Source monitoring

Gazala Habib

Air pollution sources of regional importance

Sources of air pollution

Biomass burning

Biomass fuel combustion

Chemical Fertilizers

On-road transport

Brick Kilns

Dairy Farm

Power generation

Industries

Municipal waste burning

Diesel tractors

Off-road combustion

Construction activity

Approaches for Emission Estimates

IPCC TIERS

Tier 1	Tier 2	Tier 3
Global tech / fuel / EF	•Country specific fuel characteristics •Technology based EF	•Detailed activity/technology levels •Measured regional EF

ENERGY SECTORS

Sec	Industry	Transport	Residential	Agriculture	Informal
Source Categories	•Thermal power • Heavy industry • Light industry	• On-road gasoline • On-road diesel • Railways /Shipping/ Aviation	• Cooking biofuels • Cooking LPG /kero • Lighting- kero lamps	• Agriculture residue burning • Agriculture diesel use	• Brick production • Food processing
Technologies	PC boiler, Stokers, oil-fired boilers, gas turbines, coke ovens, refineries	2-wheelers, 3-wheelers, Cars, LDV, HDV, Buses, CNG vehicles, Super-emitters, age distribution	Traditional biomass stoves, LPG stoves, kerosene stoves, kerosene wick lamps	Open field burning, Different agricultural residues, diesel tractors, diesel pumps	Bull's Trench Kiln – Fixed and moving chimney, Clamps, Zig-zag firing, VSBKs, wood-boilers



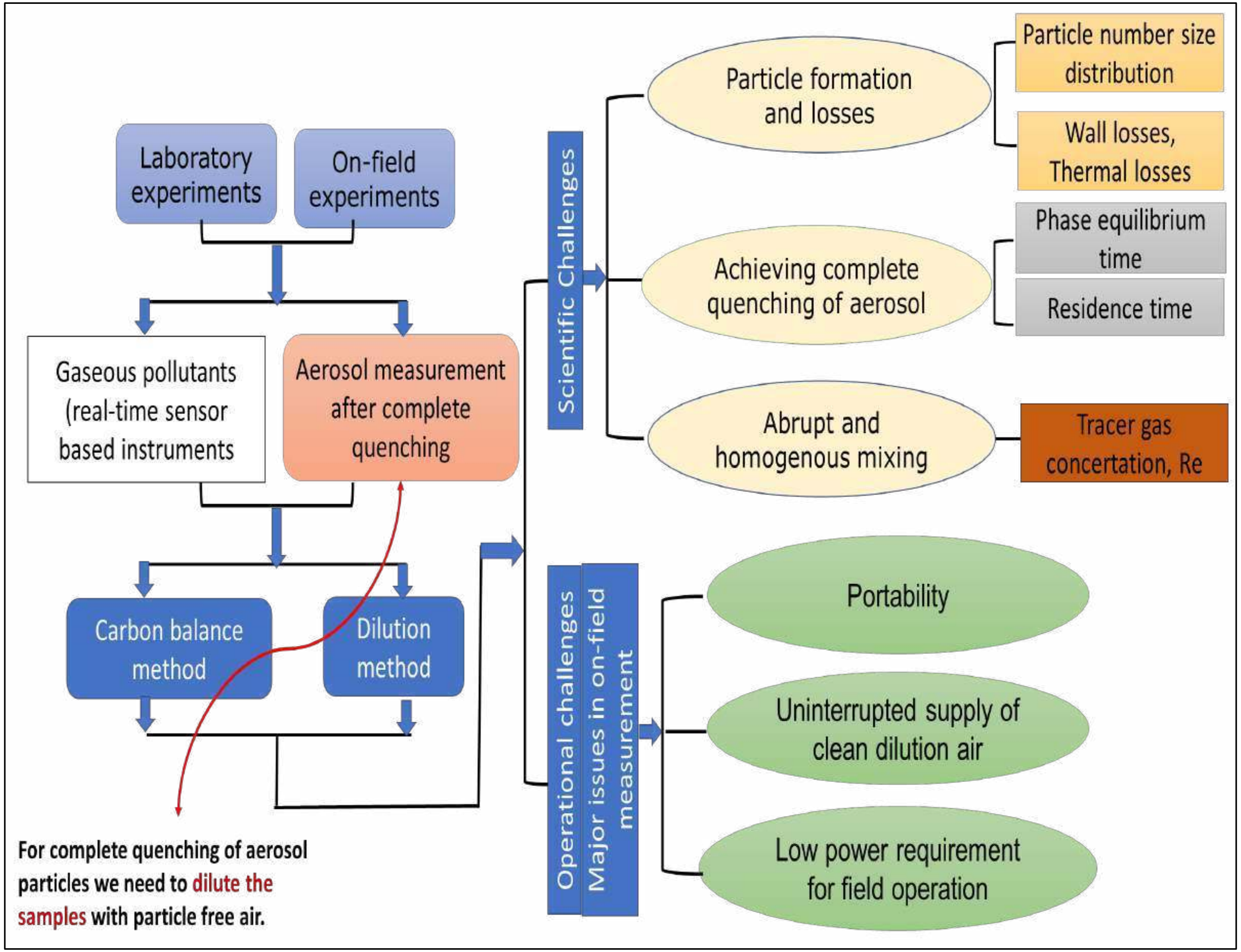

- Emission rate
  - Emission inventory development
  - Exposure assessment and risk estimate
  - To decide control equipment




Data requirement

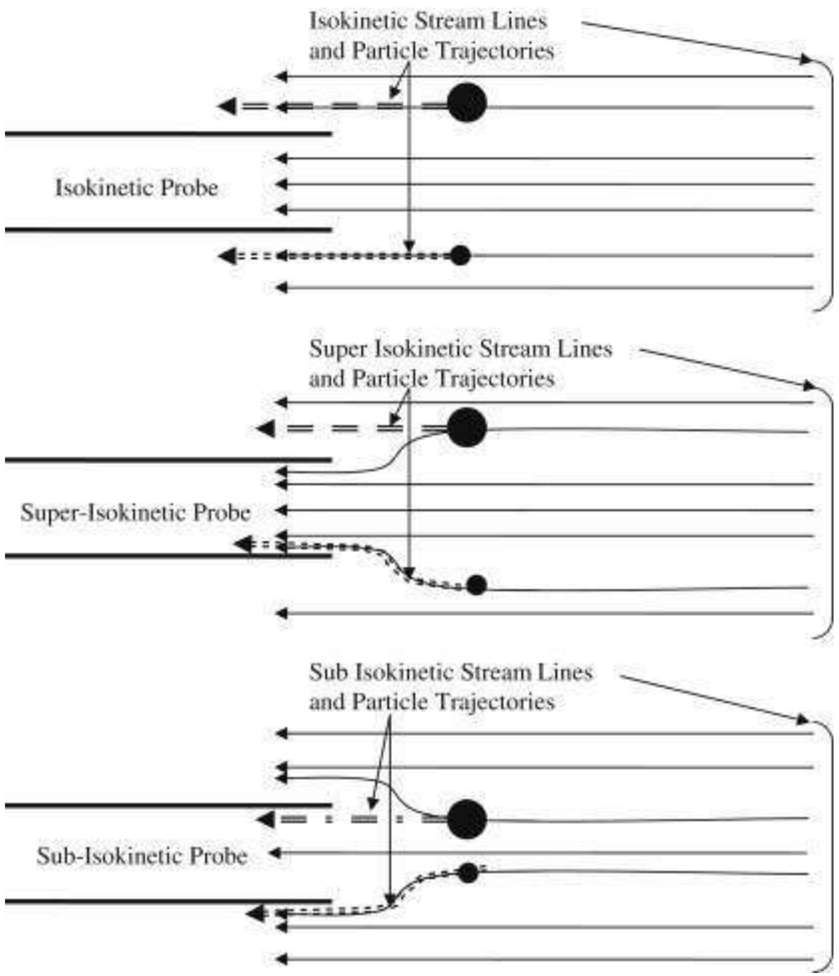
- Gas velocity
- Gas temperature
- Static pressure in duct
- Barometric pressure
- Duct diameter
- Concentration of pollutant
- Emission source name and location
- Date and time
- Wind speed and direction
- Control system operating conditions
- Process operating conditions

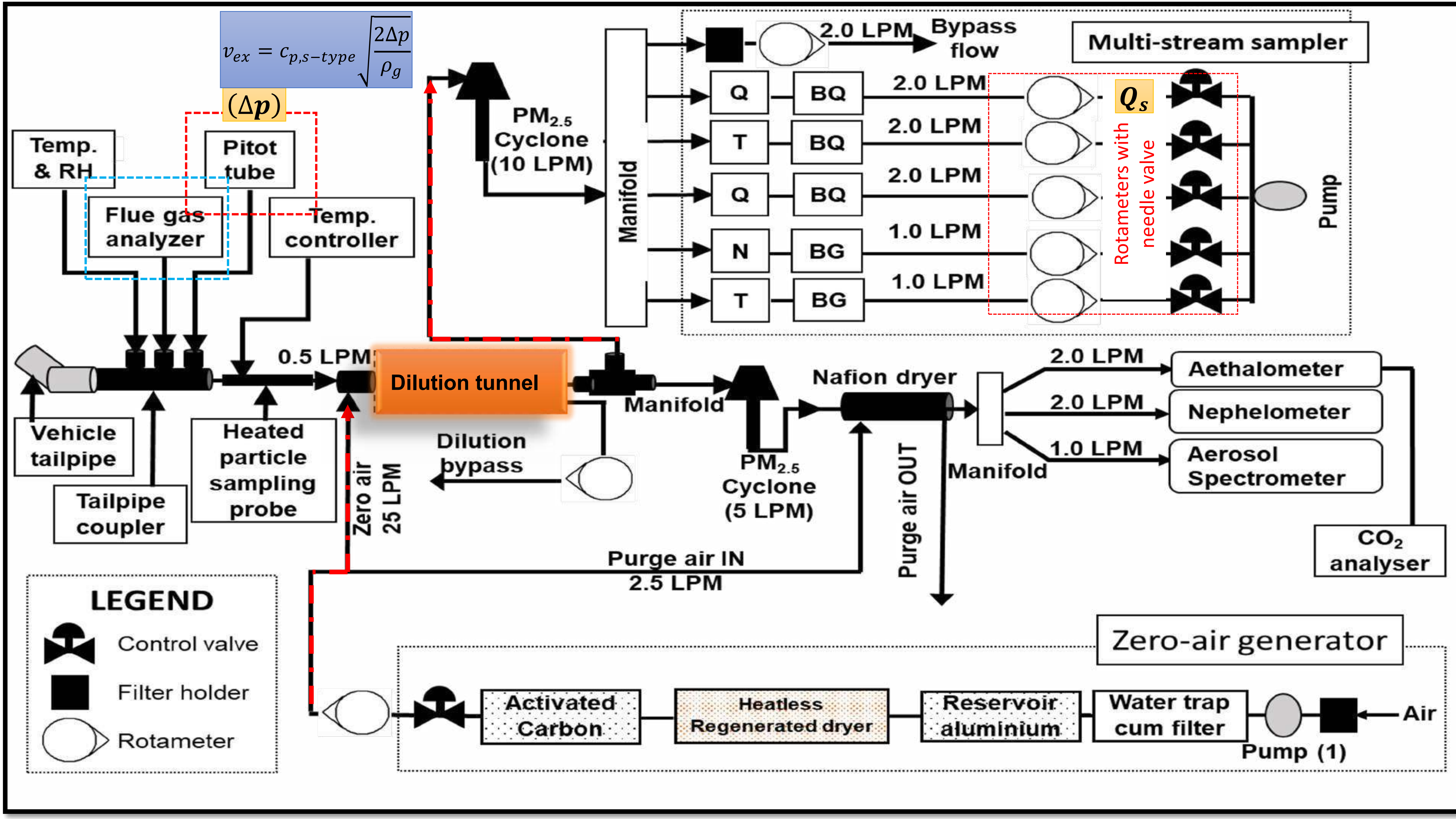
Challenges in Aerosol measurement at sources



Sampling particles from stack/duct

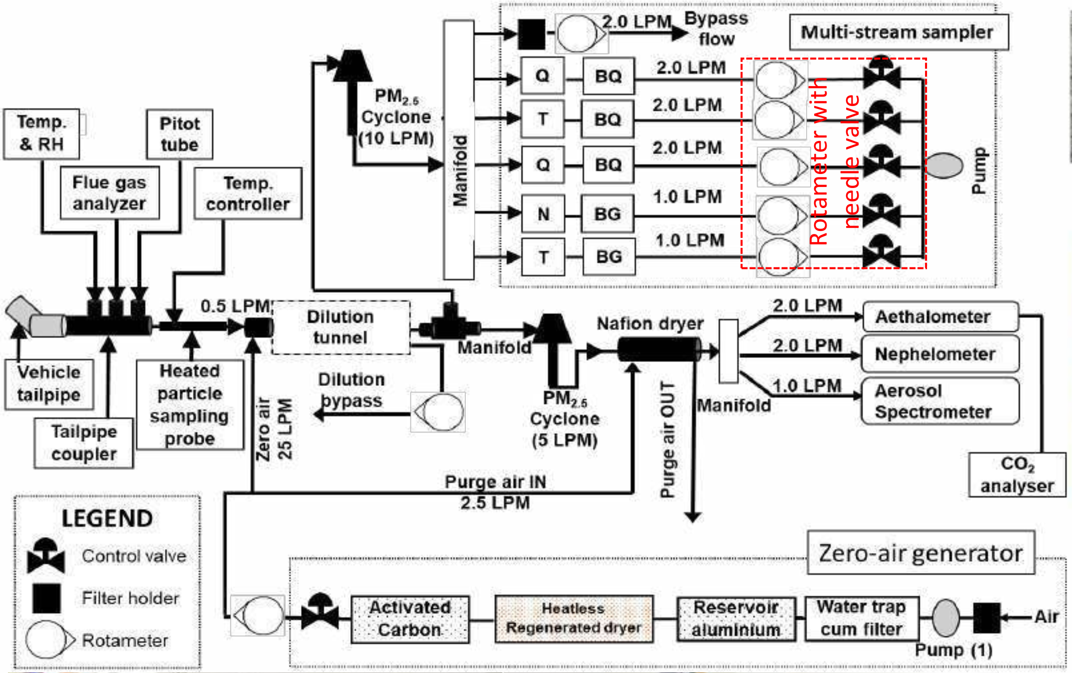
- Isoaxial Sampling
  - Iso kinetic sampling
  - Sub iso kinetic sampling
  - Super iso kinetic sampling
- Anisoaxial sampling
- Particle size distribution
- Particle losses
  - Wall losses due to charging
  - Thermophoresis losses
- Evaluation parameter for dilution tunnel

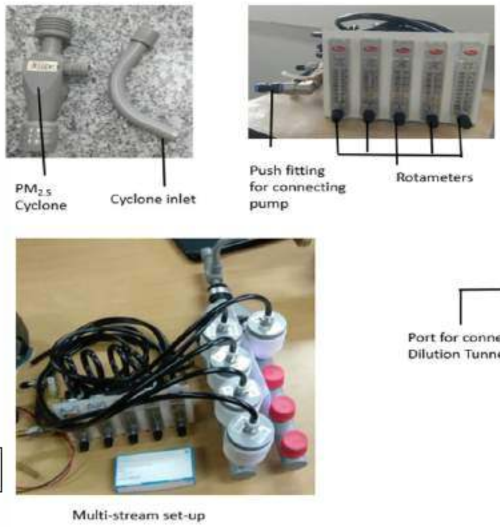


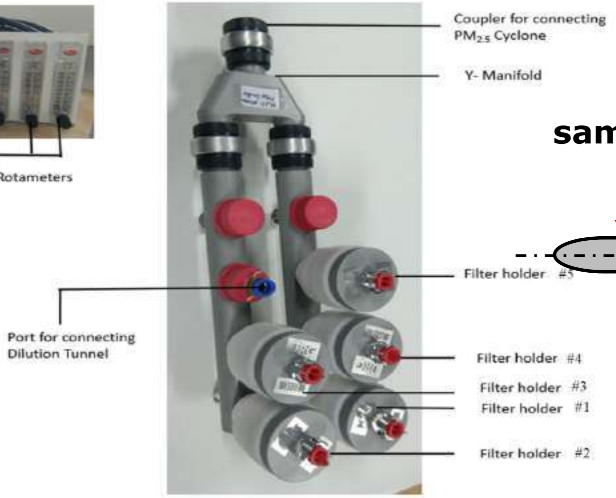


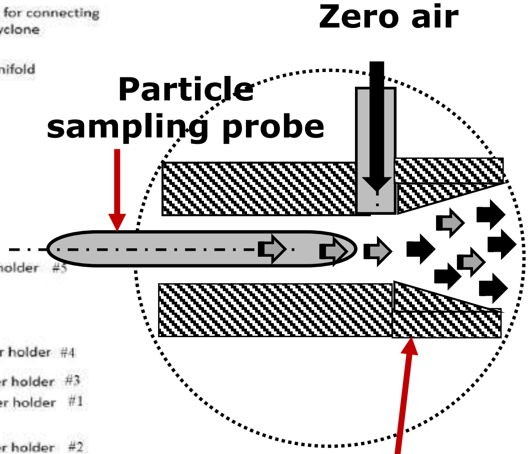
$v_{ex} = c_{p,s-type}\sqrt{\frac{2\Delta p}{\rho_g}}$
(Δp)
Temp. & RH
Pitot tube
Flue gas analyzer
Temp. controller
Vehicle tailpipe
Tailpipe coupler
Heated particle sampling probe
0.5 LPM
Dilution tunnel
Zero air 25 LPM
Dilution bypass
$PM_{2.5}$ Cyclone (10 LPM)
Manifold
2.0 LPM
Bypass flow
Multi-stream sampler
Q
BQ
T
BQ
Q
BQ
N
BG
T
BG
2.0 LPM
2.0 LPM
2.0 LPM
1.0 LPM
1.0 LPM
Q_s
Rotameters with needle valve
Pump
Manifold
$PM_{2.5}$ Cyclone (5 LPM)
Nafion dryer
Purge air OUT
Manifold
2.0 LPM
Aethalometer
2.0 LPM
Nephelometer
1.0 LPM
Aerosol Spectrometer
CO_2 analyser
Purge air IN 2.5 LPM
LEGEND
Control valve
Filter holder
Rotameter
Zero-air generator
Activated Carbon
Heatless Regenerated dryer
Reservoir aluminium
Water trap cum filter
Pump (1)
Air

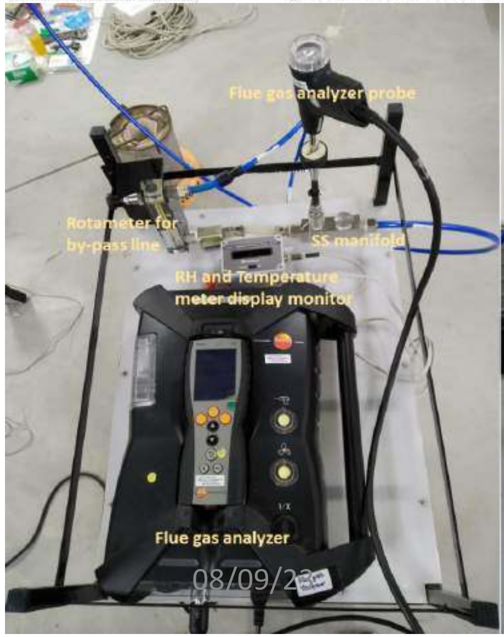
Versatile Source Sampling System (VS3)

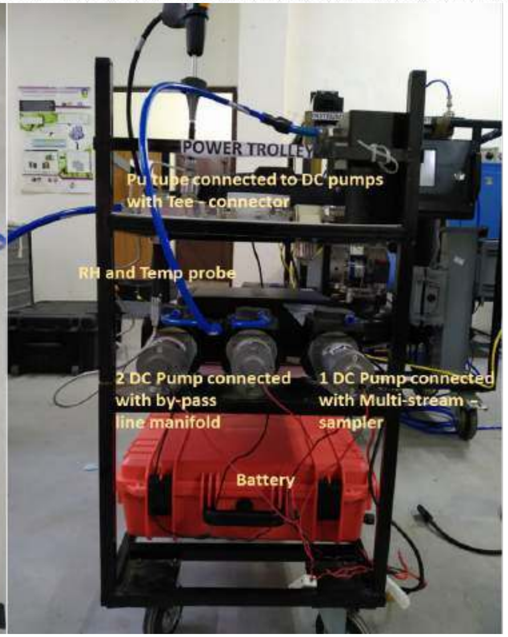






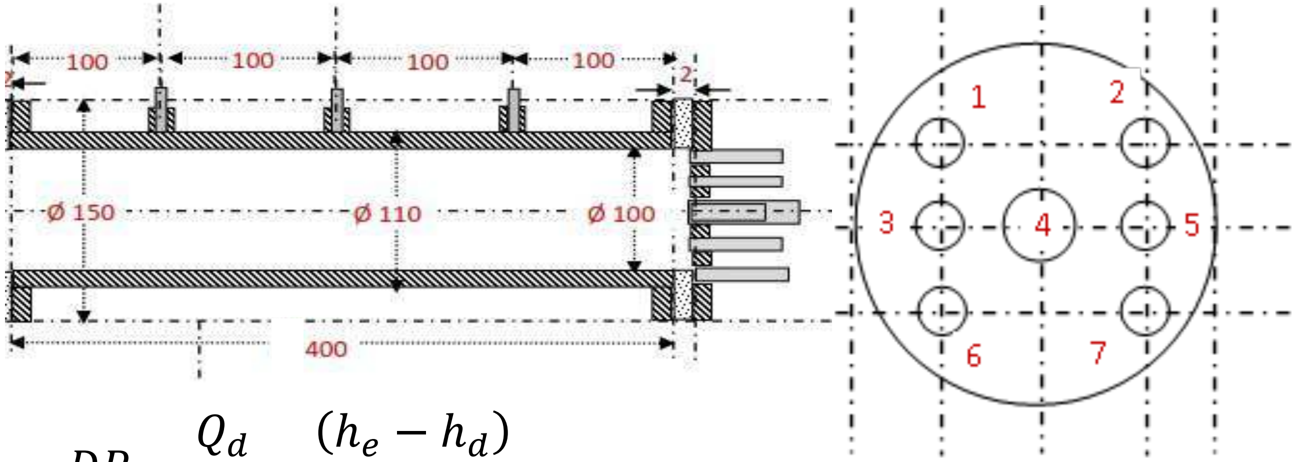






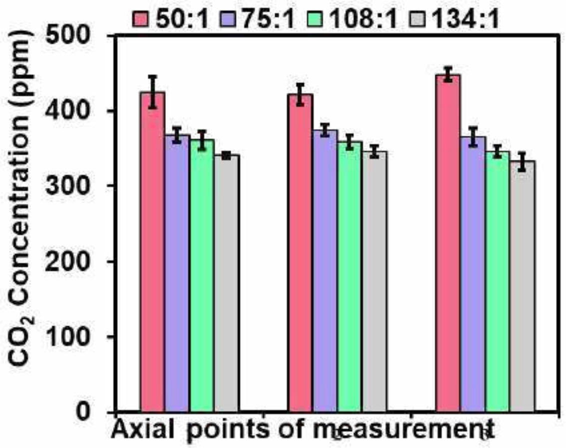
On-field emission measurement images-Residential sector and open burning

Evaluation of VS3



- ❖ Homogenous mixing
- ❖ Gas-to particle conversion
- ❖ Particle wall losses

$$DR = \frac{Q_d}{Q_e} = \frac{(h_e - h_d)}{h_d}$$

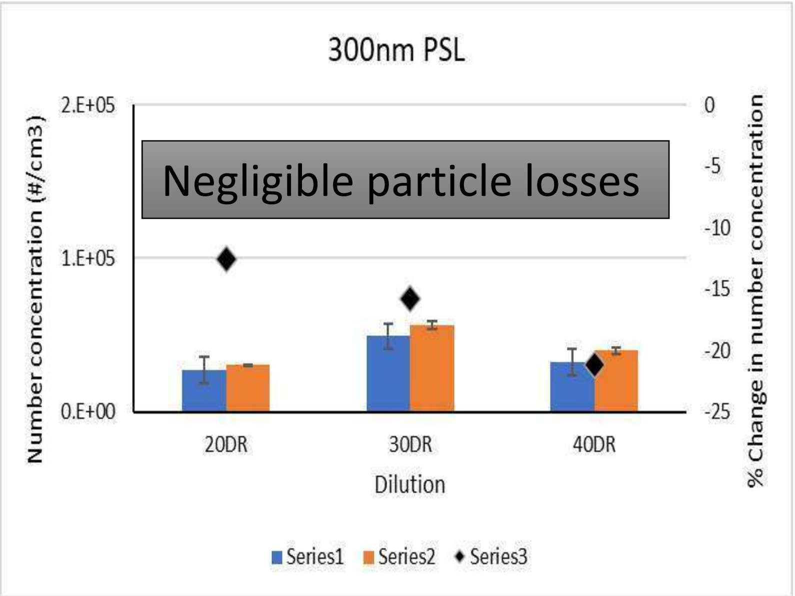


CO$_2$ concentration in longitudinal and axial direction at different dilution ratio had insignificant difference

$$Residence\ time\ (t) = \frac{Volume\ of\ dilution\ tunnel}{Flow\ rate}$$

Phase equilibrium time (τ): time required for conversion of VOCs to particles (<0.5 second)

- ✓ The ratio of $(\frac{t}{\tau})$ >4 for achieving phase equilibrium of aerosol inside dilution tunnel (Guo et al. 2016).
- ✓ At different dilution ratios $(\frac{t}{\tau})$ was always greater than 4 indicated complete gas-to-particle partitioning



Jaiprakash et al. AEROSOL SCIENCE AND TECHNOLOGY2016, VOL. 50, NO. 7, 717–731

Velocity measurement and Dilution ratio calculation

$$DR = \frac{Flow\ rate\ of\ dilution\ air}{Flow\ rate\ of\ exhaust} = \frac{Q_d}{Q_e}$$

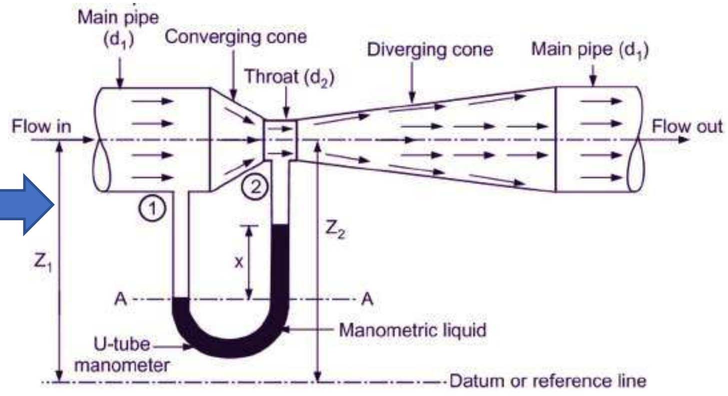
$$DR = \frac{Q_d}{Q_e} = \frac{(CO_{2-exhaust} - CO_{2-diluted})}{(CO_{2-diluted} - CO_{2-ambient})}$$

$$Particle\ concentration(C_p) = \frac{W_f - W_i}{V_s}$$

Quantity measured	Instruments	Range
Velocity	Pitot tube	>5 m/s
	Hot wire anemometer	50 mm/s - 40 m/s
Flow rate	Venturi meter	1 L/s – 100 m^3/s
	Orifice meter	1 cm3/s – 100 m^3/s
	Rotameter	0.01 cm3/s – 50 L/s
	Mass flow meter	0.1 cm3/s – 2 l/s
	Laminar flow element	0.1 cm3/s – 20 L/s
Volume	Spirometer	1-1000 L
	Soap bubble spirometer	1-1000 cm^3
	Piston meter	1-1000 cm^3
	Wet test meter	Unlimited
	Dry gas meter	Unlimited
Pressure	Manometer	1-200 kPa [0-2 atm]
	Micromanometer	0-0.5 kPa [0 – 0.005 atm]
	Aneroid pressure gauge	0-30 kPa [0-0.3 atm]
	Bourdon tube gauge	>20 kPa [>0.2 atm]

Flow rate measurement through particle collection substrate

- Variable-head meter-Venturi and orifice meters
- Variable area meter- Rotameter



- Differential pressure
- k=0.98 and k=0.62
- Critical orifice downstream pressure<0.53*Upstream pressure.
- Velocity at throat is the speed of sound and further reduction in down stream pressure does not increase the velocity through the throat

$$Q = kA_2\left[\frac{2(\Delta p)}{\rho_g\left(1-\left(\frac{A_2}{A_1}\right)^2\right)}\right]^{1/2}$$

$$1\ mm\ Hg = 133.3\ Pascal$$

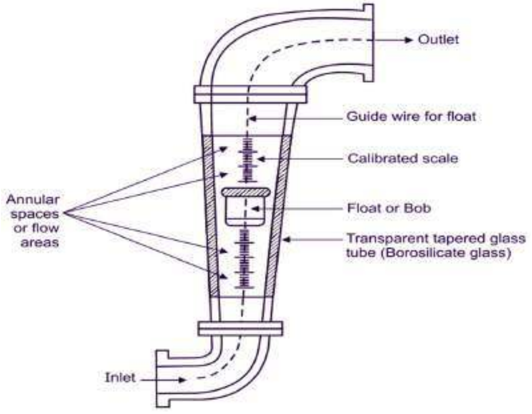
$$Critical\ orifice$$

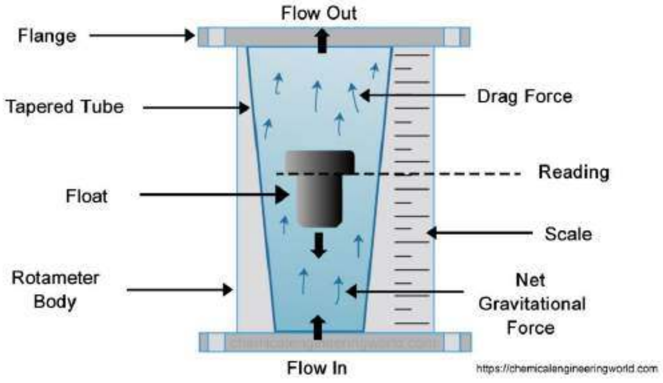
$$Q = 11.7kA_0$$

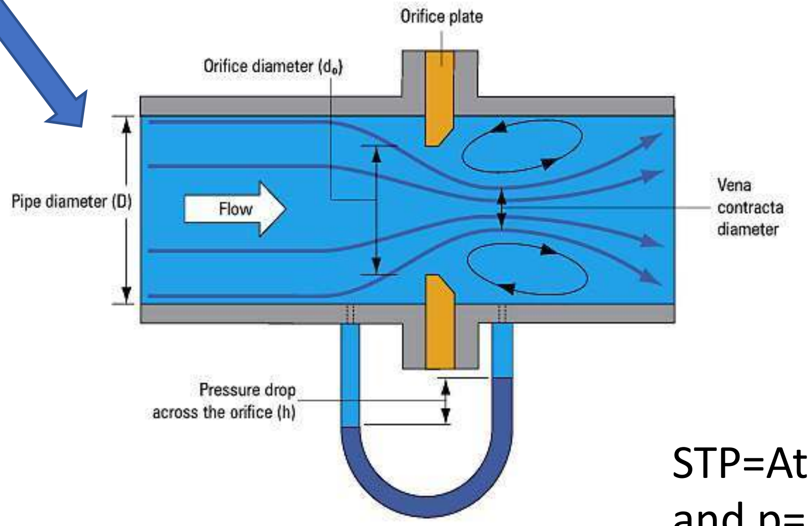
k=0.98, 0.62

$$Q_{STP} \propto \frac{p_1}{\sqrt{T_1}}$$

- Variable area
- Constant pressure







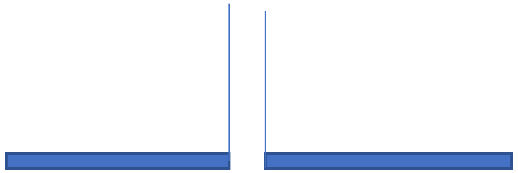
STP=At sea level t=0 C and p= 1 atm

$$Q = C_rA_0\left[\frac{2gm_f}{\rho_gA_f}\right]^{1/2}$$

- ✓ $C_r = rotameter\ coefficient = 0.6 - 0.8$
- ✓ $A_0 = Open\ area\ at\ float\ position$
- ✓ $m_f = Mass\ of\ float$
- ✓ $A_f = Cross\ sectional\ area\ of\ float$

$$Q_{STP} = Q_{obs}\left[\frac{\rho_r}{\rho_{STP}}\right]^{1/2} = Q_{obs}\left[\frac{p_r}{p_{STP}}\right]^{1/2}$$

Source monitoring plan



- Source location
- Gas flow rate: velocity pressure or Gas kinetic
  - Measurement of static pressure (velocity pressure=total pressure-static pressure)
    - Wall type
    - Static tip
    - Low pressure
  - Velocity
    - Vane probe velocity meter
    - Mass flow sensor/anemometer
- Volumetric flow rate for turbulent flow

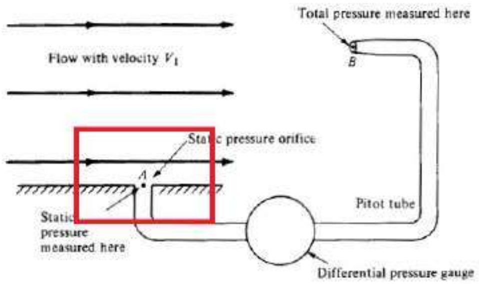
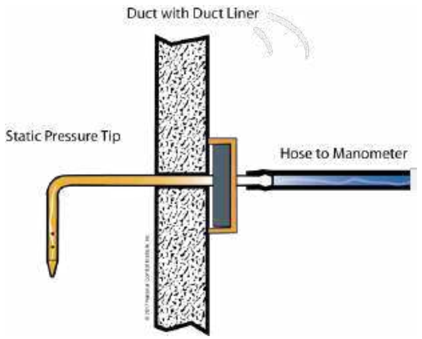
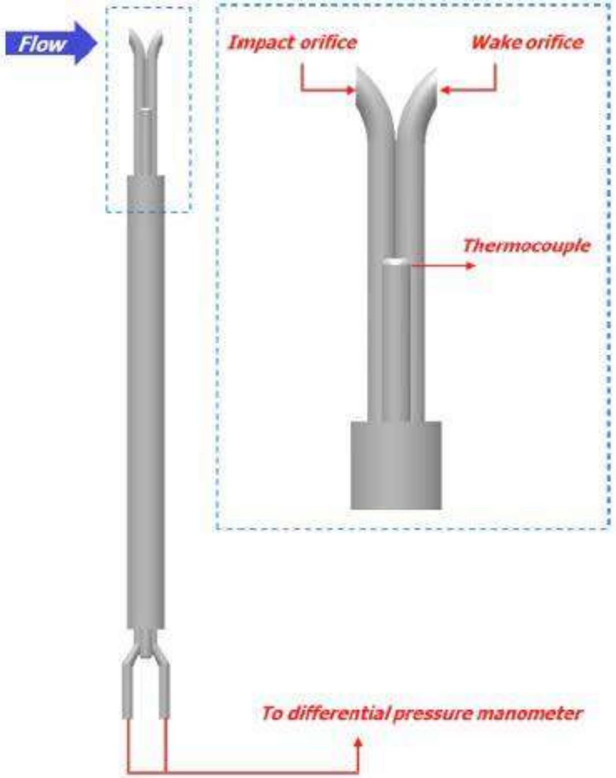


Figure 4.14 Schematic of a Pitot-static measurement.



Carbon balance method for emission factor calculation



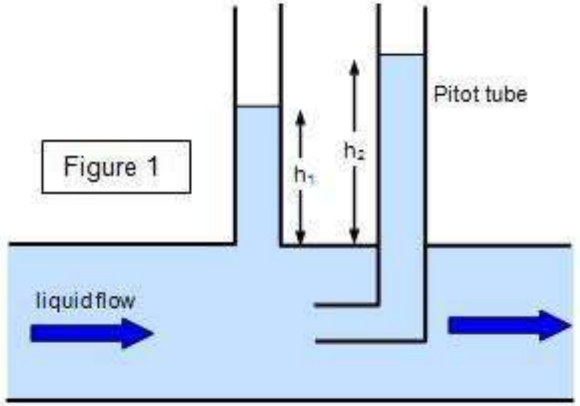
$$v = c_{p,s-type}\sqrt{\frac{2\Delta p}{\rho_g}}$$

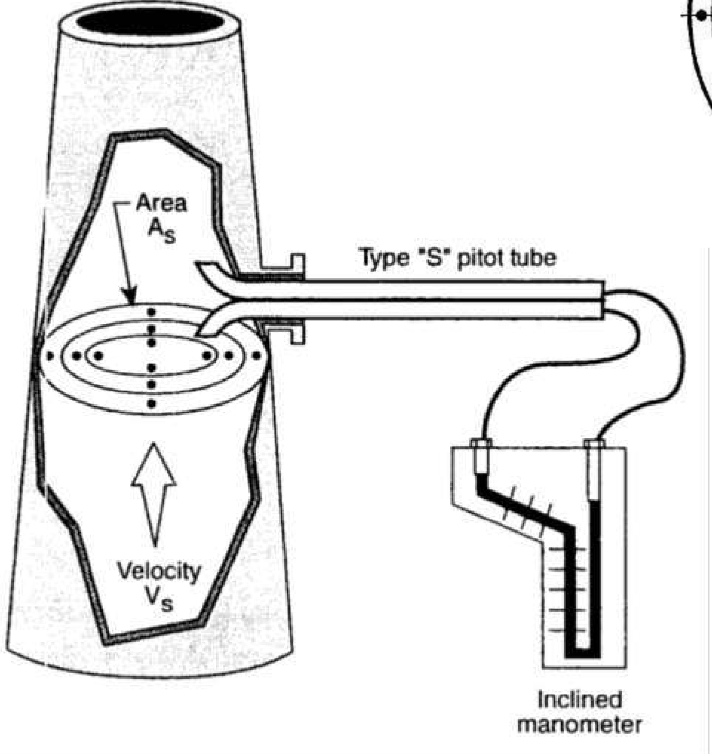
$v = velocity\ in\ m/s$

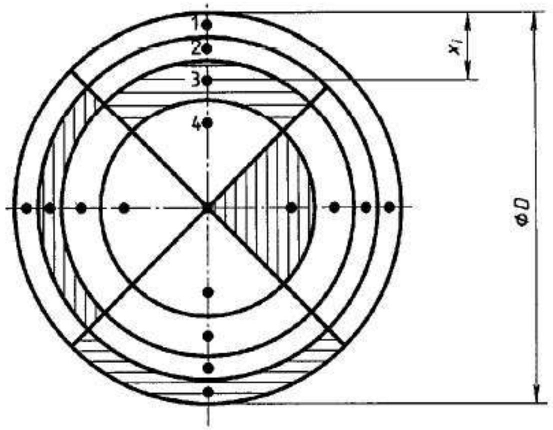
$C_{p,s-type} = coefficient\ for\ S - type\ pitot\ tube$

$\Delta p = Differential\ pressure$

$\rho_g = density\ of\ flue\ gas$







Stack Diameter 2R (m)	raidus	numbers	Distance from center of stack r_1	r_2	r_3	r_4	r_5
< 1	1	4	0.707 R	-	-	-	-
1 ~ 2	2	8	0.500 R	0.866 R	-	-	-
2 ~ 4	3	12	0.408 R	0.707 R	0.913 R	-	-
4 ~ 4.5	4	16	0.354 R	0.612 R	0.791 R	0.935 R	-
> 4.5	5	20	0.316 R	0.548 R	0.707 R	0.837 R	0.949 R

Emission factor calculation

$$EF\left(\frac{g}{kg}\right) = \frac{C_p \times DR \times V_{ex}}{F}$$

$$V_{ex} = volume\ of\ exhaust$$

$$F = Mass\ of\ fuel\ used$$

The carbon balance method used for emission factor calculation

$$EF_i\left(\frac{g}{kg}\right) = CMF_{fuel}\left(\frac{g}{kg}\right) * \frac{C_i\left(\frac{g}{m^3}\right)}{\Delta C_{CO_2}\left(\frac{g}{m^3}\right)\left(\frac{M_C}{M_{CO_2}}\right) + \Delta C_{CO}\left(\frac{g}{m^3}\right)\left(\frac{M_C}{M_{CO}}\right)}$$

$$Emission\left(in\frac{g}{y}\right) = EF_p\left(\frac{g}{kg}\right) \times fuel\ consumption\ (in\ kg) * days\ of\ activity\ in\ a\ year$$

Problem 1c. Determine the emission factor of particles if 100 kg of wood was burned in 30 min.

$$EF\left(\frac{g}{kg}\right) = \frac{Mass\ of\ pollutant\ emitted}{Mass\ of\ fuel\ burned}$$

$$EF_p\left(in\ \frac{g}{kg}\right) = \frac{26389}{100} = 263.89$$

Problem 1a. The particle is collected on quartz filter of initial weight 2.5 mg from monitoring of brick kiln stack. The final weight of the filter was measured as 2.85 mg. The monitoring was conducted for 30 min at 1 LPM. Determine the concentration of the particle in sampled air which was diluted using 40 LPM clean air.

$$Particle\ concentration(C_p) = \frac{W_f - W_i}{V_s}$$

$$Particle\ concentration(C_p)\ in\ sampled\ air\left(\frac{\mu g}{m^3}\right) = \frac{(2.85 - 2.5)\times 10^3}{1\times 10^{-3}\times 30} = 11667$$

Problem 1b. What would be the concentration in exhaust?

$$Conc.of\ particles\ in\ exhaust = DR * Concentration\ in\ sampled\ air$$

$$Conc.in\ exhaust = \frac{40}{1}\times 11667 = 466667\ \mu g m^{-3}$$

Problem 1c. What would be the mass of particles emitted in 30 min if the measured average velocity of exhaust was recorded as 10 m/s? The stack diameter was 2.0 m at sampling point.

$$Mass\ of\ particles\ emitted = V_{ex} * Concentration\ in\ exhaust$$

$$V_{ex} = Cross\ sectional\ area\ of\ duct \times v_{ex}$$

$$V_{ex} = \frac{\pi}{4}(2^2)\times 10\times 30\times 60 = 56549\ m^3$$

$$M_p(in\ g) = \frac{56549\ m^3\times 466667}{10^6} = 26389$$