
<tr>
<td>22</td>
<td>98.9  94.5</td>
</tr>
<tr>
<td>23</td>
<td>96.8</td>
</tr>
<tr>
<td>24</td>
<td>98.9</td>
</tr>
</tbody>
</table>
Method B: Determination of Stack Gas Velocity and Volumetric Flow Rate

Â The average gas velocity in a stack or duct is determined from the gas density and from the measurement of velocity pressure with an S-type pitot tube.

Â A standard pitot tube may be used where plugging of the tube openings due to particulate matter and/or moisture is not likely to occur.

Â Stack gas volumetric flow rate is determined from measurements of stack gas velocity, temperature, absolute pressure, dry gas composition, moisture content, and stack diameter.
Determination of gas composition:

- Gas composition can be determined by **Orsat apparatus**.
- The gas is collected in the Orsat apparatus and analyzed for the composition of CO\(_2\), O\(_2\) and CO in the same order and the remaining is assumed to be nitrogen.

- Molecular weight of gas = \(\Sigma M_x B_x\)

Where

\(M_x\) = Molecular weight of CO\(_2\), O\(_2\) and CO and N\(_2\) (44, 32, 28 and 28 respectively) and \(B_x\) represent % of gases
Determination of moisture Content:

The moisture content in the stack may be determined by any one of the following methods:

- **Wet bulb and dry bulb temperature technique**
  (Moisture content is less than 18 % and dew point is less than 51 °C and can not be used for acid stream)

- **Condenser technique**

- **Silica gel tube**
Determination of Temperature:

- The temperature has to be measured across the cross-section of the stack at predetermined traverse point.
- The temperature probe is inserted into the stack and the readings are taken with the help of a pyrometer.

<table>
<thead>
<tr>
<th>Types of probe</th>
<th>Temperature range, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromel/Alumel</td>
<td>148.8 - 1260</td>
</tr>
<tr>
<td>Copper/Constantan</td>
<td>148.8 - 348.9</td>
</tr>
<tr>
<td>Iron/Constantan</td>
<td>115.5 - 1010</td>
</tr>
<tr>
<td>Platinum / Platinum</td>
<td>0 - 1537.7</td>
</tr>
<tr>
<td>10 % &amp; Rhodium</td>
<td></td>
</tr>
</tbody>
</table>
S-type Pitot Tube and Manometer Assembly
# Velocity Traverse Data Sheet

<table>
<thead>
<tr>
<th>Plant</th>
<th>Stack Diameter (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Barometric Pressure (kPa)</td>
</tr>
<tr>
<td>Test</td>
<td>Static Press. in Stack (mm H₂O)</td>
</tr>
<tr>
<td>Date</td>
<td>S-type Pitot Coefficient</td>
</tr>
<tr>
<td>Time Started</td>
<td>Test Conducted by</td>
</tr>
<tr>
<td>Time Completed</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Traverse Point</th>
<th>Stack Gas Velocity Pressure (Δp)</th>
<th>Stack Gas Temperature (Tₙ)</th>
<th>Stack Gas Velocity (Uₙ)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(ₙ) avg  (Uₙ) avg
Calculations

Absolute stack gas pressure at the sampling site is calculated using equation:

\[ P_s = P_{bar} + \Delta p_s \]

Actual stack gas velocity at each traverse point is calculated using equation:

\[ U_s = 128.95 C_p \left( \frac{\Delta p T_s}{P_s M_s} \right)^{1/2} \]

The average stack gas volumetric flow rate on a dry basis at reference conditions is calculated using equation:

\[ Q_s = 3600 (U_s)_{avg} A_s (1-B_{w,o}) \frac{T_{ref} P_s}{(T_s)_{avg} P_{ref}} \]
**Typical sampling provision**

**Sampling Ports**

A. 2 ports, 90° W diameter less than 3M + port length
   4 ports 90° apart W/ diameter over 3M + port length

AT LEAST TWO STACK DIAMETERS BELOW STACK EXIT

AT LEAST EIGHT STACK DIAMETERS ABOVE LAST OBSTRUCTION

Work area clearance

Work platform

A. AT LEAST 1M WIDE (1.2M WIDE FOR STACKS WITH 3M OR GREATER ID.) AND CAPABLE OF SUPPORTING 3 PEOPLE AND 91Kg OF TEST EQUIPMENT

B. SAFE GUARDRAIL ON PLATFORM WITH ACCESS BY SAFE LADDER OR OTHER SUITABLE MEANS. IF LADDER IS USED, LADDER WELL MUST BE LOCATED AT LEAST 1M FROM PORTS

C. NO OBSTRUCTIONS TO BE WITHIN 1M HORIZONTAL RADIUS ON PLATFORM BENEATH PORTS

**Port Dimension Requirements**

- 0.5M MIN
- 2M MAX. UNLESS GATE VALVE INSTALLED
- 0.4M ID (MIN) INDUSTRIAL FLANGE CAPPED WHEN NOT IN USE
- INSTALL GATE VALVE IF STACK CONTAINS DANGEROUS GASES OR GASES OVER 200°F UNDER POSITIVE PRESSURE

**Strength Requirements**

- 23Kg SIDE LOAD
- 23Kg RADIAL TENSION LOAD
- 91Kg VERTICAL SHEAR LOAD
- 105Kg M MOMENT

AT LEAST ONE STACK DIAMETER PLUS 0.9M FROM STACK CIRCUMFERENCE

Work CLEARANCE ZONE 0.9M

Power source

220V 15A SINGLE PHASE 50HZ AC LOCATED ON PLATFORM
Preparation of the Sampling Train

Stack

Heated probe with filter in heated box

1ST Impinger for condensation may be filled with distilled water (50 ml).

Silica gel impinger

Rotameter (Stack monitoring kit)

Dry gas meter

Pump

Fig 2: Sampling train for Particulate Matter
Steps for Stack Sampling

Procedure for particulate matter sampling
1. Determine the gas composition and correct to moisture content.
2. Determine the temperature and velocity at each traverse point.
3. Determine the empty weight of the thimble ($W_1$).
4. Mark out the traverse points on the probe. The marks are normally fixed by tying with asbestos thread.
5. Check all points for leakages.
6. Determine the flow rate to be sampled under isokinetic condition.
Steps for Stack Sampling

Procedure for particulate matter sampling

7. Insert the probe at the traverse point 1, very close to the stack. Start the pump and adjust the flow so that the rotameter reads the predetermined value.

8. Switch off the pump at the end of sampling time.

9. Read the vacuum at the dry gas meter (DGM) and also the temperature.

10. Move the probe to subsequent traverse points by repeating the steps five to eight.

11. After completion of collection of samples, remove the probe and allow it to cool.
Steps for Stack Sampling

Procedure for particulate matter sampling

12. Remove the thimble carefully. Some of the dust would have adhered to the nozzle. This should be removed by trapping and transferred to the thimble.

13. Weight the thimble with the sample. The difference in weight gives the dust collected.

14. The volume of sample collected in either given by the dry gas meter (m$^3$) or by sampling rate given by rotameter multiplied by the sampling time.

15. Hence from (13) and (14), the emission rate can be calculated. This will be at DGM conditions. This is to be corrected for temperature and pressure so as to obtain values for standard conditions.
Steps for Stack Sampling

Sample recovery:

Â After cooling, the outside of probe assembly is cleaned with cotton waste. Disconnect the nozzle.
Â Remove the thimble and keep it in a clean glass beaker.
Â The particulate matter adhered to the inside walls of the nozzle, should be transferred carefully to the thimble.
Â Weigh the thimble with sample ($W_2$).
Â The difference in weight ($W_2 - W_1$) will give the particulate collected.
Steps for Stack Sampling

Sample recovery:

Â After cooling, the outside of probe assembly is cleaned with cotton waste. Disconnect the nozzle.
Â Remove the thimble and keep it in a clean glass beaker.
Â The particulate matter adhered to the inside walls of the nozzle, should be transferred carefully to the thimble.
Â Weigh the thimble with sample \((W_2)\).
Â The difference in weight \((W_2 - W_1)\) will give the particulate collected