Chapter 15

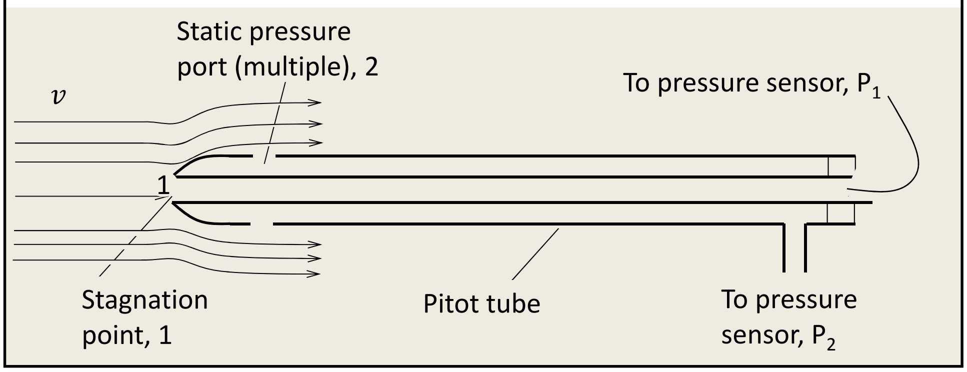
Air Monitoring

Source Sampling

- A representative sample is the key to the accurate measurement of emissions from a source.
- Different source test methods have been developed for a variety of realistic environments.
- In the USA, for example, most states rely upon either US EPA Reference Methods, Methods 1 to 8, for characterization of the gas flow and specific air pollutants from a stationary source.

Flow Rate and Velocity Measurement

- There are a number of flow rate measurement technologies and related instruments; one of them is Pitot tube
- It is widely employed in engineering practices because of its simplicity, accuracy, reliability and cost-effectiveness.
- A standard Pitot tube is an L-shaped tube
- When it is located in a pipe, streamlines connect the stagnation point and the multiple static taps, which are small holes evenly distributed along the circumference of the outer tube.



$$\Delta P = P_1 - P_2 = \frac{1}{2}\rho u_2^2$$

$$u = u_2 = \left(\frac{2\Delta P}{\rho}\right)^{1/2}$$

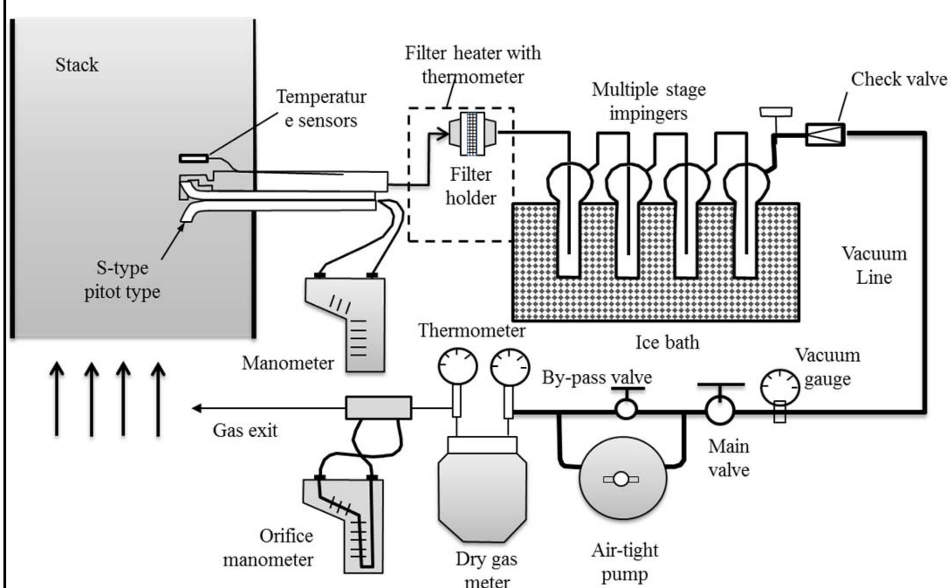
$$Q = Au$$

Source Sampling

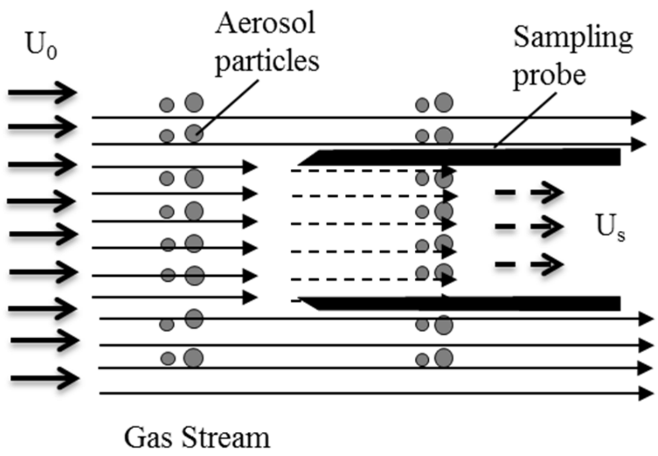
US EPA Methods 1-8

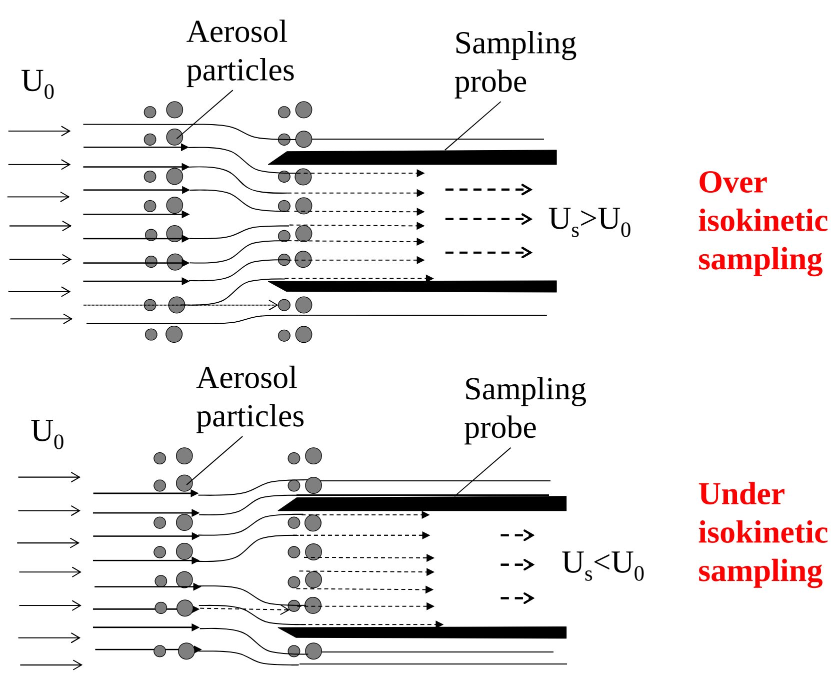
- Method 1: Sample and velocity transverse for stationary sources
- Method 2: Determination of stack gas velocity and volumetric flow rates using Type S Pitot tube,
- Method 3: Gas analysis for the determination of dry molecular weight
- Method 4: Characterizing moisture content in stack gases
- Method 5: Determination of particulate matter emission from stationary sources
- Method 6: Determination of sulfur dioxide emissions from stationary sources
- Method 7: Determination of nitrogen oxide emissions from stationary sources
- Method 8: Determination of sulfuric acids and sulfur dioxide emissions from stationary sources

Sampling Train for Particulate Emissions
EPA Method 5



Isokinetic sampling $U_s = U_o$





Sampling efficiency $\eta_s = C_s/C_o$

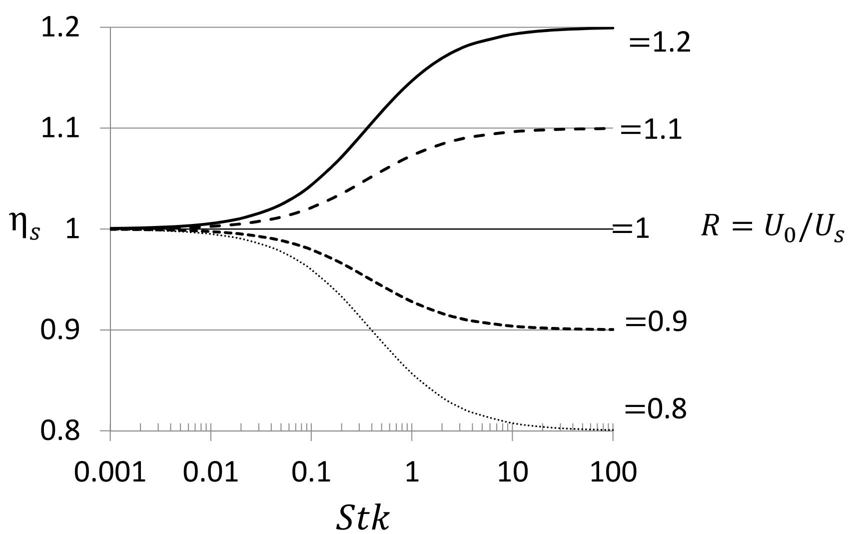
Sampling efficiency η_s due to velocity mismatch only

$$\eta_s = 1 + (R-1)\beta(Stk, R)$$

$$\beta(Stk, R) = 1 - \frac{1}{1 + (2 + 0.617/R)Stk}$$

$$R = U_0/U_s$$

Sampling efficiency η_s vs. *R* and *Stk*
(Velocity mismatch only)

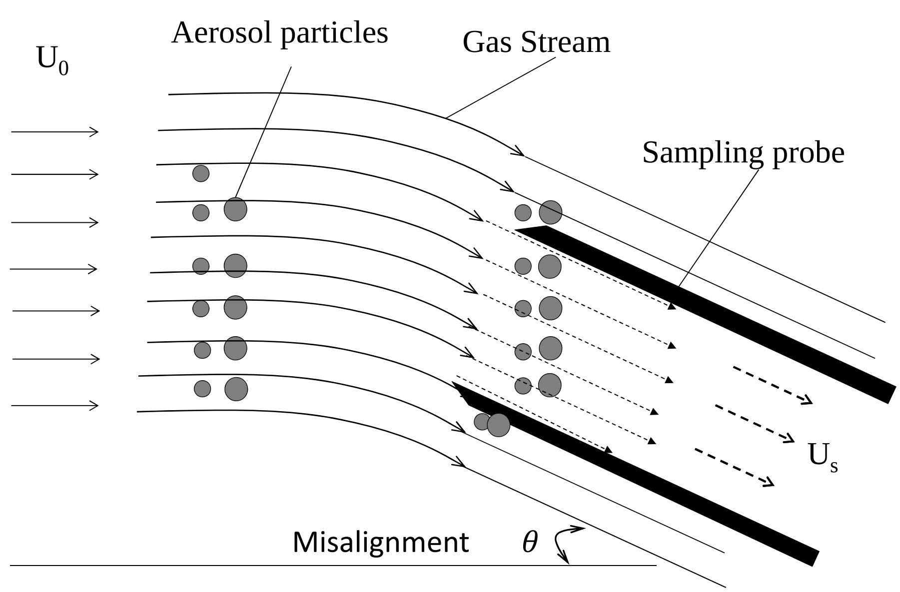


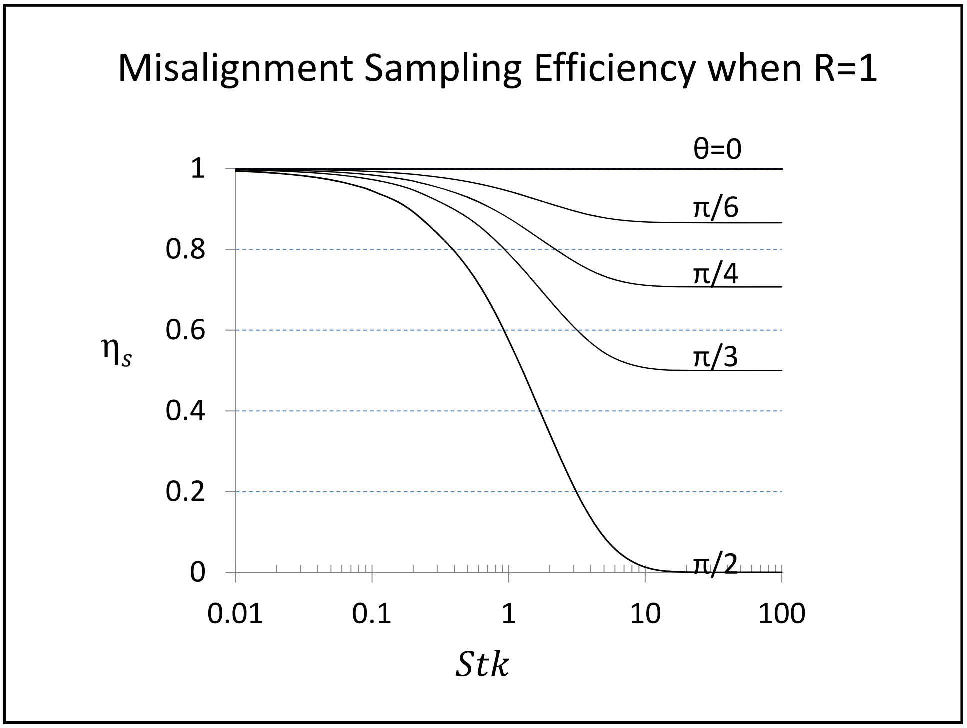
Sampling Efficiency due to Misalignment Effect

- Empirical equations were given by Duraham and Lundgren (1980) to quantify the misalignment effect for anisokinetic sampling as follows.

$\eta_s = 1 + (cos\theta - 1)\beta'(Stk', \theta)$	for R = 1
$\eta_s = 1 + (Rcos\theta - 1)\beta'(Stk', \theta)\dfrac{\beta(Stk', R)}{\beta(Stk', R = 1)}$	for R ≠ 1
$\beta'(Stk'_{,\theta}) = 1 - \dfrac{1}{1 + 0.55Stk'\ exp(0.25Stk')}$	
$Stk' = Stk \times exp(0.022\theta)$	$for\ 0 \le \theta < \pi/2$

Misalignment Effect

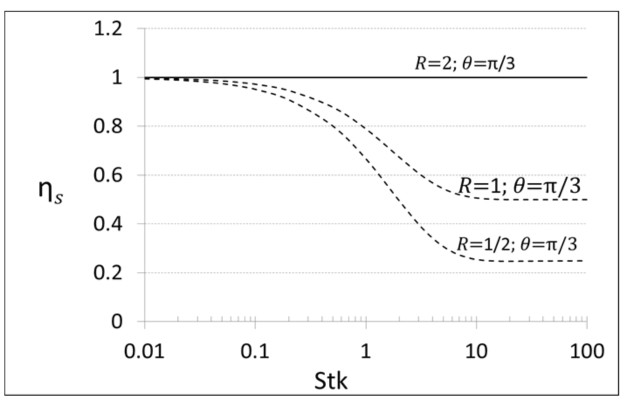




Misalignment and R ≠ 1

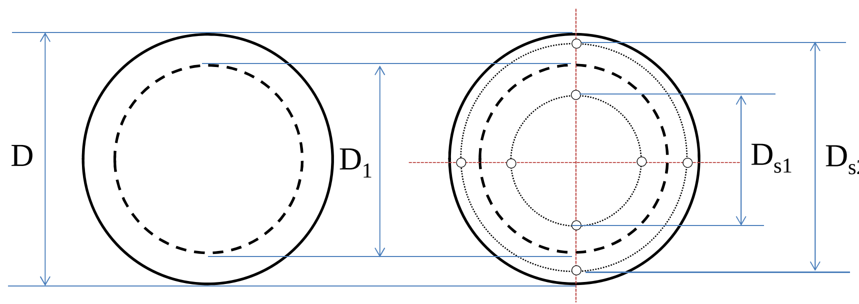
$$\eta_s = 1 + (R\cos\theta - 1)\beta'\left(Stk', \theta\right)\frac{\beta\left(Stk', R\right)}{\beta\left(Stk', R = 1\right)}$$

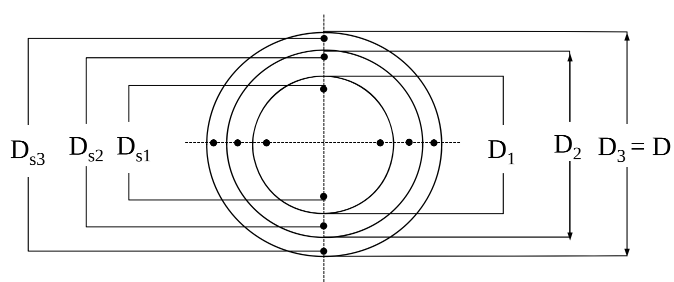
- However, it is useful to realize that the sampling efficiency is always 1 when $R\cos\theta = 1$



Multiple Point Source Sampling

- Equal area rule





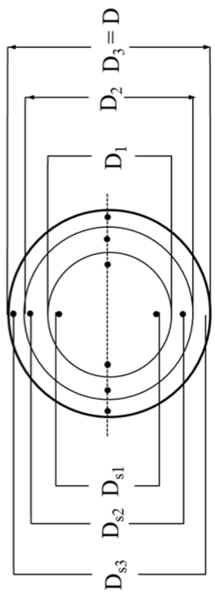
$$D_{si}^2 = \frac{i}{2n} D^2$$

$$D_{si} = D\sqrt{i/_{2n}} \quad where\ i = 1, 3\ \dots\ 2n - 1$$

$$D_i = D\sqrt{i/_{2n}} \quad where\ i = 2, 4\ \dots\ 2n$$

Example 15.1

A stack with an inner diameter of 1.2 m is subject to source tests. Determine the sampling points by dividing the stack area into 3 equal sub-areas.



Solution

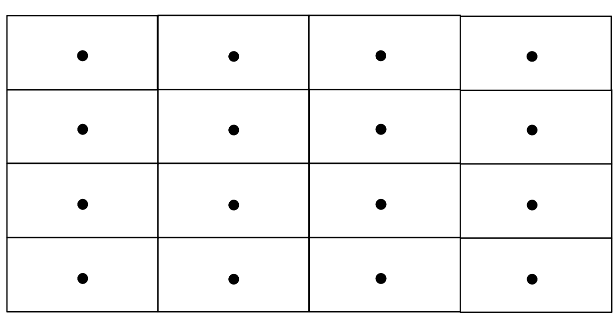
In this problem, n = 3 and D=1.2 m are given. The sampling points are on the circles with diameters of $D_{si} = D\sqrt{i/_{2n}}$ $\quad where\ i = 1, 3$ and 5

$$D_{s1} = 1.2 \times \sqrt{1/_6} = 0.4899\ (m)$$

$$D_{s2} = 1.2 \times \sqrt{3/_6} = 0.8485\ (m)$$

$$D_{s3} = 1.2 \times \sqrt{5/_6} = 1.0954\ (m)$$

These sampling points are depicted in Figure 8-8, where readers can determine the equal area circle D_i by using the same equation with $i = 2, 4\ and\ 6.$



Data Analysis

- The total gas flow rate discharged from a stack to the atmosphere is Q (m^3/s),
- and a sample is taken with a volume flow rate of Q_s (m^3/s) for a period of time, t (s).
- Analysis of this sample, either in situ or in a laboratory setting, shows that the mass of air pollutant of interest m (kg).
- With this information, one can calculate the mass concentration of the air pollutant in the sample (kg/m^3)

$$c = m/Q_s t$$

- If the sample is representative it can be used to represent the concentration of the air pollutant in the stack: $C = c$.
- Then the mass flow rate, $\dot{m}$, of this air pollutant in the stack is

$$\dot{m} = \frac{Qm}{Q_s t}$$

Data Reporting

- A common standard for emission test report is to correct the concentrations against 50% excess air, 7% or 12% of CO_2, or 7% of O_2.
- Take 12% of CO_2 as an example, the calculated emission rate is converted using the equation that follows. Actual procedure is much more complex, and readers are encouraged to seek local guidelines for more information.

$$C_{std\ (12\%\ CO_2)} = C_s \times \frac{12\%}{100\% \times x_{CO_2}}$$

x_{CO_2} is the mole fraction of CO_2 in the stack gas measured (e.g. following US EPA Method 3).