Lesson 1

Course 450

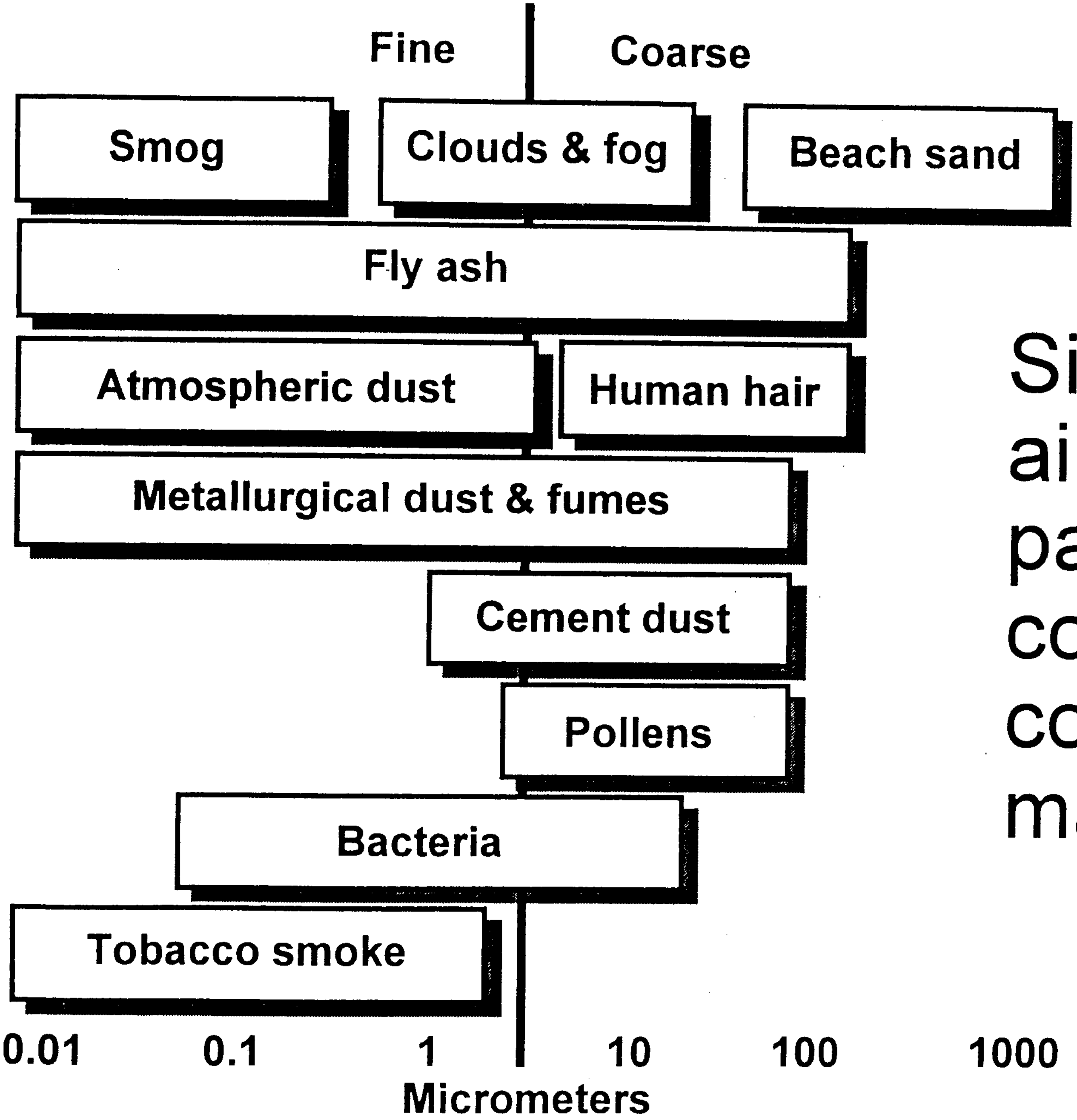
Introduction to Method 5

Particles

Small, discrete masses of solid or liquid matter

Examples: dust, smoke, mist, and fly ash

Sizes of typical airborne particles compared to common materials



Fine

Coarse

Smog

Clouds & fog

Beach sand

Fly ash

Atmospheric dust

Human hair

Metallurgical dust & fumes

Cement dust

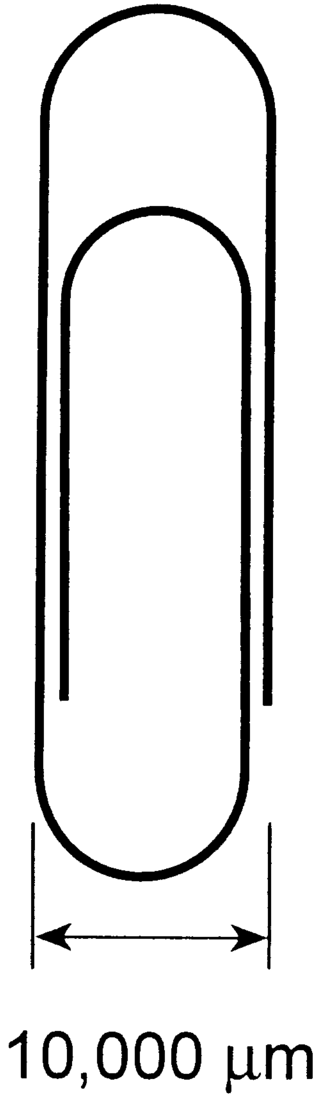
Pollens

Bacteria

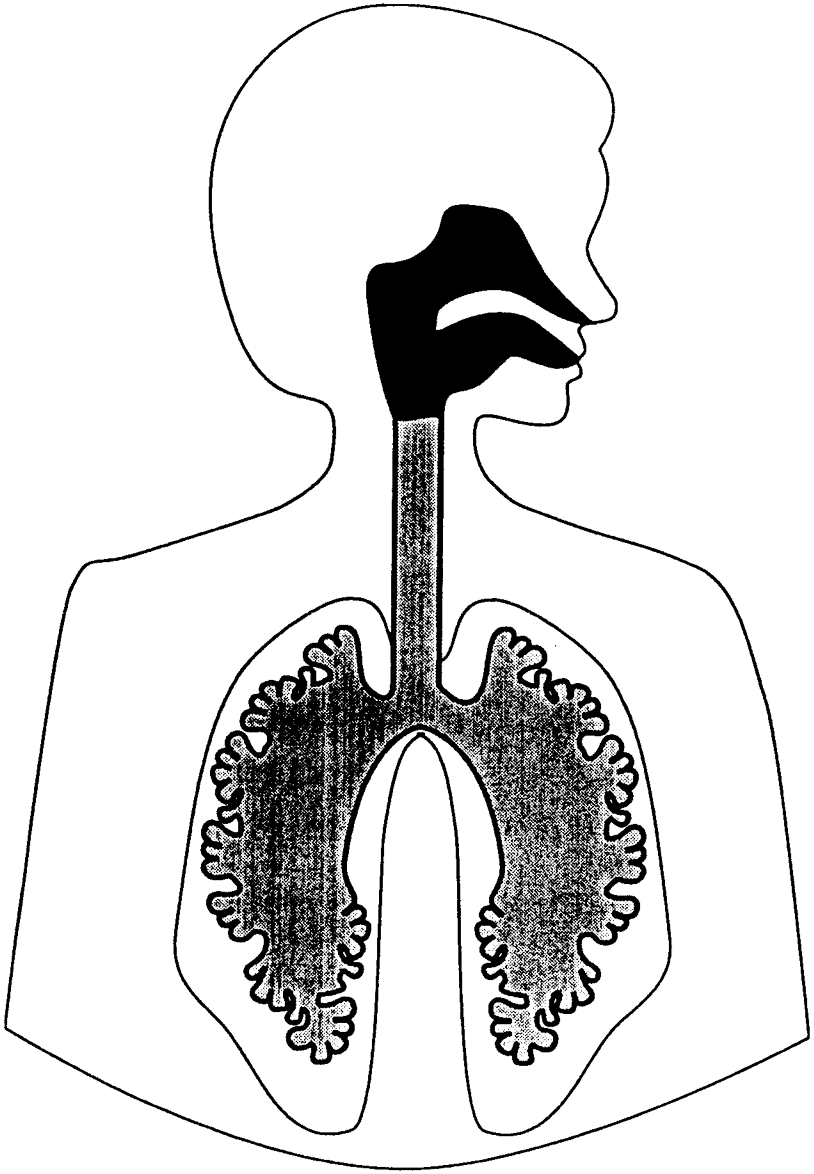
Tobacco smoke

0.01 0.1 1 10 100 1000

Micrometers

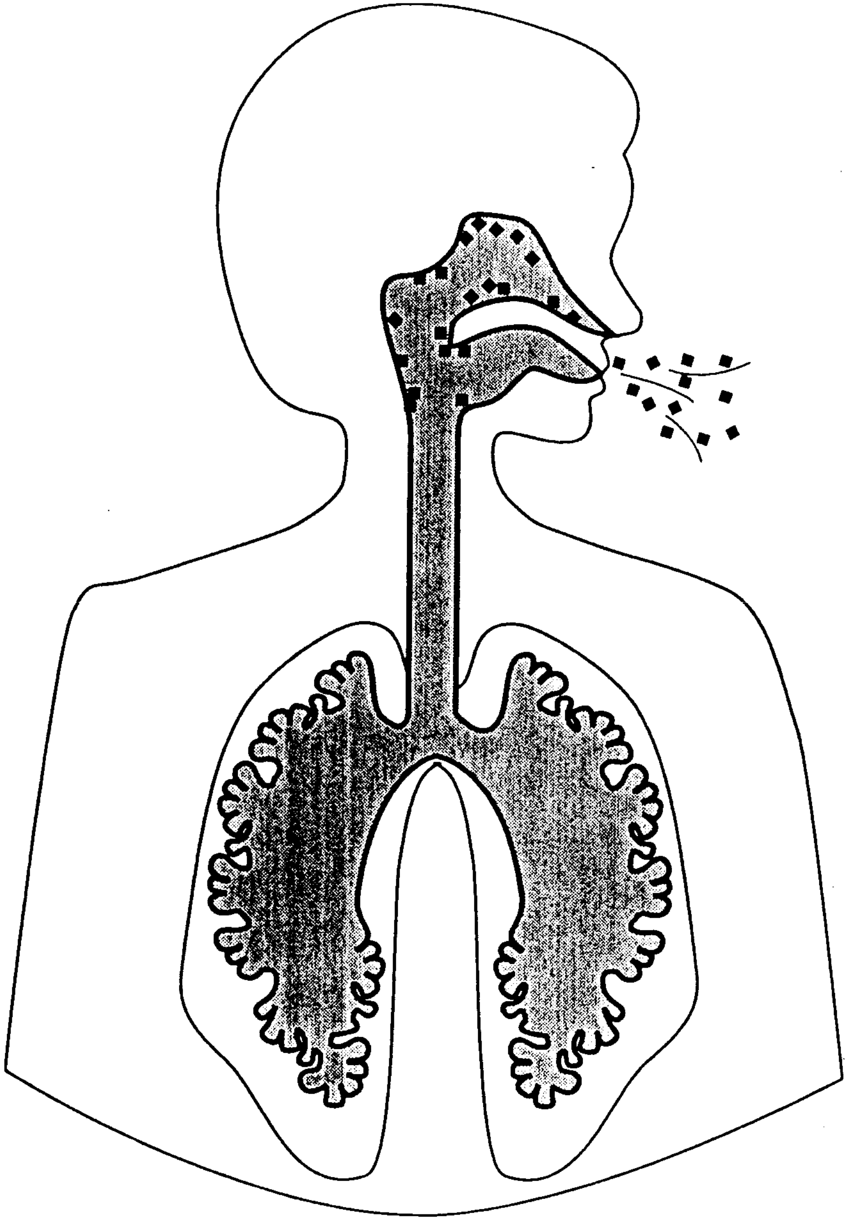


It would take 10,000 particles, each 1 micrometer (μm) in diameter, laid end to end, to stretch across the width of a small paper clip.



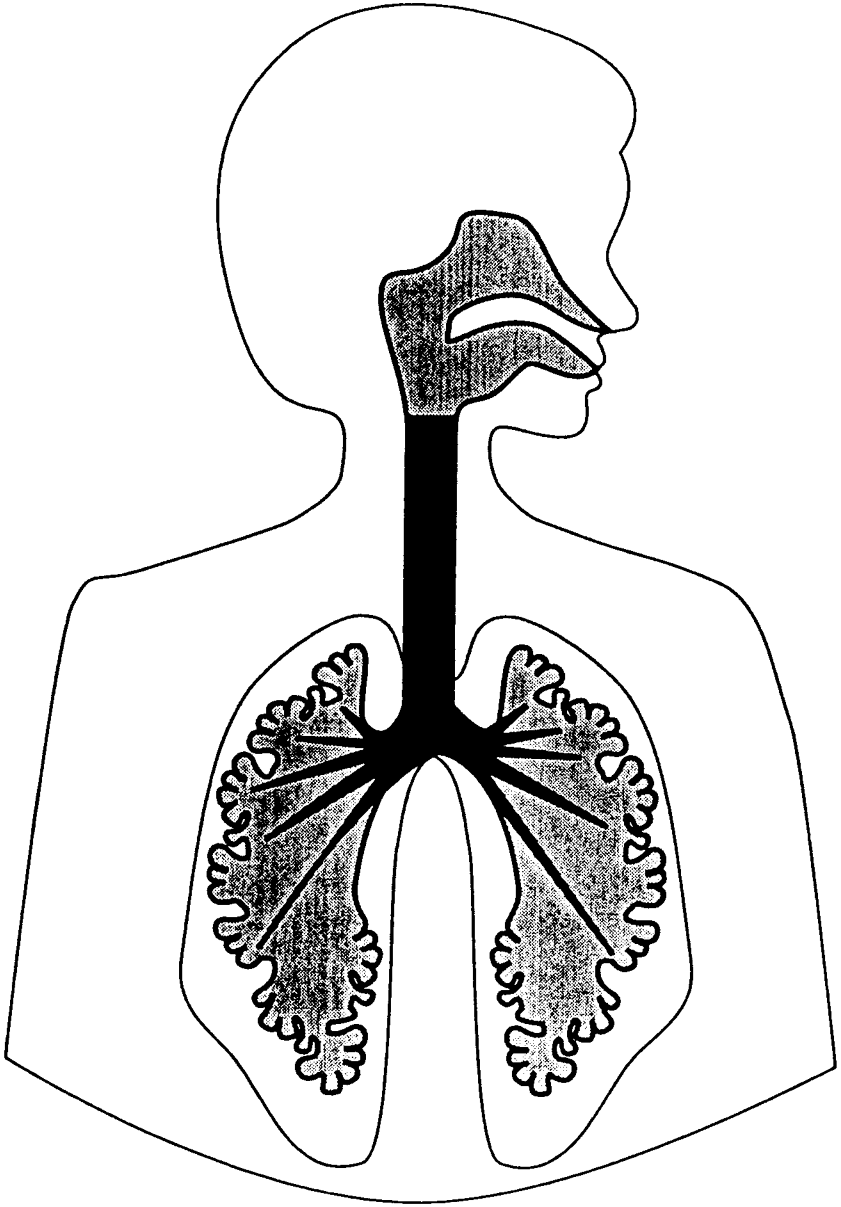
Particles > 10 μm

Collect in upper part of respiratory system



Particles collect moisture as they move through moist air of upper respiratory region, making them heavier and causing them to strike walls of throat, nose, etc.

They are eliminated by sneezing, coughing, nose blowing, spitting, or by the digestive system.

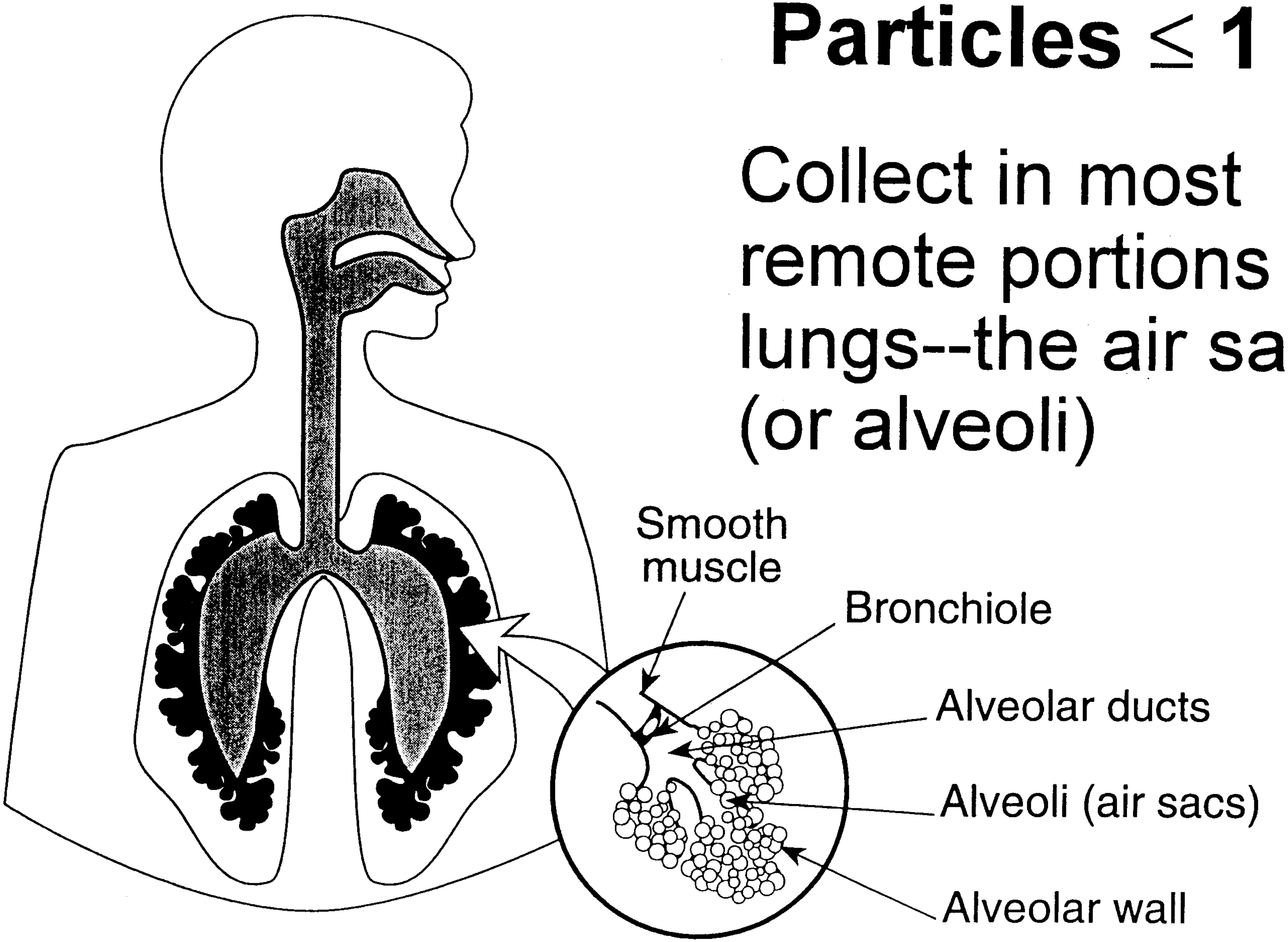


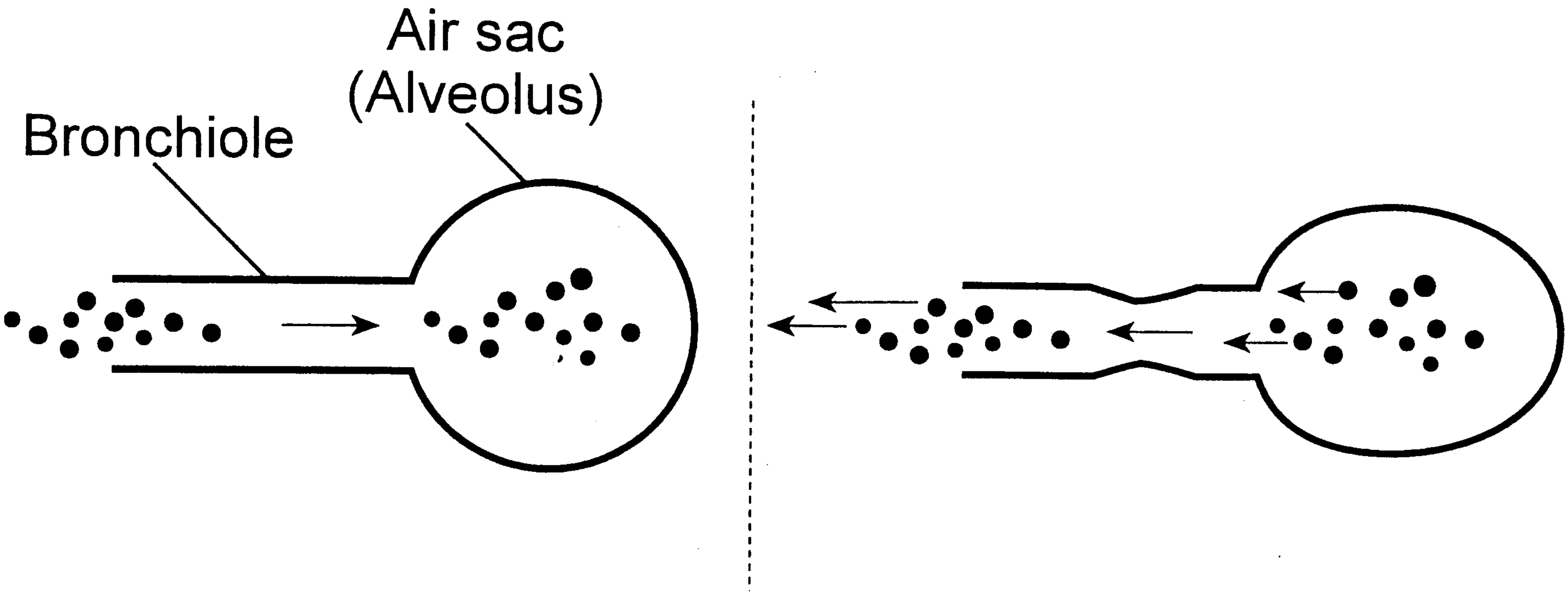
Particles 1-10 μm

Collect in middle part of respiratory system--the tracheobronchial region

Particles ≤ 1 μm

Collect in most remote portions of lungs--the air sacs (or alveoli)





Particles with diameters of 0.5 μm or less float in the air sac and are expelled with the next breath or two.

Health Effects - Nontoxic Particles

Concentration of Particles in μg/m^3	Effect
2000 μg/m^3 with 0.4 ppm SO_2 (24-hr avg) episodes of several days duration	Increase in deaths due to bronchitis
1000 μg/m^3 with 0.25 ppm SO_2 (24-hr avg) during episodes	Increase in mortality from all causes including respiratory and cardiac disease
300 μg/m^3 with 0.21 ppm SO_2 (annual avg)	Significant increase in bronchitis symptoms
130 μg/m^3 with SO_2 (annual avg)	Increase in frequency and severity of lower respiratory illness
100-200 μg/m^3 with 0.05 to 0.08 ppm SO_2 (avg seasonal levels)	Increase in incidences of bronchitis reported above this level

Emission Generation Categories

- Transportation
- Stationary source fuel combustion
- Industrial processes
- Solid waste disposal
- Miscellaneous

Stationary Combustion Sources

Produce energy but no other products.
Emissions result from fuel combustion.

- Fixed energy generating sources range in size from home heating furnaces to major power plants.
- Sources include commercial, institutional, industrial, and steam-electric power plants.
- Fuels used include coal, oil, natural gas, and wood. Other fuels such as liquefied natural gas, propane, process gas, etc. may also be used.

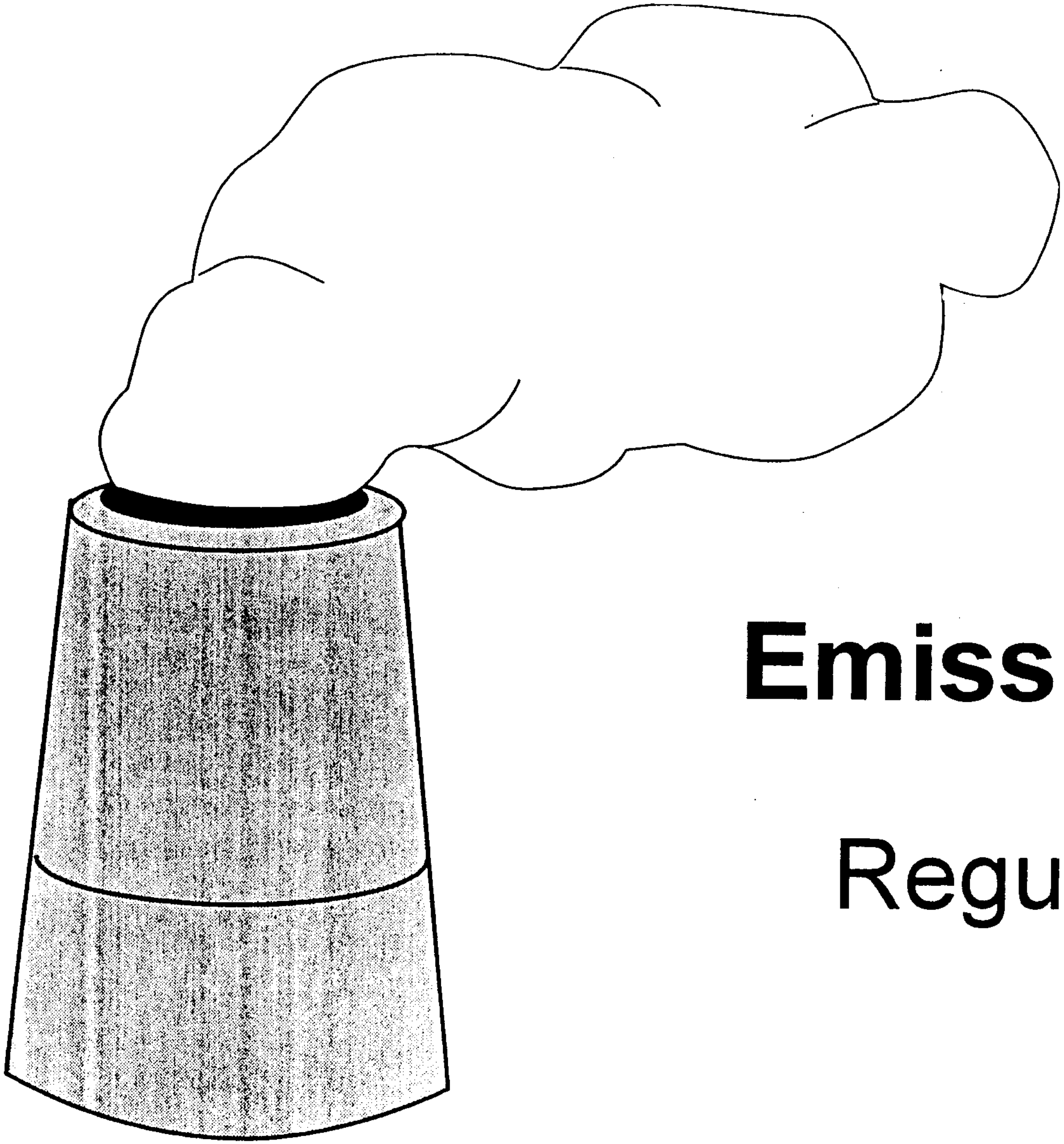
Industrial Processes

Emit pollutants in the course of manufacturing products

- Major sources include chemical processing, food and agricultural industries, metallurgical and mineral product factories, petroleum refining, petrochemical plants, petroleum storage, and wood-processing industries.
- Smaller sources include painting, dry-cleaning, and degreasing operations.

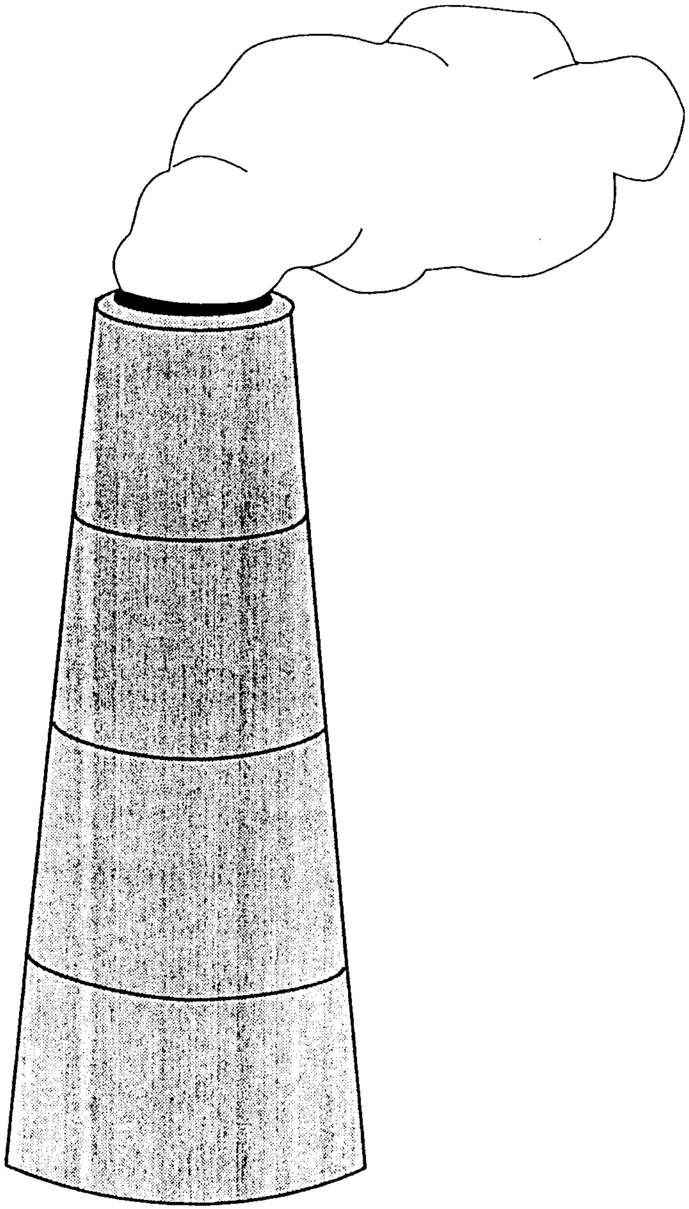
Solid Waste Disposal

Facilities that dispose of unwanted products and by-products. Emissions result from the disposal process --usually burning.



Emission Standards

Regulations in force



Emission Standard

A regulation that sets:

- Rate of emissions
- Level of opacity
- Equipment or fuel specifications
- Other measures

Stationary Source Regulations

- Largest and most varied class of regulations
- General
- By source category
- Source-specific

Inspection/Testing/ Obtaining Information

Require record-keeping by sources

- Emissions data
- Process data

Perform inspections

Conduct emissions testing

Federal Register System

Basic means of proposing and promulgating federal administrative regulations/decisions

- Daily Federal Register
- Code of Federal Regulations

Daily Federal Register

Issued every working day

Contains:

- Proposed rules
- Rules and regulations
- Notices
- Proclamations, executive orders, etc.
- 55 FR 47471 (11/14/90)

Code of Federal Regulations

Annual compilation of all administrative regulations

Organized by:

- Title
- Chapter
- Subchapter
- Part
- Section

40 CFR 60 Appendix A

Emission Standards for Sources

- Concentration of stack gas (c_s)
- Pollutant mass rate (pmr)
- Emission rate (E)
- Process weight rate (E)

Concentration of Stack Gas (c_s)

Can be expressed in:

- ppm
- g/dscm
- gr/dscf

For example:

The New Source Performance Standards (NSPS) for asphalt concrete plants is:

0.04 gr/dscf <=> 90 mg/dscm.

Pollutant Mass Rate (pmr)

Can be expressed in:

- lb/hr
- g/hr

$$\text{pmr} = \text{Concentration} \times \begin{array}{c}\text{Stack gas}\\ \text{volumetric}\\ \text{flow rate}\end{array}$$

$$= \frac{\text{lb}}{\text{dscf}} \times \frac{\text{dscf}}{\text{hr}}$$

$$= \frac{\text{lb}}{\text{hr}}$$

Emission Rate (E)

Can be expressed in:

- lb/10^6 Btu heat input
- ng/joule heat input

$$E = \frac{\text{Pollutant mass rate}}{\text{Heat input rate}}$$

$$= \frac{\text{lb/hr}}{10^6\ \text{Btu/hr}}$$

$$= \frac{\text{lb}}{10^6\ \text{Btu}}$$

For example:

The NSPS emission rate for fossil-fuel fired steam generators (FFFSG) is:

particulate emissions limited to $0.03\ \mathrm{lb}/10^6\ \mathrm{Btu}$.

Process Weight Rate (E)

Can be expressed in:

- lb/tons of product
- kg/metric tons of product

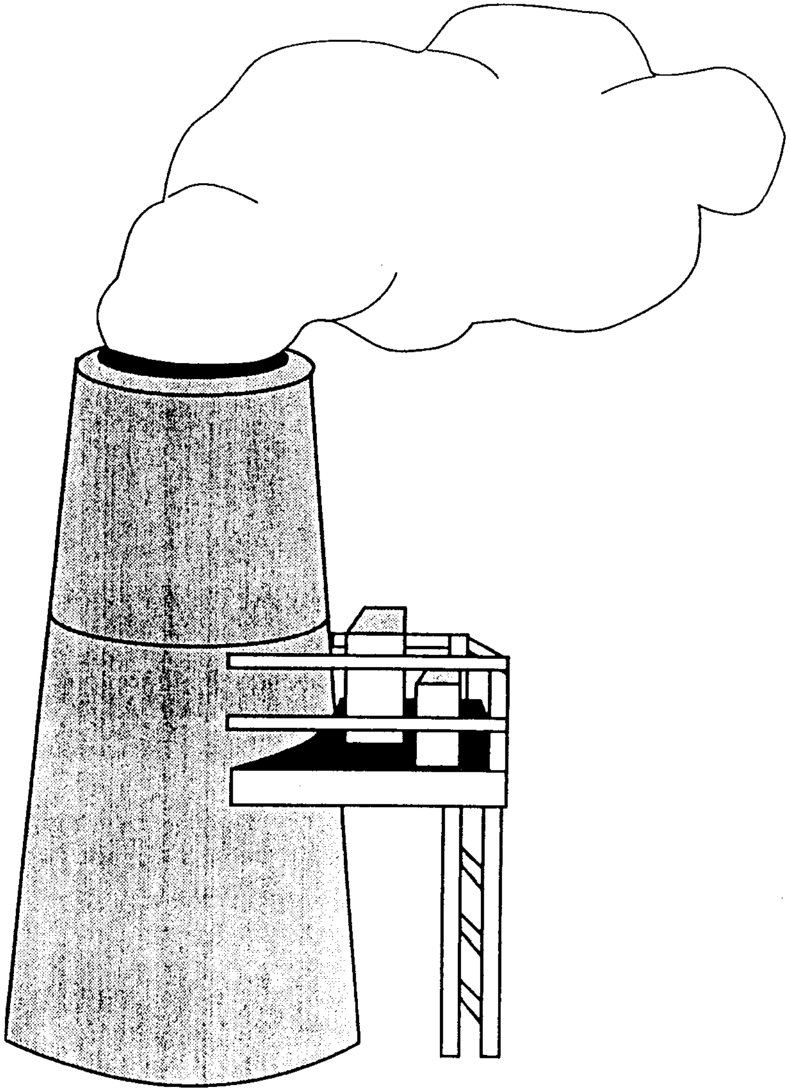
For example:

The NSPS for sulfuric acid plants is:

SO_2 emissions limited to 2 kg SO_2/metric ton H_2SO_4 produced.

$$\text{Combustion} = \frac{\text{Pollutant mass rate}}{\text{Heat input rate}}$$

$$\text{Process} = \frac{\text{Pollutant mass rate}}{\text{Item or mass process rate}}$$



Measurement of Source Pollutant Emissions

Methods for Measuring Emissions

Manual sampling

Continuous monitoring

- Extractive
- In-situ

Remote sensing

EPA Reference Methods

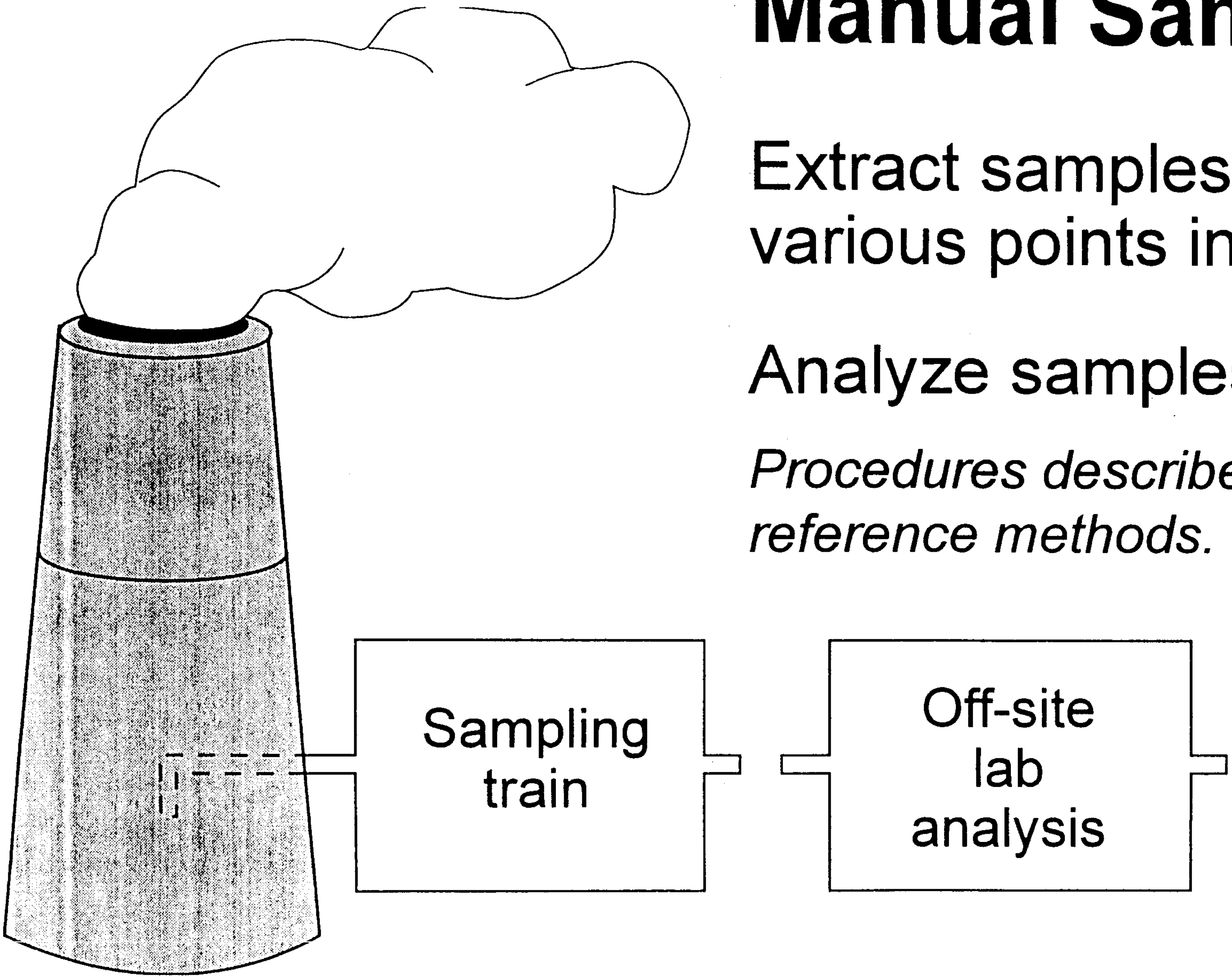
- Used for source compliance testing
- Describe actual testing procedure
- Found in Code of Federal Regulations

Manual Sampling

Extract samples from various points in stack.

Analyze samples in lab.

Procedures described by reference methods.

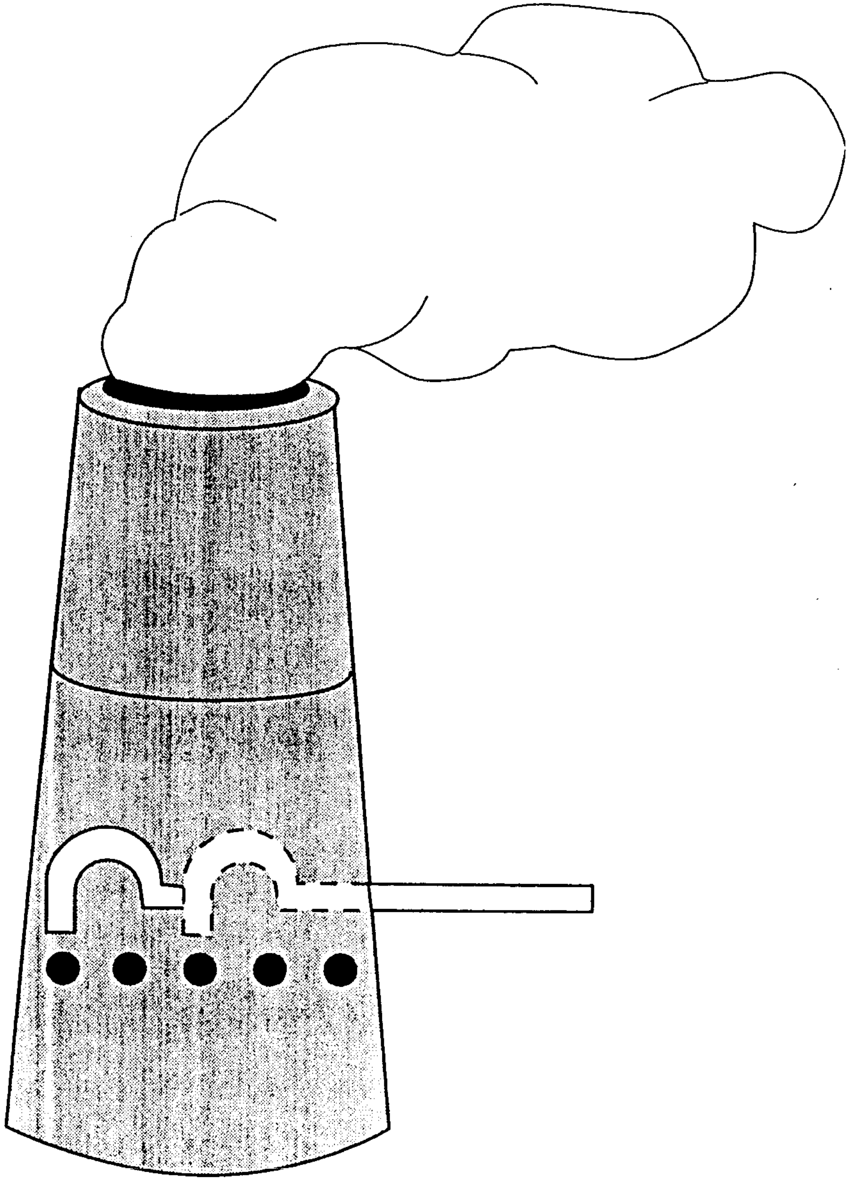


Methods 1 - 4

Used in other reference methods

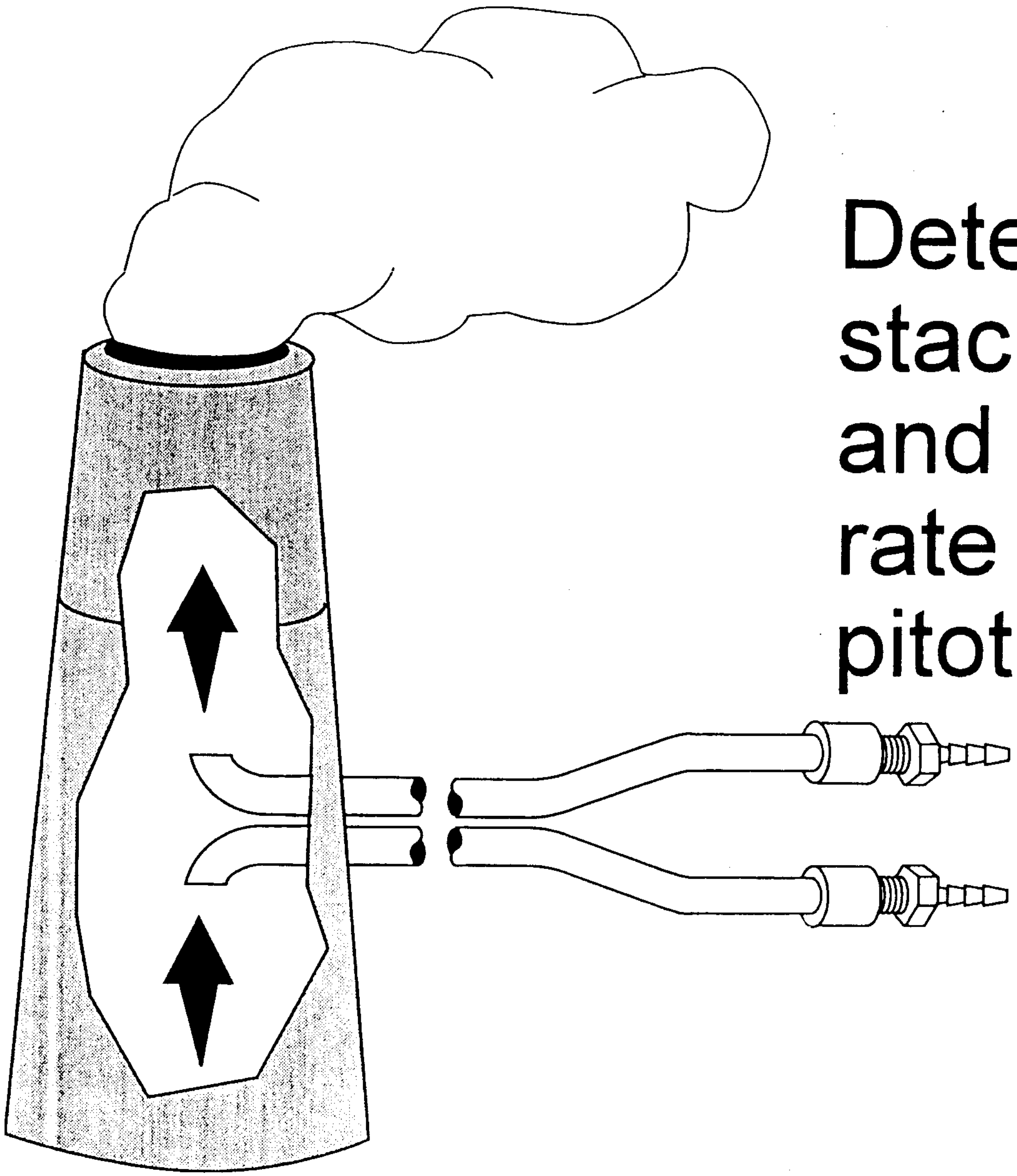
Used to determine:

- Number of sampling points (Method 1)
- Stack gas velocity (Method 2)
- Stack gas molecular weight (Method 3)
- Stack gas moisture content (Method 4)



Method 1

Selection of traverse points

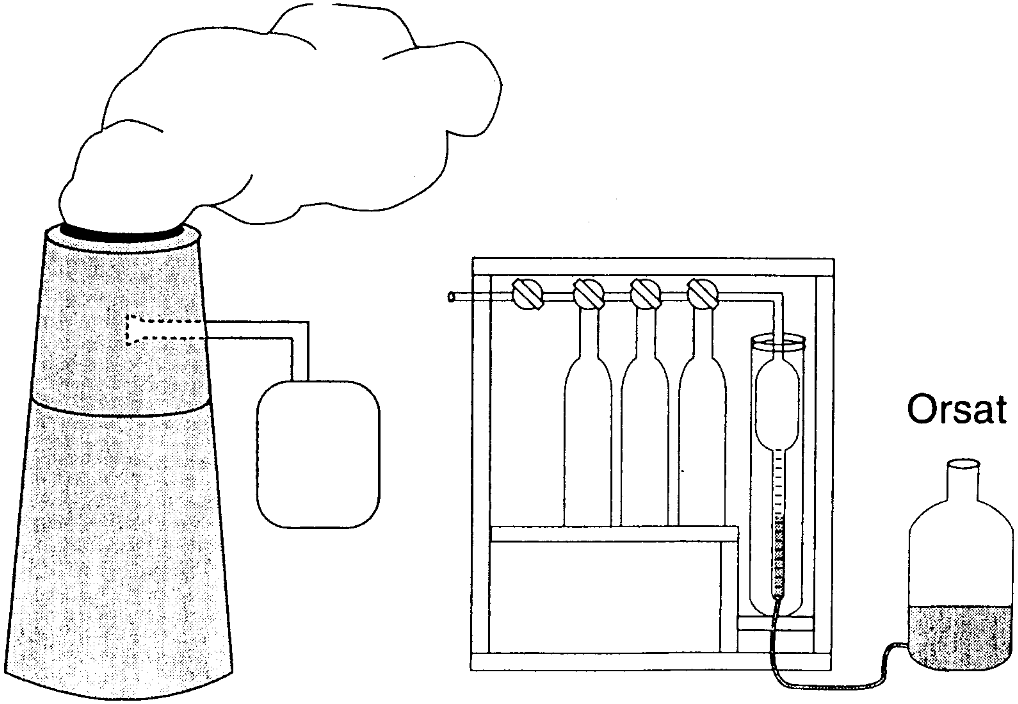


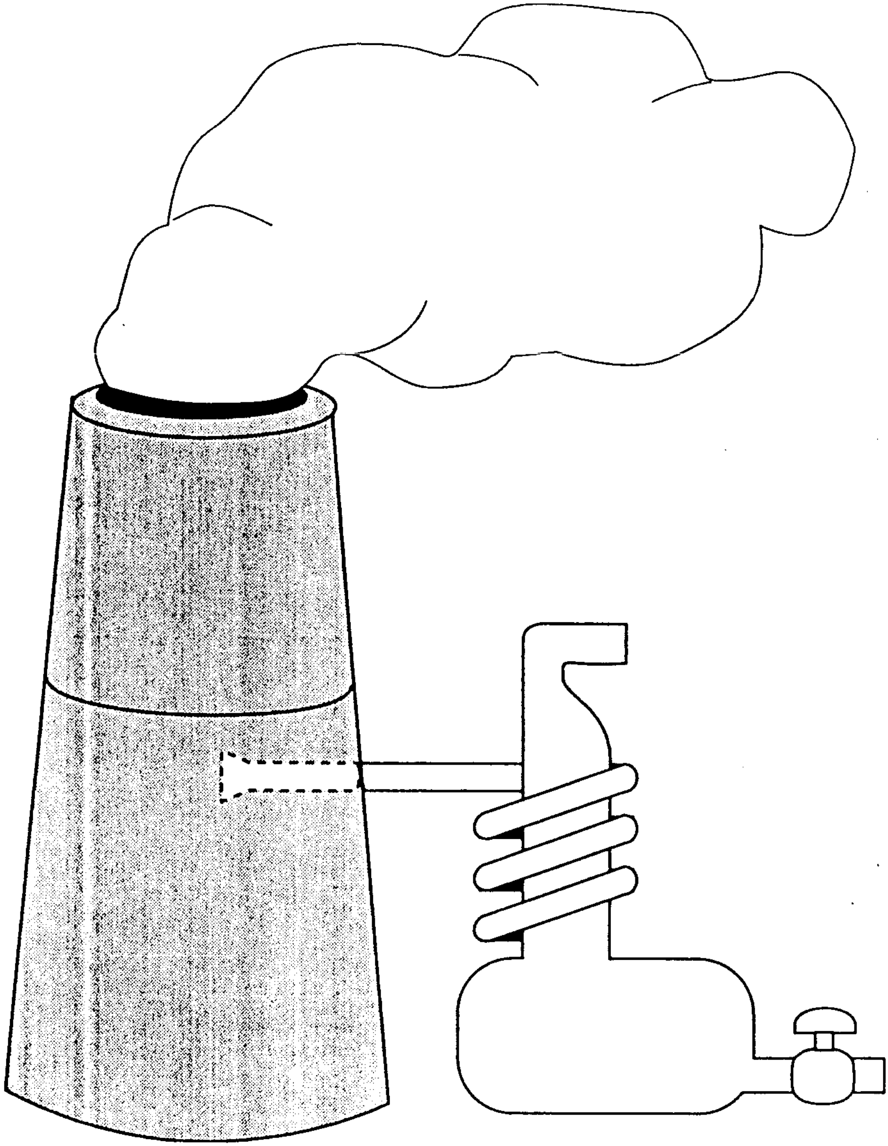
Method 2

Determination of stack gas velocity and volumetric flow rate (using Type S pitot tube)

Method 3

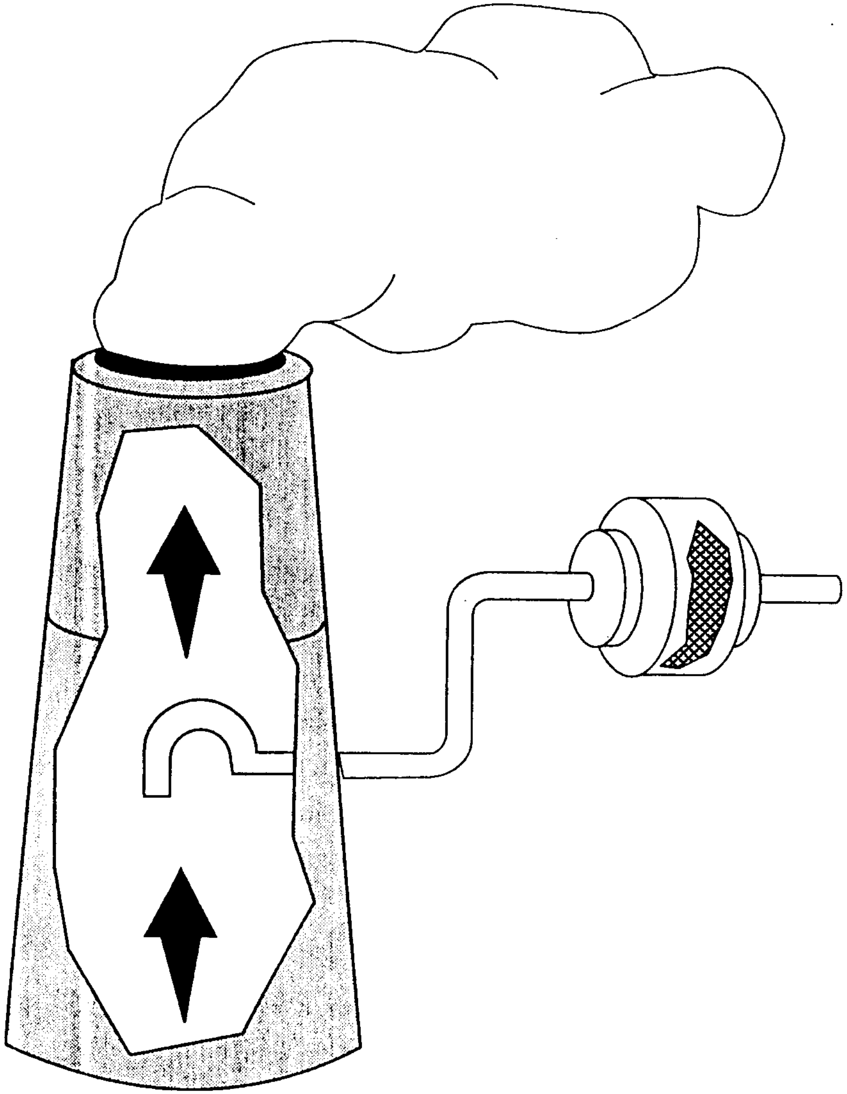
Determination of the dry molecular weight of flue gas (using Orsat apparatus measuring %O_2, %CO_2, and %CO)





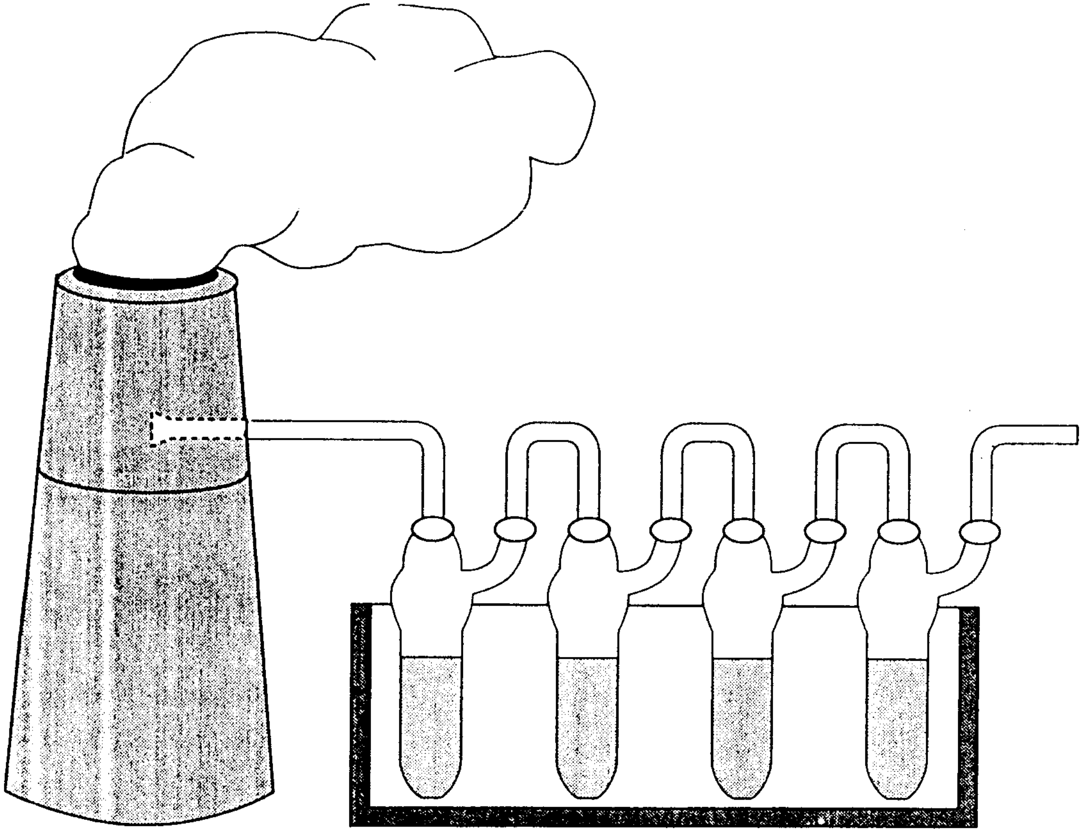
Method 4

Determination of moisture content of stack gas (by condensation method)



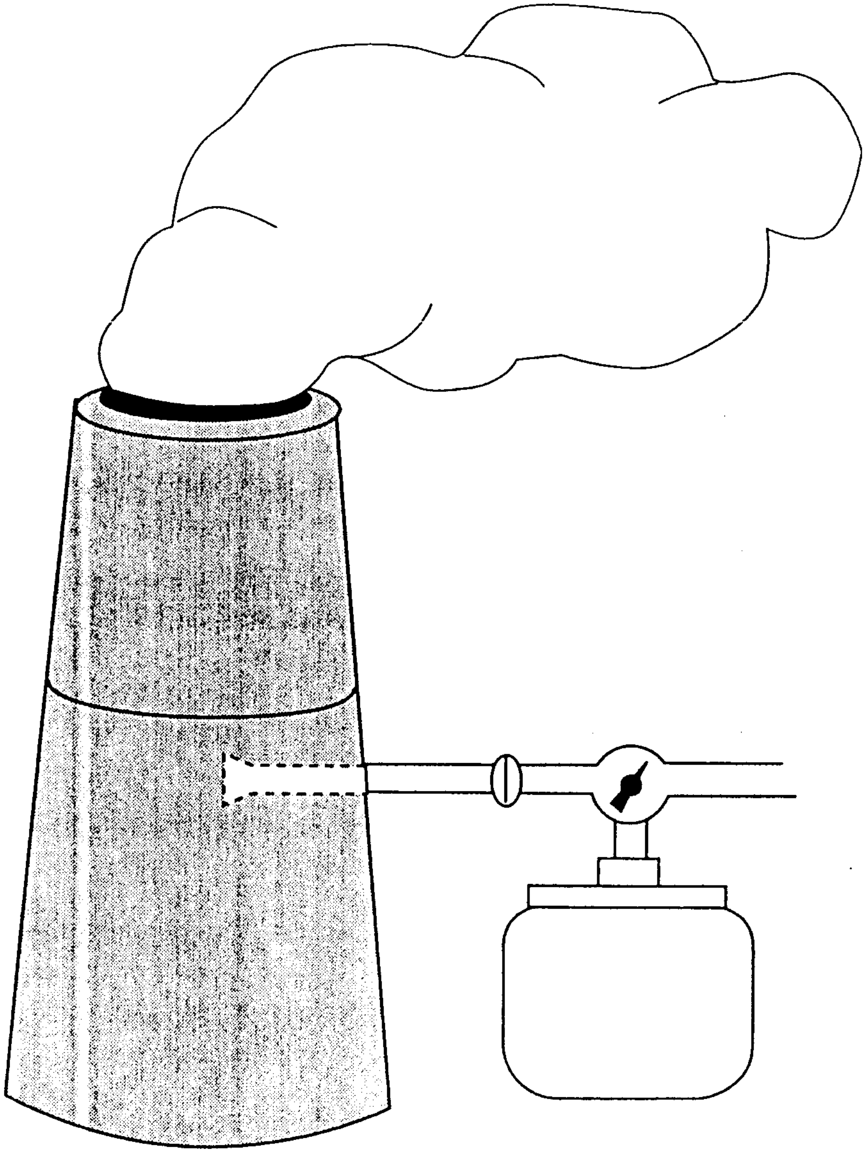
Method 5

Sampling method for particulate matter (isokinetic collection of particles on a filter)



Method 6

Sampling and analytic method for determining SO_2 emissions (barium-thorin titration)

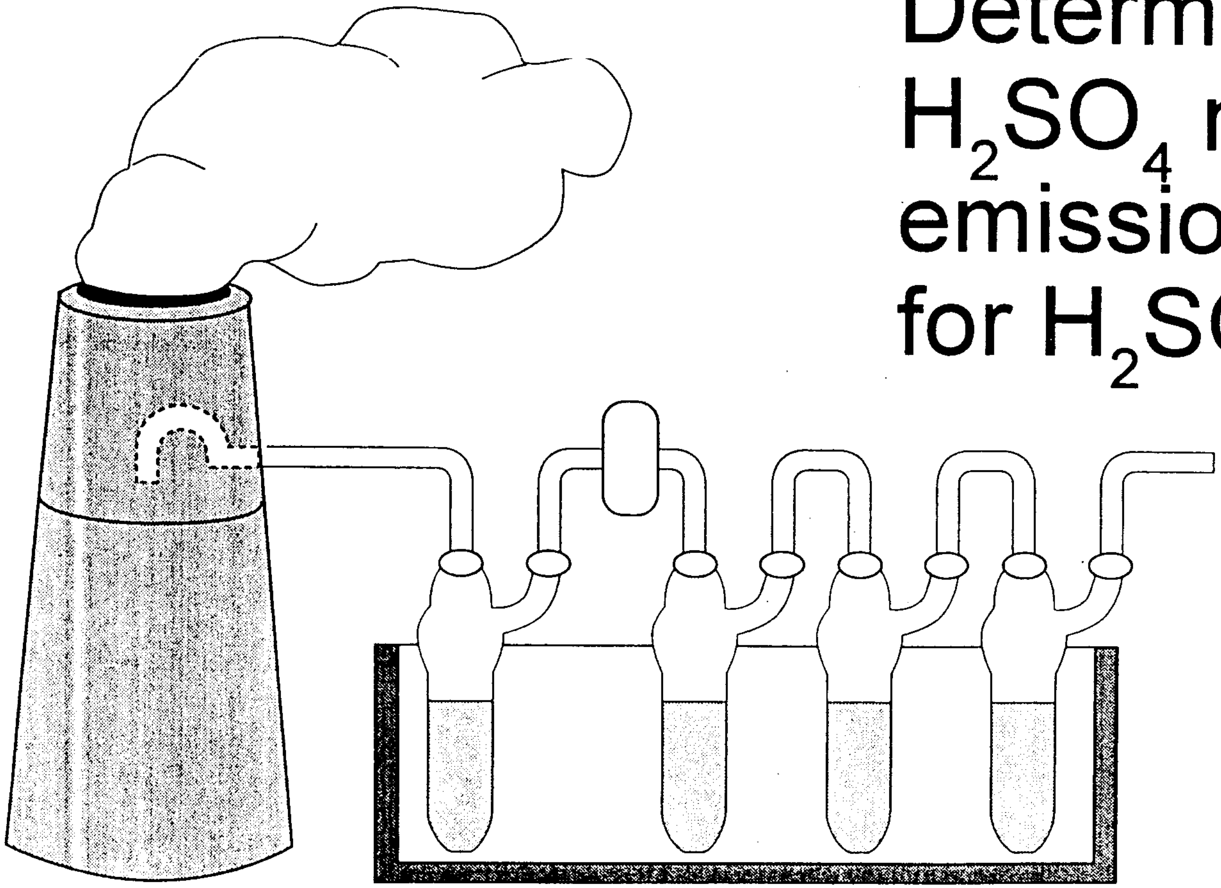


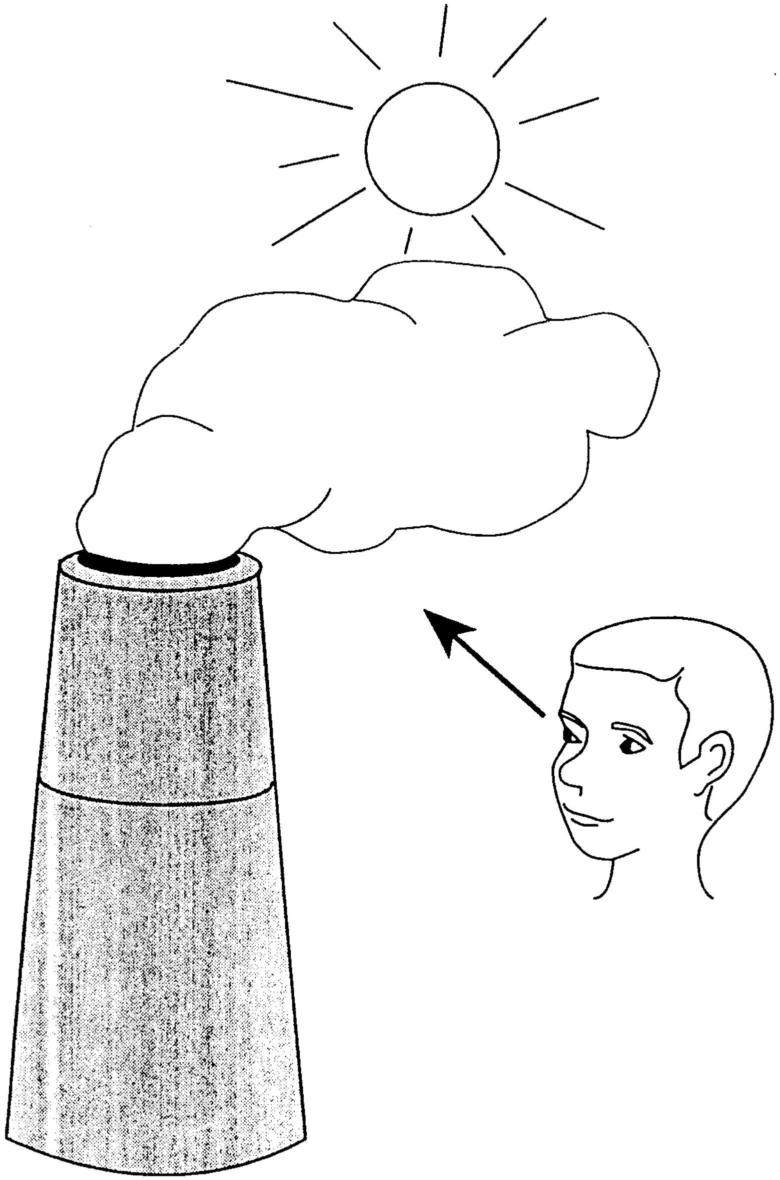
Method 7

Determination of NO_x emissions (colorimetric phenoldisulfonic acid method)

Method 8

Determination of H_2SO_4 mist and SO_2 emissions (intended for H_2SO_4 plants)





Method 9

Determination of stack plume opacity (by visual observation)

Method 10	Determination of CO
Method 11	Determination of fluorides
Method 12	Determination of inorganic lead emissions
Method 13, 14	Determination of H_2S
Method 15	Determination of H_2O, COS, CS_2
Method 16	Determination of total reduced sulfur
Method 17	Determination of particulates (in-stack filtration method)

Lesson 2

Course 450

Basic Principles

Temperature

Degrees Fahrenheit: °F

Degrees Centigrade: °C

$°C = 5/9\,(°F - 32)$

$°F = 9/5\,(°C) + 32$

Absolute Temperature

Degrees Rankine: R

Degrees Kelvin: K

R = °F + 459.49

K = °C + 273.16

Absolute Pressure, P

$P = P_b + p_g$

P_b = Barometric pressure

p_g = Gauge pressure

Units of Pressure

- in. Hg
- mmHg
- in. H_2O
- atmospheres
- torr
- pascals

Conversions

1 in. Hg = 13.6 in. H_2O

1 Atmosphere =

29.92 in. Hg

39.90 ft H_2O

14.70 lbs/in.$_2$

760 mmHg

1 torr

EPA Standard Pressure and Temperature

P_{std} = 29.92 in. Hg

T_{std} = 20° C or 68° F

Atomic Weight

A number that indicates how heavy (on the average) an atom is compared to an atom of another element

(Assign carbon atomic wt = 12)

Molecular Weight, M

The sum of the atomic weights of all the atoms in a molecule

n = number of moles
1 mole =

The molecular weight of a compound expressed in lbs (lb-mole) or in grams (g-mole)

1 gram-mole =

6.023×10^{23} molecules

(Avogadro's Number)

An Avogadro's Number worth of molecules

(6.023×10^{23})

occupies

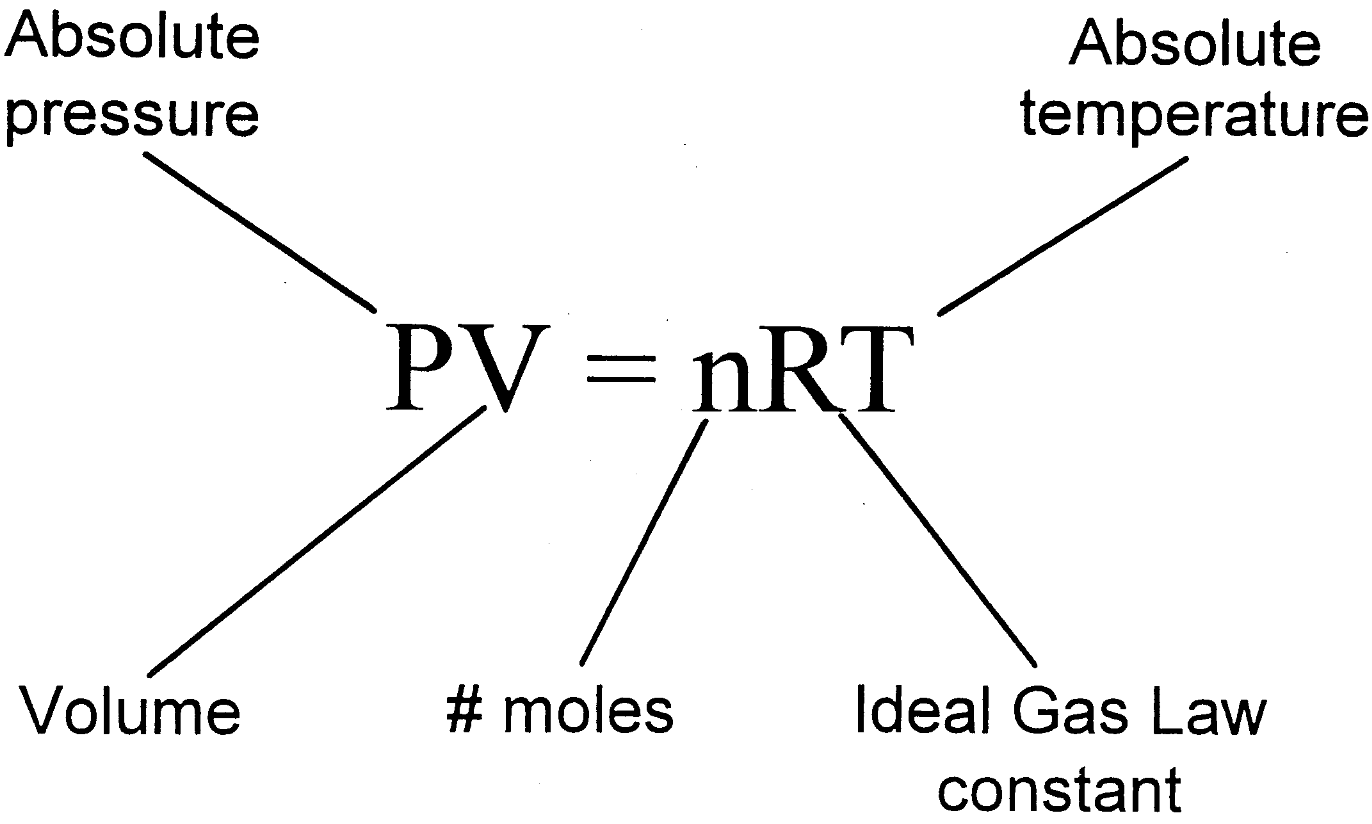
22.4 L

at 0° C and 1 atmosphere

Given a mass, m, of a compound, the number of moles is calculated by:

$$n = \frac{m}{M}$$

The Ideal Gas Law



$$PV = nRT$$

Absolute pressure

Absolute temperature

Volume

moles

Ideal Gas Law constant

R

The gas law constant is dependent on units used for EPA reference methods in English units:

$$R = 21.83 \frac{(\text{in. Hg})(\text{ft}^3)}{(\text{lb-mole})(^\circ\text{R})}$$

Correcting Volume to Standard Conditions

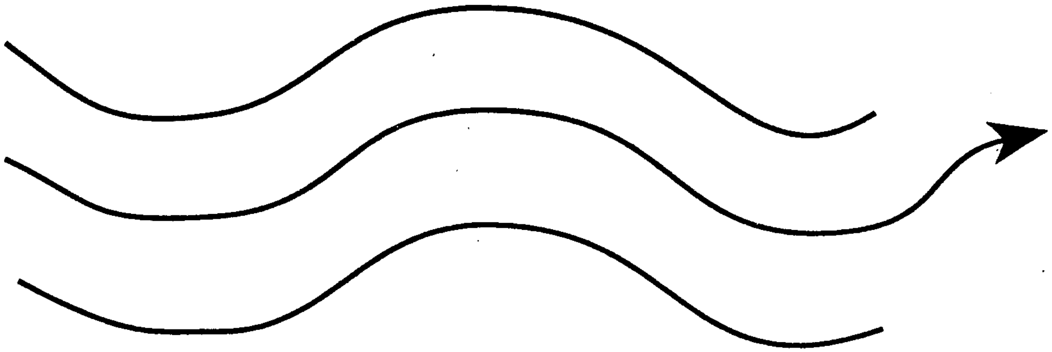
$$V_{stack} = nR\frac{T_s}{P_s}$$

$$V_{std} = V_s\frac{T_{std}\,P_s}{P_{std}\,T_s}$$

Moving Gases

- Velocity
- Volumetric flow rate
- Pollutant mass rate

Velocity



$$v_s = \text{ft/sec or ft/hr}$$

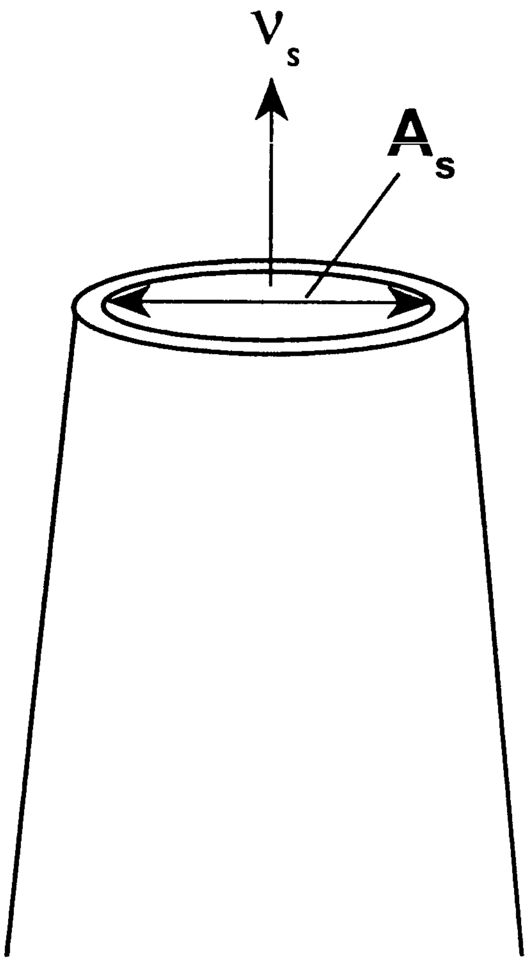
Velocity, v_s , $\frac{\text{ft}}{\text{sec}}$, $\frac{\text{ft}}{\text{hr}}$

Determined by Method 2 using the Type S pitot tube

The Pitot Tube Equation

$$\nu_S = K_p C_p \sqrt{\frac{T_S \Delta P}{P_S M_S}}$$

Volumetric Flow Rate



$$Q_s = \nu_s A_s$$

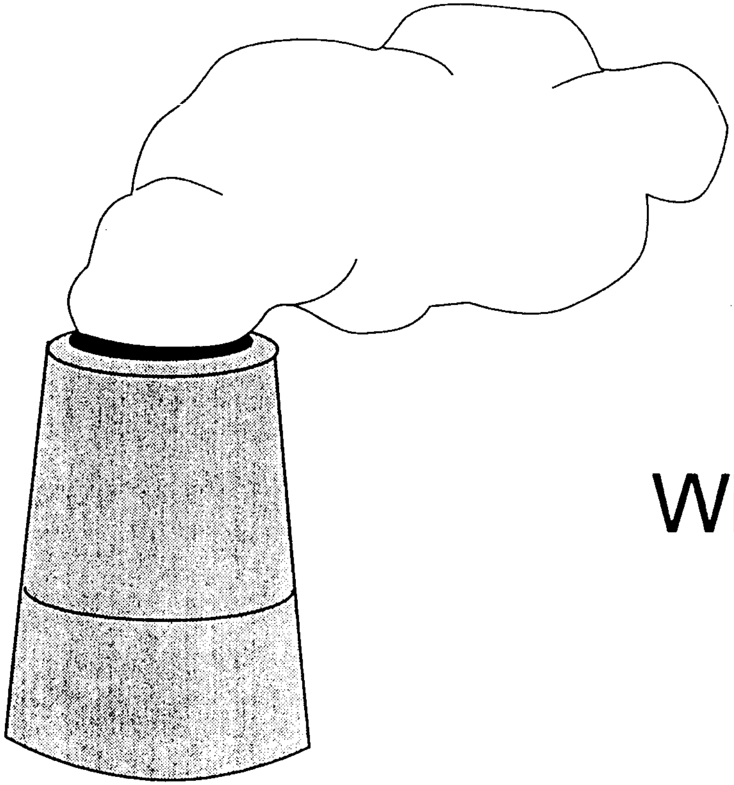
$$\frac{ft^3}{sec} = \frac{ft}{sec} \times ft^2$$

or

$$\frac{ft^3}{hr} = \frac{ft}{hr} \times ft^2$$

Pollutant Mass Rate

pmr_s



$$pmr_s = c_s\ Q_s$$

Where: c_s = the pollutant concentration

Concentration, c_s

$$c_s = \frac{m}{V} = \frac{\text{Quantity of pollutant (mass)}}{\text{Quantity of effluent gas (vol)}}$$

Units: g/m^3, lbs/ft^3, gr/ft^3, ppm

Note: 7000 grains (gr) = 1 lb

$$\mathbf{pmr_s = c_s\, Q_s}$$

$$\frac{\text{lbs}}{\text{hr}} = \frac{\text{lbs}}{\cancel{\text{ft}^3}} \times \frac{\cancel{\text{ft}^3}}{\text{hr}}$$

Emission Rate (Combustion Sources)

$$E = \frac{pmr_s}{Q_H}\left(\frac{\text{lbs}}{10^6\ \text{Btu}}\right)$$

Where: Q_H = heat input rate in units of Btu/hr

Lesson 3

Course 450

The Method 5 Sampling Train

Sampling Train Components

- The probe assembly
- The sample box
- The umbilical
- The meter box

The Probe Assembly

- Nozzle
- Pitot tube
- Thermocouple
- Probe liner
- Probe sheath

Sampling Nozzle

- Stainless steel seamless tubing
- Buttonhook or elbow design
- Wide range of nozzle diameters
- Calibration with micrometer to nearest 0.001 in. internal diameter
- Repair or replace nicked, dented or corroded nozzles

The Pitot Tube

- Usually Type S
- Nozzle entry plane must be even with pitot orifice
- Centerline of orifice and nozzle must agree
- Minimum separation of 1.9 cm
- Geometry of pitot, probe sheath, and thermocouple important

Probe Sheath

- Usually stainless steel
- Pitot tube welded to sheath to prevent misalignment
- Protects liner from breakage

Probe Liner

Borosilicate or quartz glass

Heating system to maintain exit gas temperature of 120° C

Borosilicate temperature to 480° C

Quartz glass temperature to 900° C

The Sample Box

Heated Filter Box

- Heating element to maintain filter temperature of 120° C
- Filter holder
- Flexibility for vertical and horizontal traverses
- Insulated

Impinger Box

- Provide support and protection for glassware
- Insulated
- Holding container for ice to cool impingers

The Umbilical Line

- Sample lines
- Pitot lines
- Electrical connections
- Covered in a protective sheath

The Meter Box

- Pump
- Dry gas meter
- Inclined manometers for Δp and ΔH readings
- Flow control valves
- Thermocouple readouts
- Ports for integrated gas sampling

Lesson 6

Course 450

Use of Computers and Programmable Calculators for Isokinetic Sampling

The Basic Calculations

$$D_{n(est)} = \sqrt{\frac{0.0358\ Q_m P_m}{T_m C_p \left(1 - B_{ws(est)}\right)} \sqrt{\frac{T_s M_s}{P_s \Delta p_{est}}}}$$

$$K = 846.872\ D^4_{n(act)}\ \Delta H_{@}\ C^2_p \left(1 - B_{ws}\right)^2 \left(\frac{M_d}{M_s}\right)\left(\frac{T_m}{P_m}\right)\left(\frac{P_s}{T_s}\right)$$

The Basic Calculations

$$\Delta H = K \Delta p$$

$$T_s = t_s + 460$$

$$T_m = t_m + 460$$

$$M_s = M_d \left(1 - B_{ws(est)}\right) + 18\ B_{ws(est)}$$

Methods for Calculating D_n (est) and K

- Nomograph
- Slide rule calculators
- Simple calculators
- Programmable calculators (scientific, card read)
- Programmable calculators (continuous memory)
- Computers (desktop)
- Portable computers/notebooks

Programs

Programmable Options

D_n(est) and $\Delta H = K\Delta p$ calculations only

(1) + % I calculations

(1) + (2) + calculations for v_s and Q_s

Other Options

- Methods 1, 2, 3, 4 calculations
- Report programs - print-out of results
- Field cross-check programs
- Fancy graphics - displays

Published Programs

Calculator

TI-59	EPA 450/2-83-006
HP-41	EPA 340/1-85-018
HP-65	EPA 600/8-76-002

Programs in Basic

- See EMTIC bulletin board

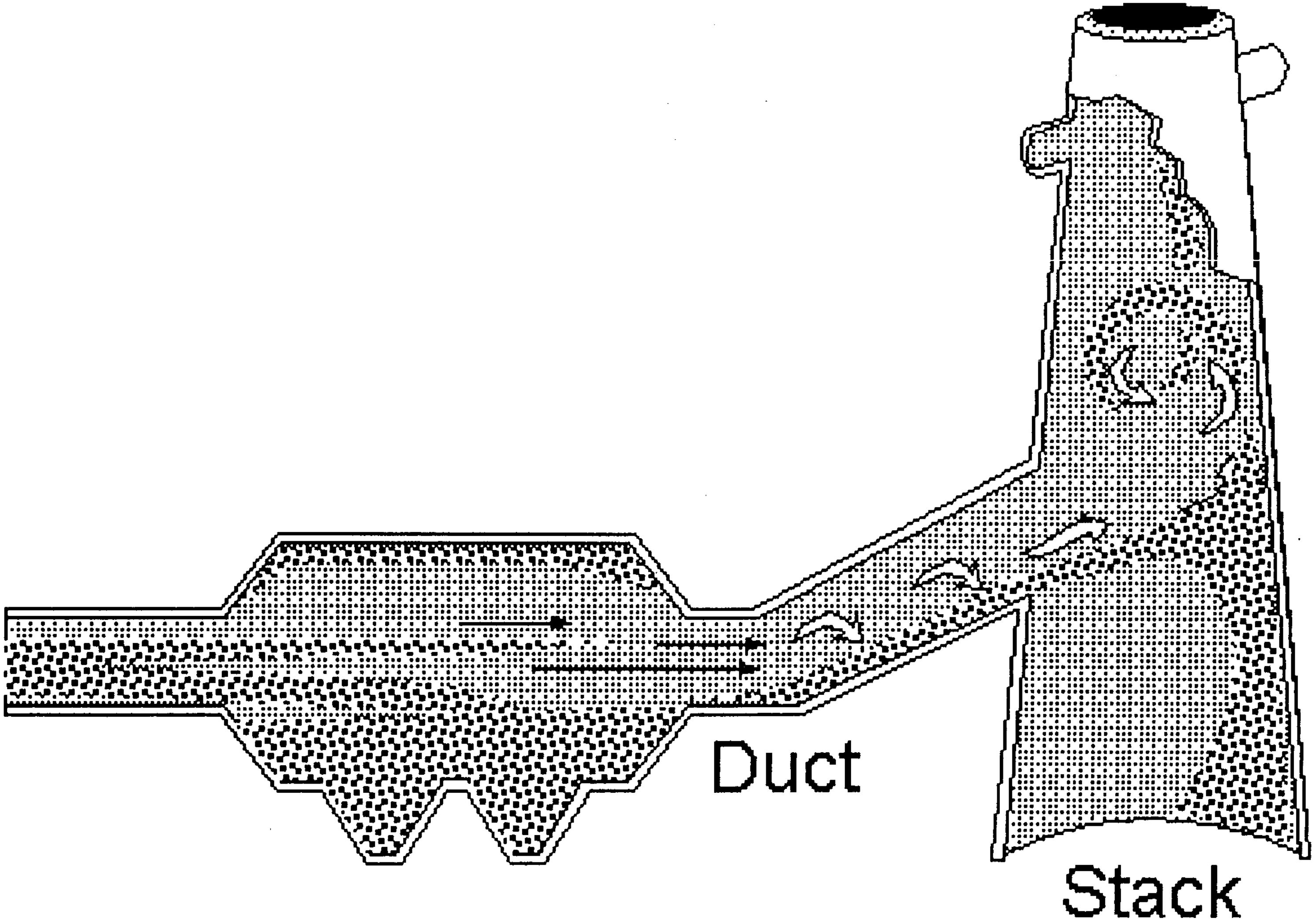
Lesson 7

Course 450

Methods 1-4

Method 1

Sample and Velocity Traverse Points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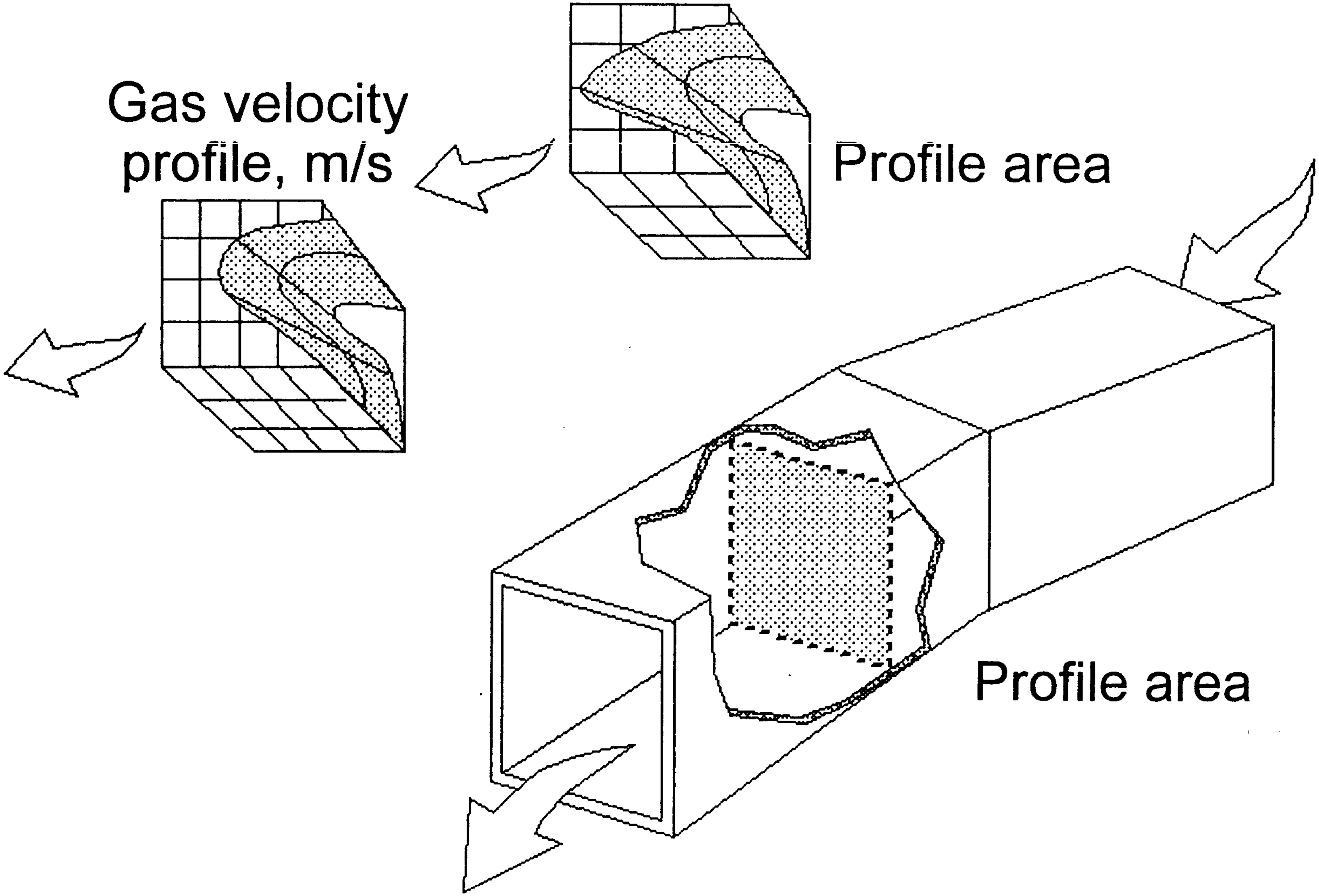
Stack

Particle mass concentration profile, mg/m^3



Source: Adapted from Buhne, 1977

Determining the Number of Traverse Points

Equivalent Diameters

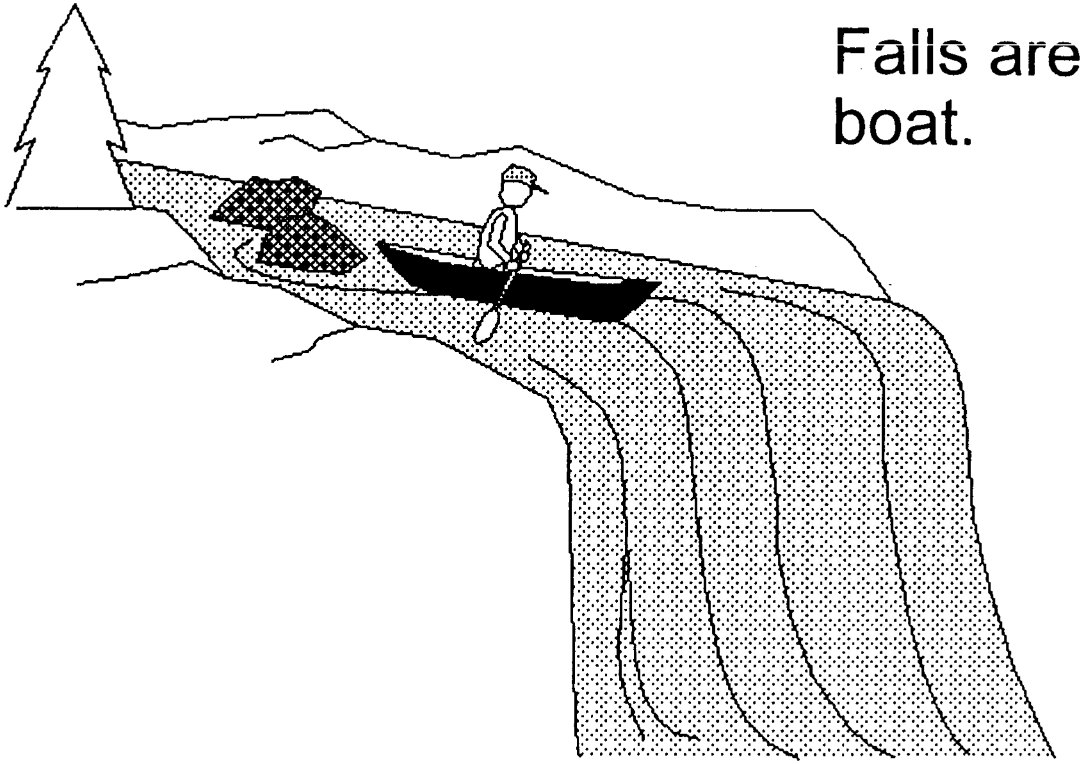
$$D_e = \frac{2\,LW}{(L + W)}$$

Boat is downstream from rocks.

Rocks are upstream from boat.

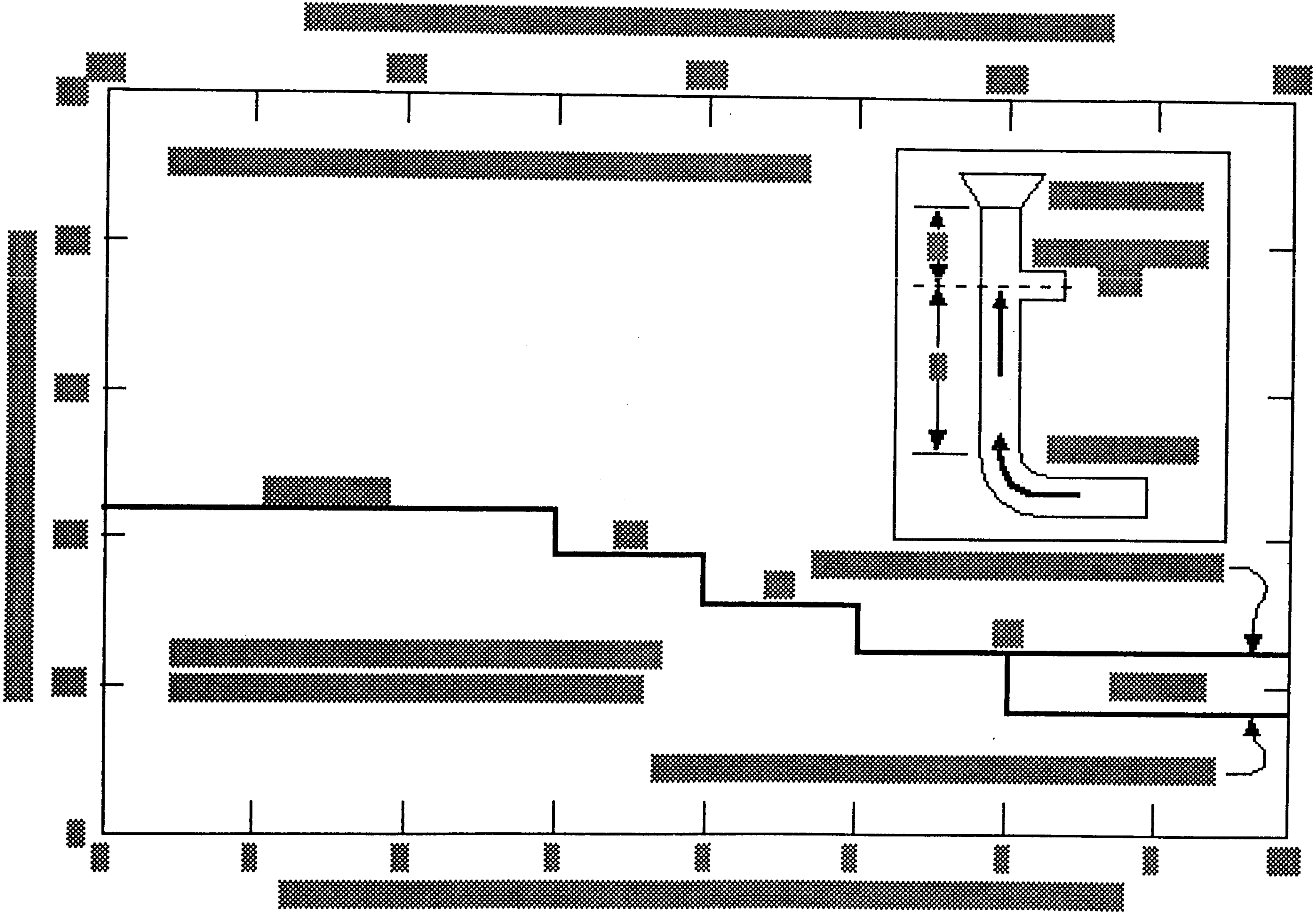
Boat is upstream from falls.

Falls are downstream from boat.



Flow

The position of objects relative to a boat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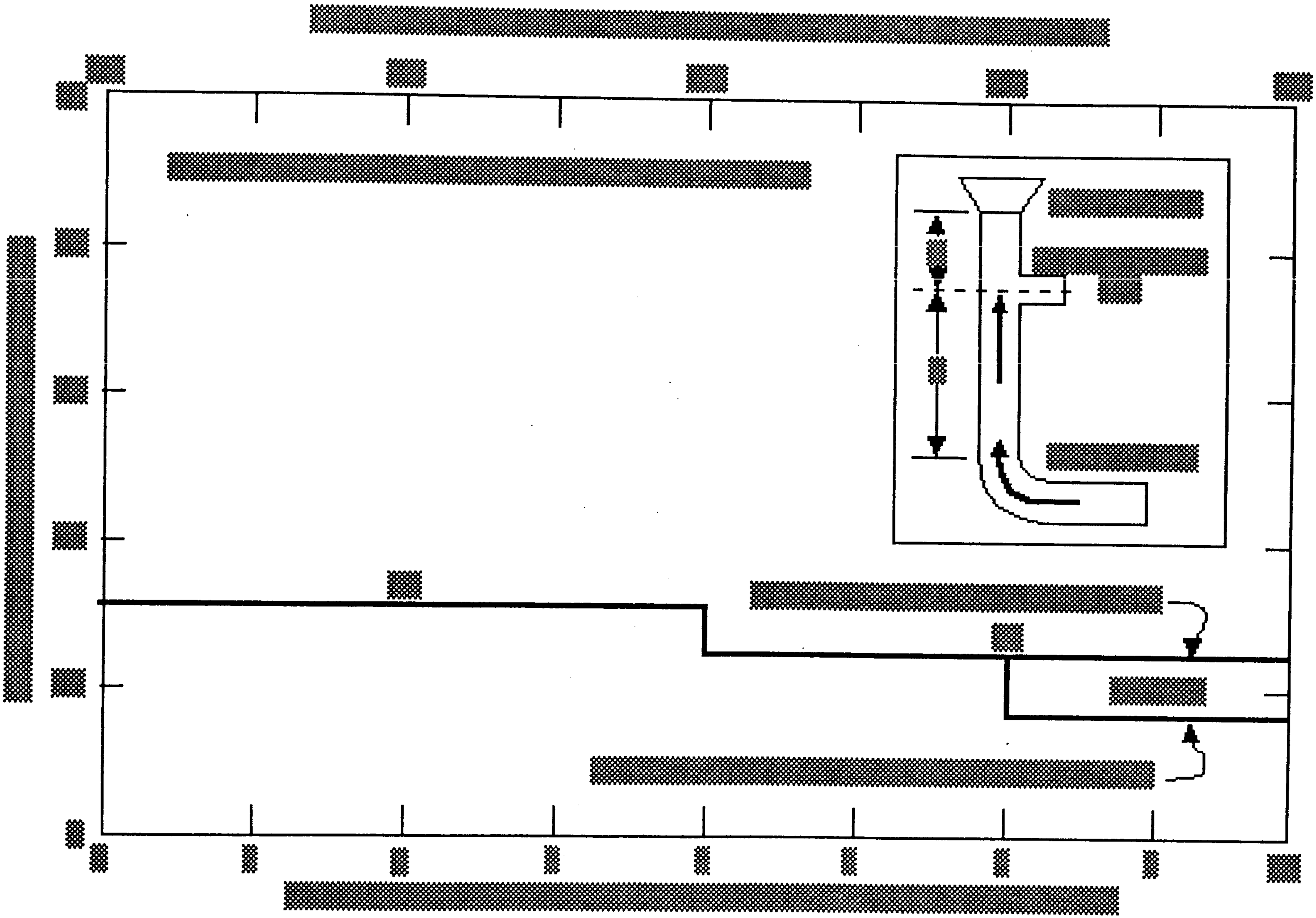

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07-09

Cross-Sectional Layout and Location of Traverse Points

Table 1-1. Cross-Section Layout for Rectangular Stacks

Number of traverse points	Matrix layout
9	3x3
12	4x3
16	4x4
20	5x4
25	5x5
30	6x5
36	6x6
42	7x6
49	7x7

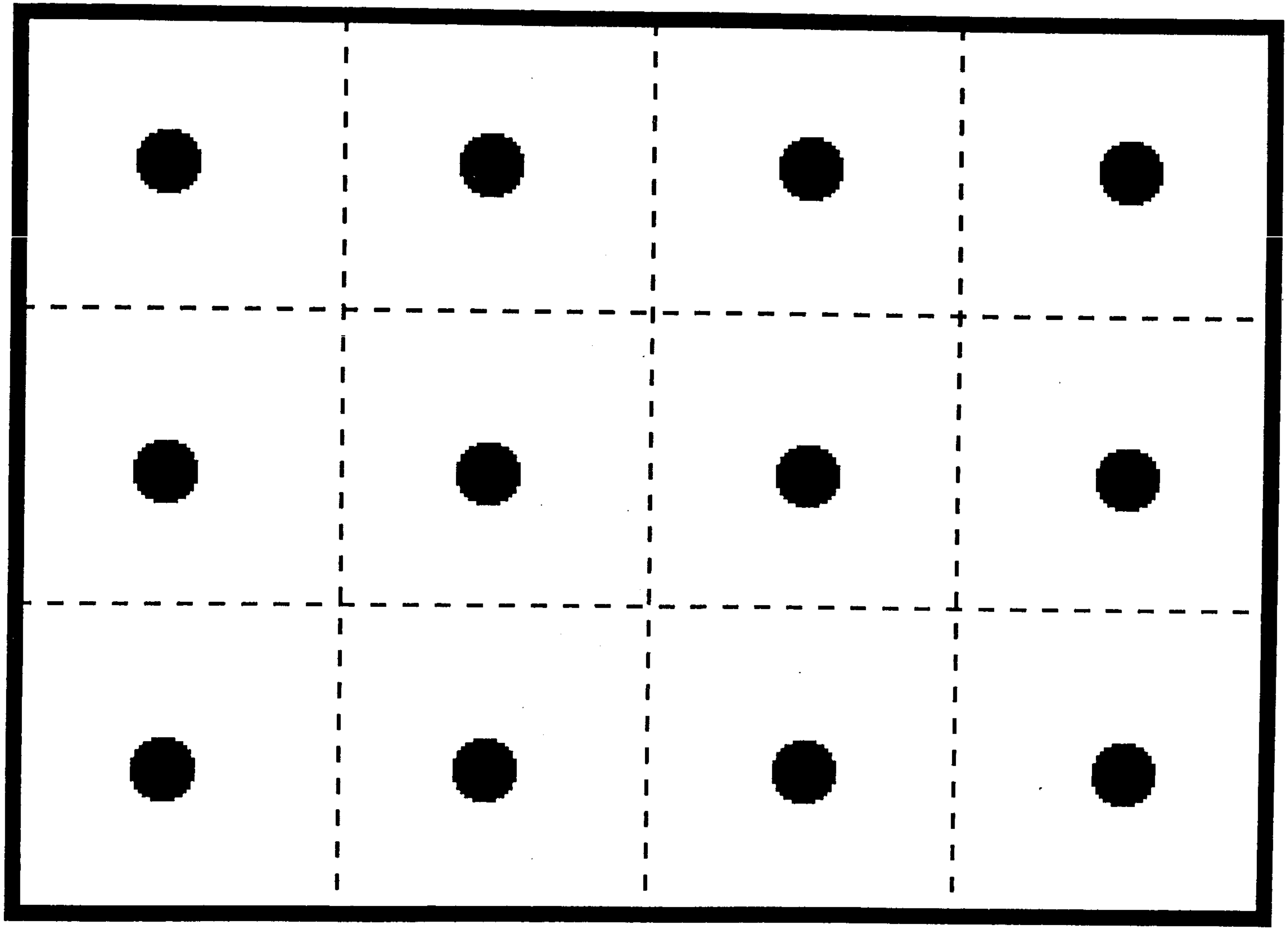

Table 1-2. Location of Traverse Points in Circular Stacks

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Pt. 60, App. Meth. 1

Traverse Point	Distance, % of diameter
1	4.4
2	14.6
3	29.6
4	70.4
5	85.4
6	95.6

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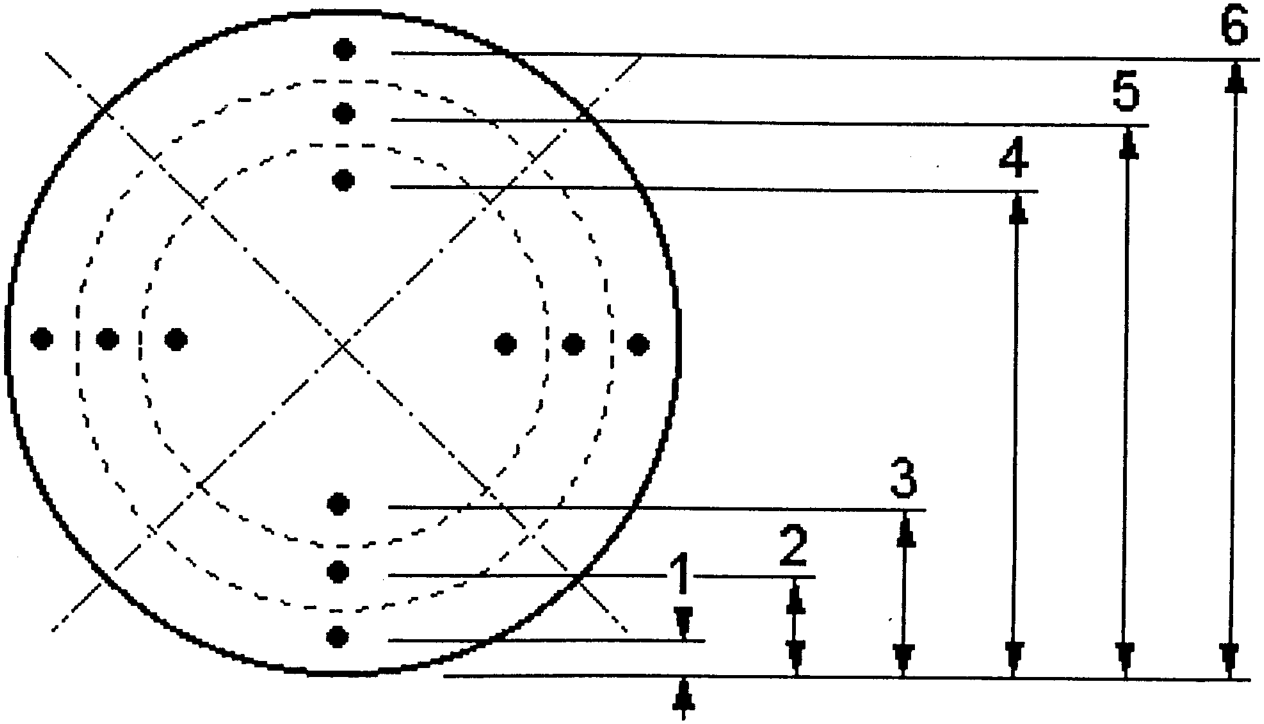
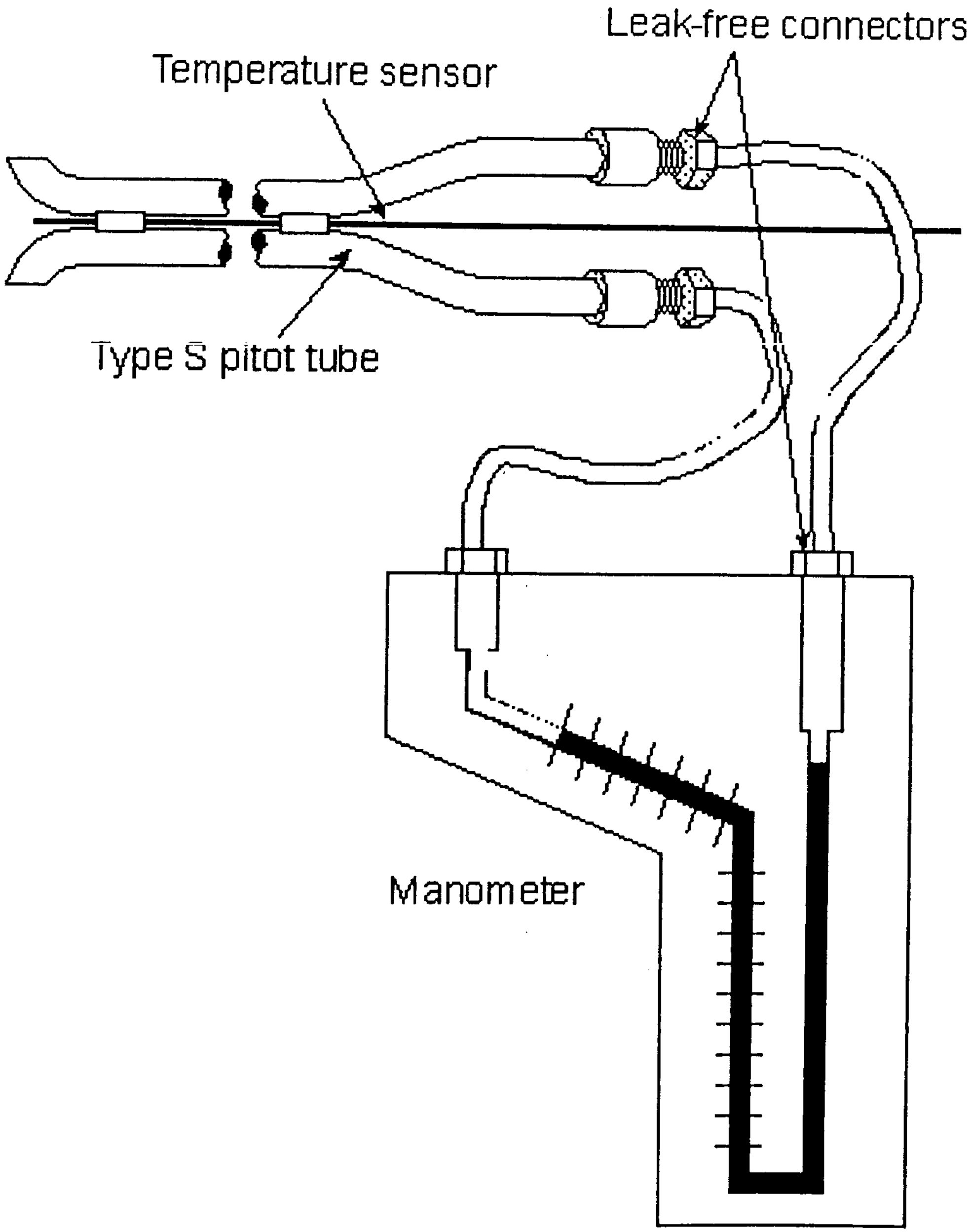


Method 2

Determination of
Stack Gas Velocity
and
Volumetric Flow Rate
(Type S Pitot Tube)


Leak-free connectors
Temperature sensor
Type S pitot tube
Manometer

$$\mathbf{v}_S = \mathbf{K}_p \mathbf{C}_p \sqrt{\frac{\mathbf{T}_s \Delta p}{\mathbf{M}_s \mathbf{P}_s}}$$

Pitot Tube Calibration

Dimensional specification

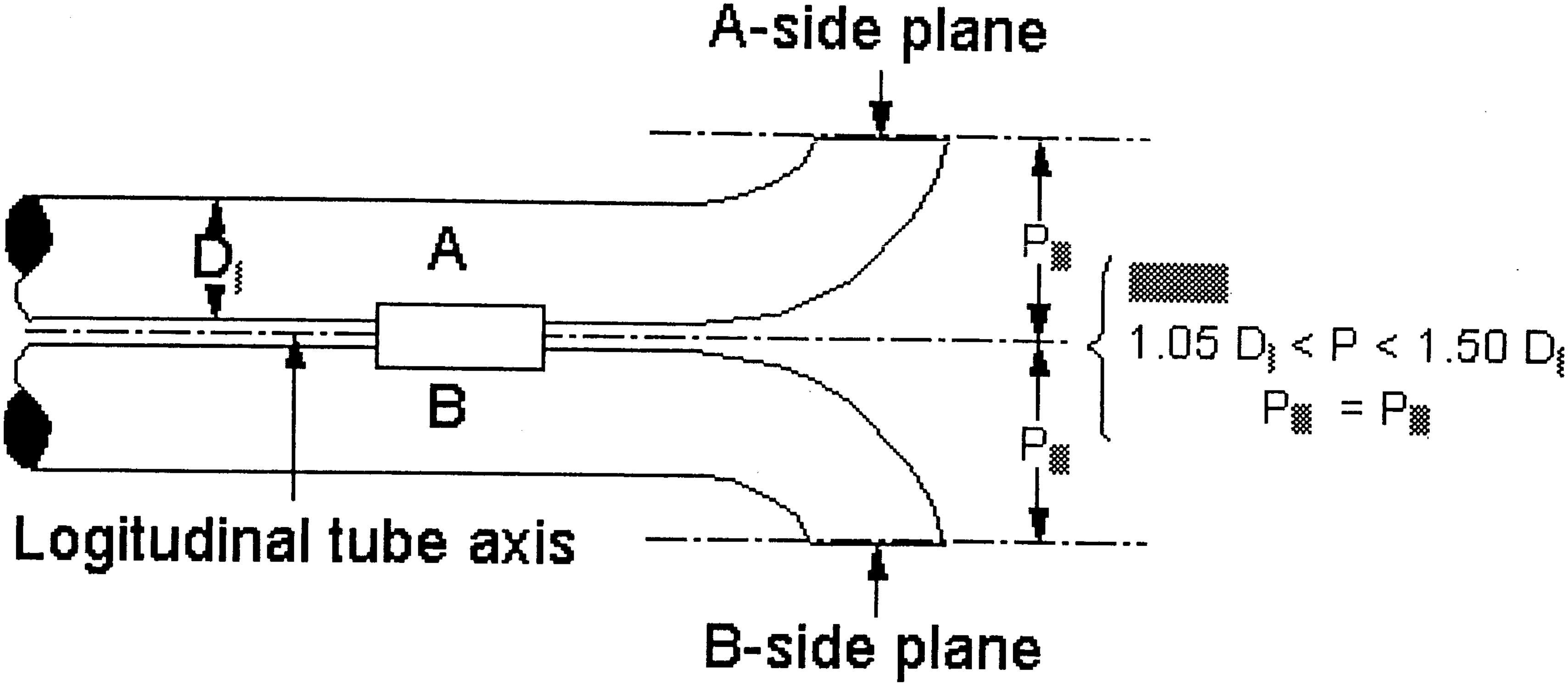
and/or

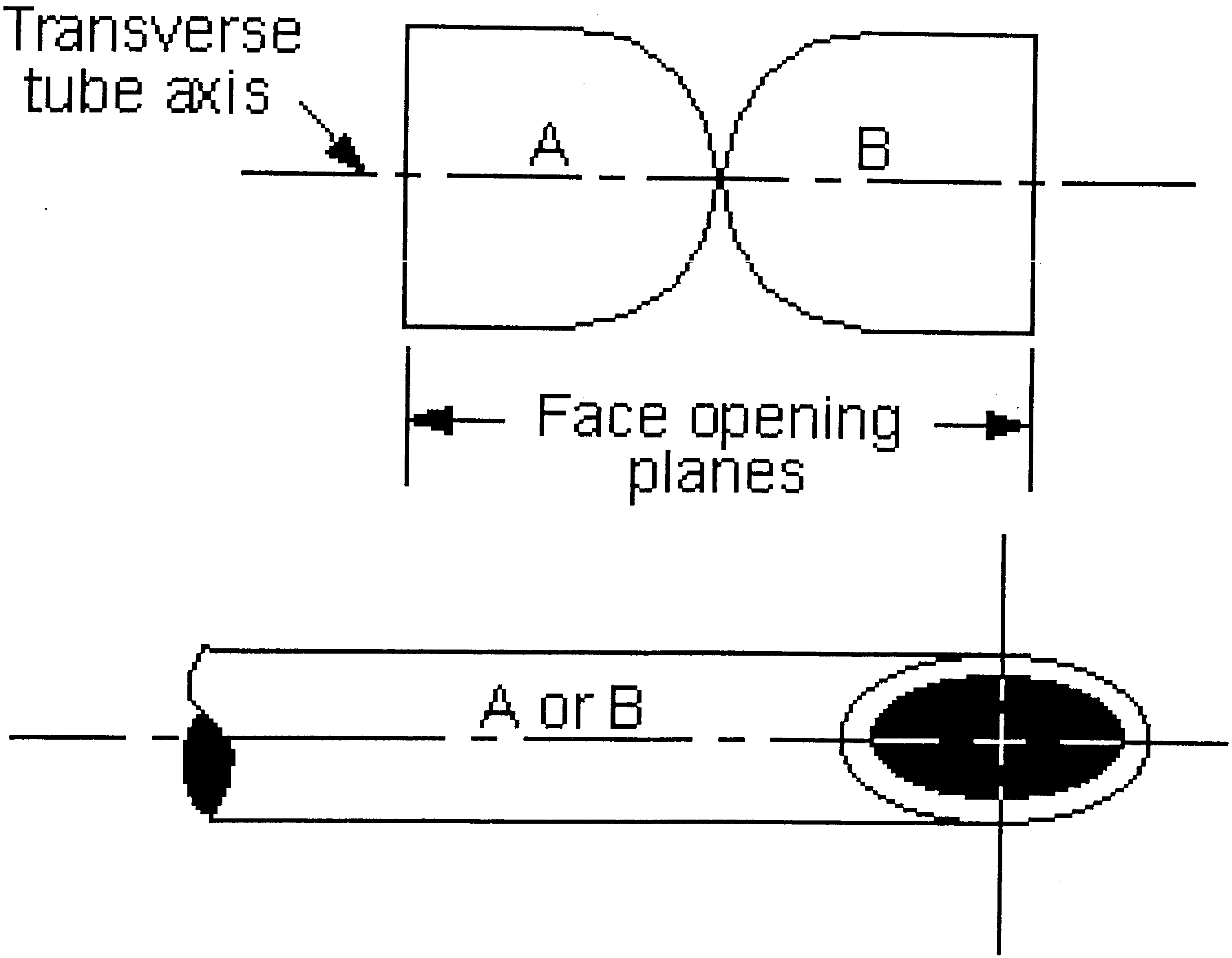
Calibrate in wind tunnel against standard pitot tube, preferably with National Bureau of Standards (NBS) traceable coefficient

Type S Pitot Tube

Design criteria for assigning

$$C_p = 0.84$$


A-side plane
D
A
B
P
P
1.05 D < P < 1.50 D
P = P
Logitudinal tube axis
B-side plane



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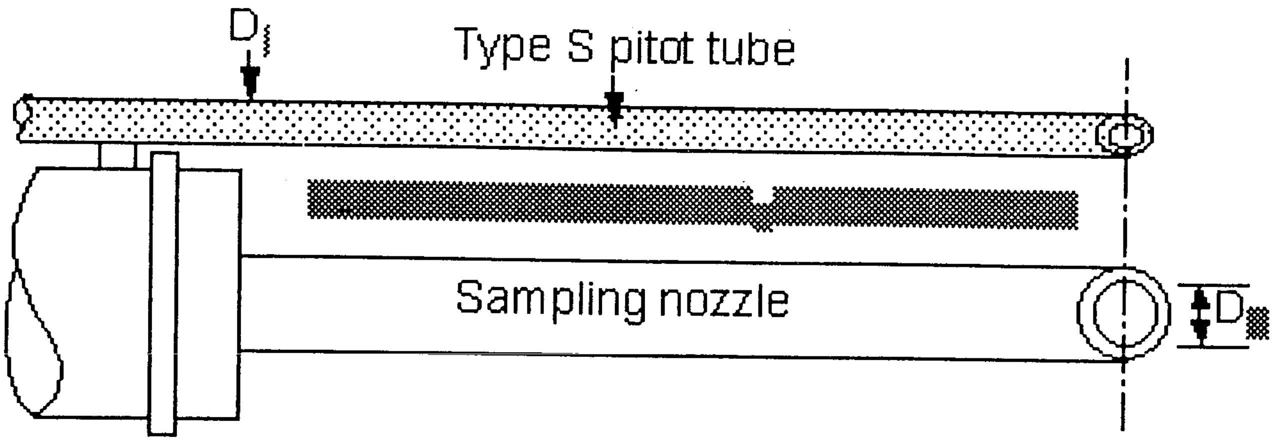
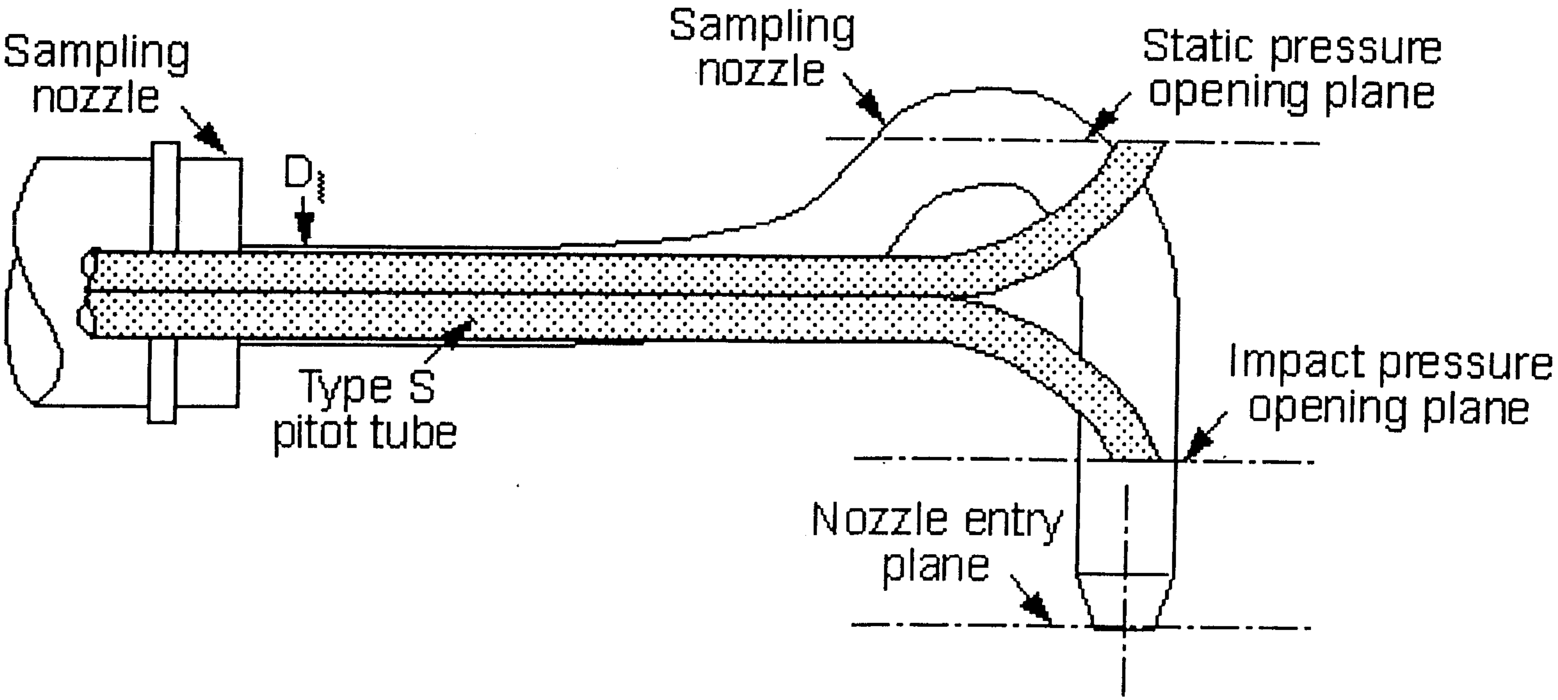
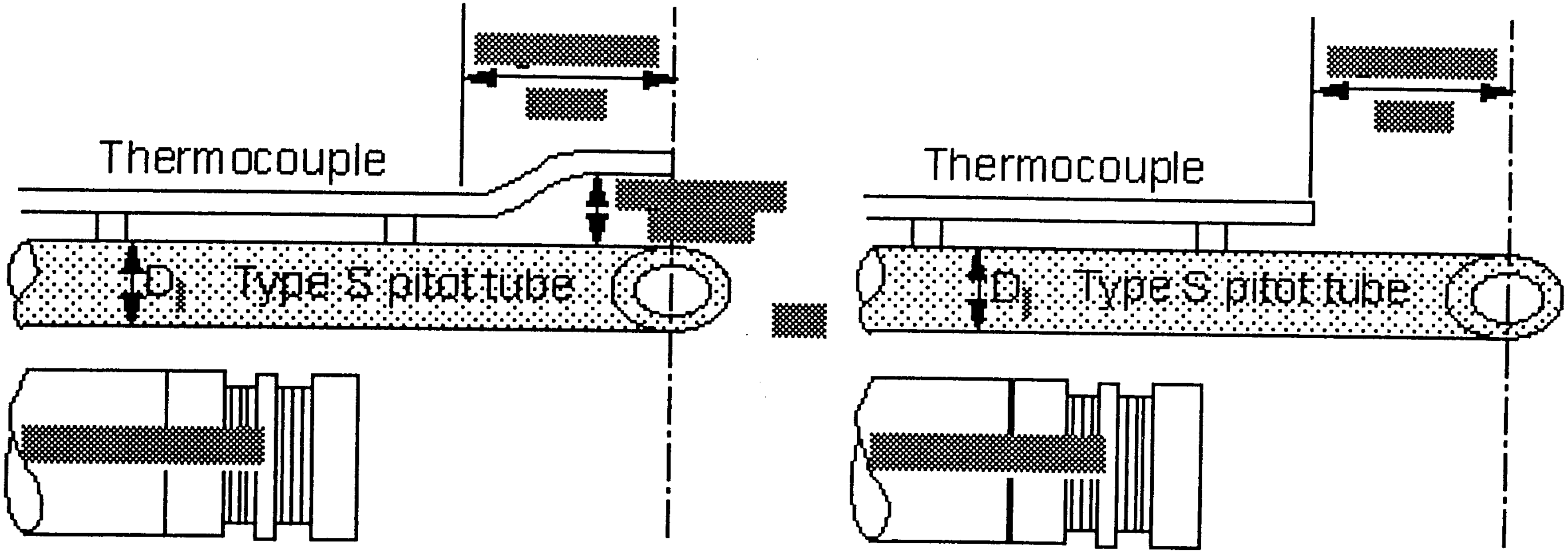
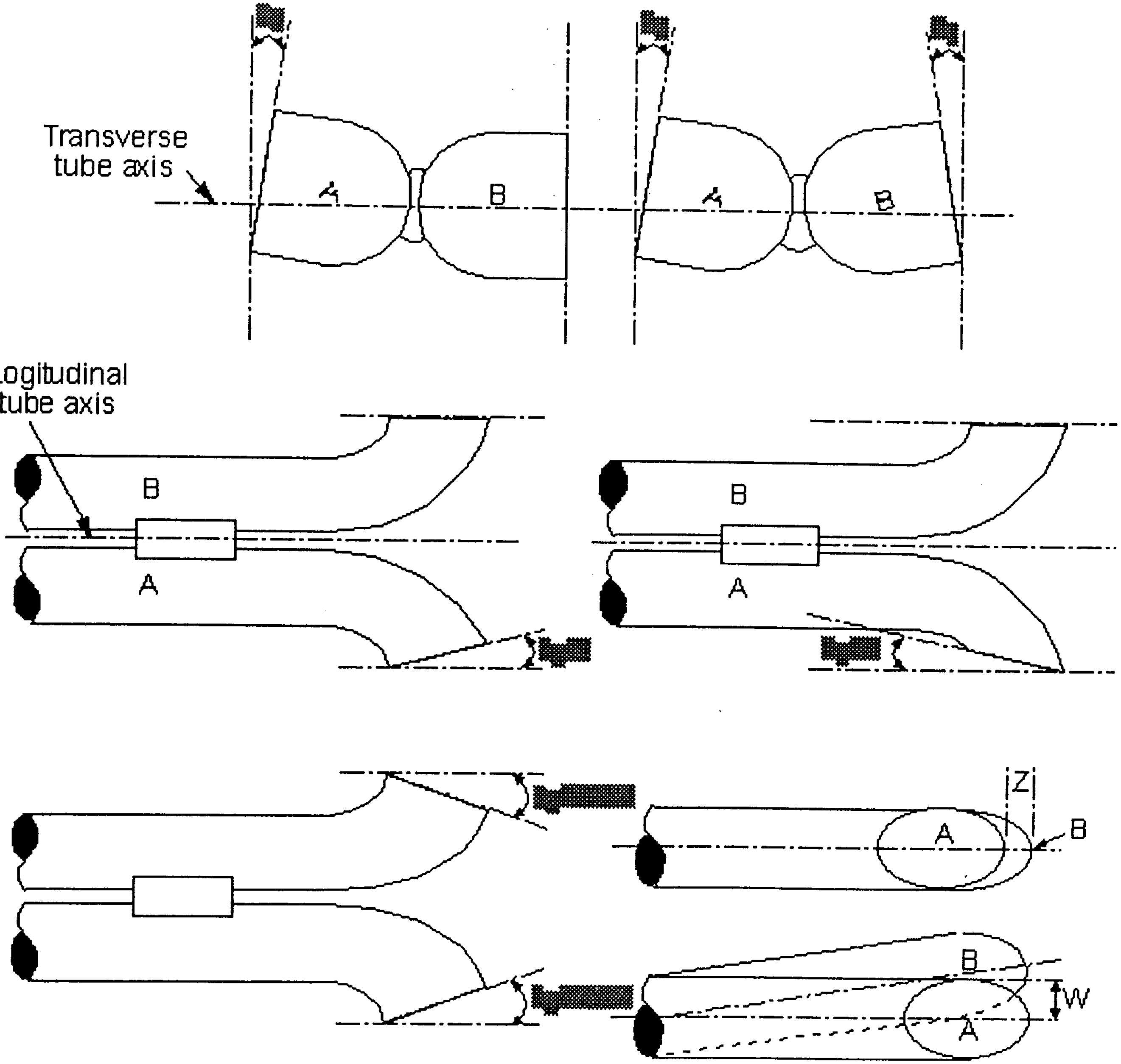
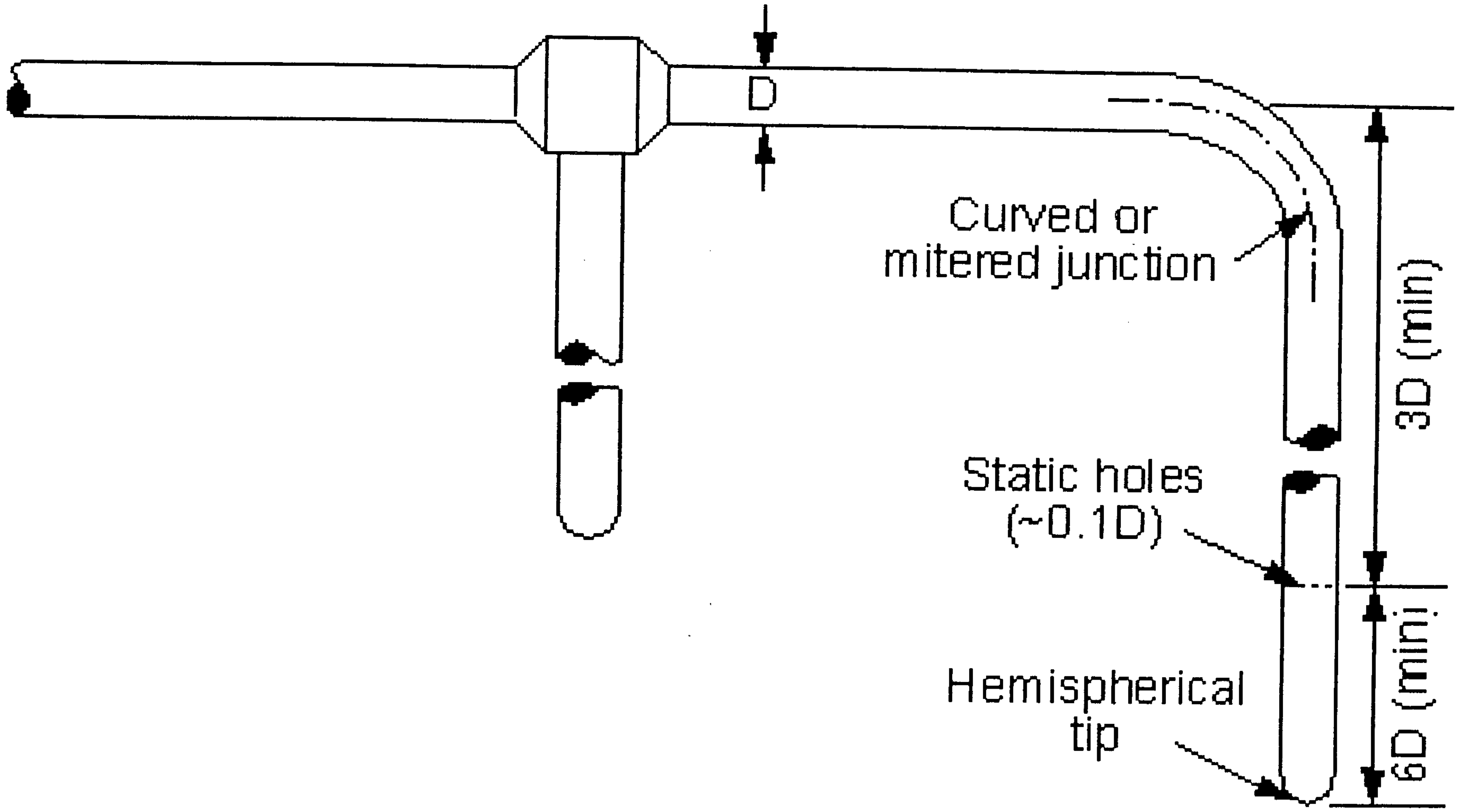

D
Type S pitot tube
Sampling nozzle
D


Sampling nozzle
Sampling nozzle
Static pressure opening plane
D
Type S pitot tube
Impact pressure opening plane
Nozzle entry plane

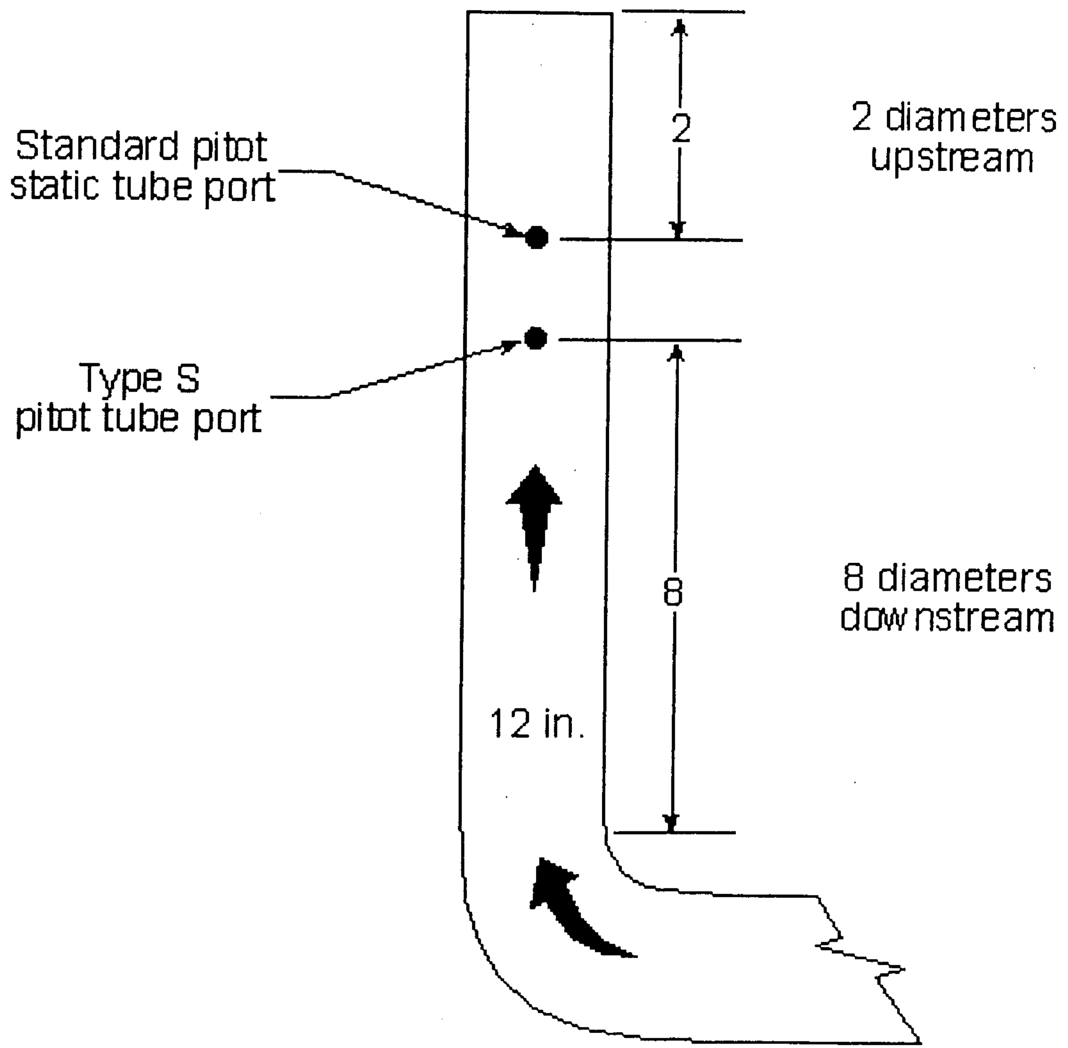

Thermocouple
D_t
Type S pitot tube
Thermocouple
D_t
Type S pitot tube


Transverse
tube axis
A
B
A
B
Logitudinal
tube axis
B
A
B
A
Z
A
B
B
W
A

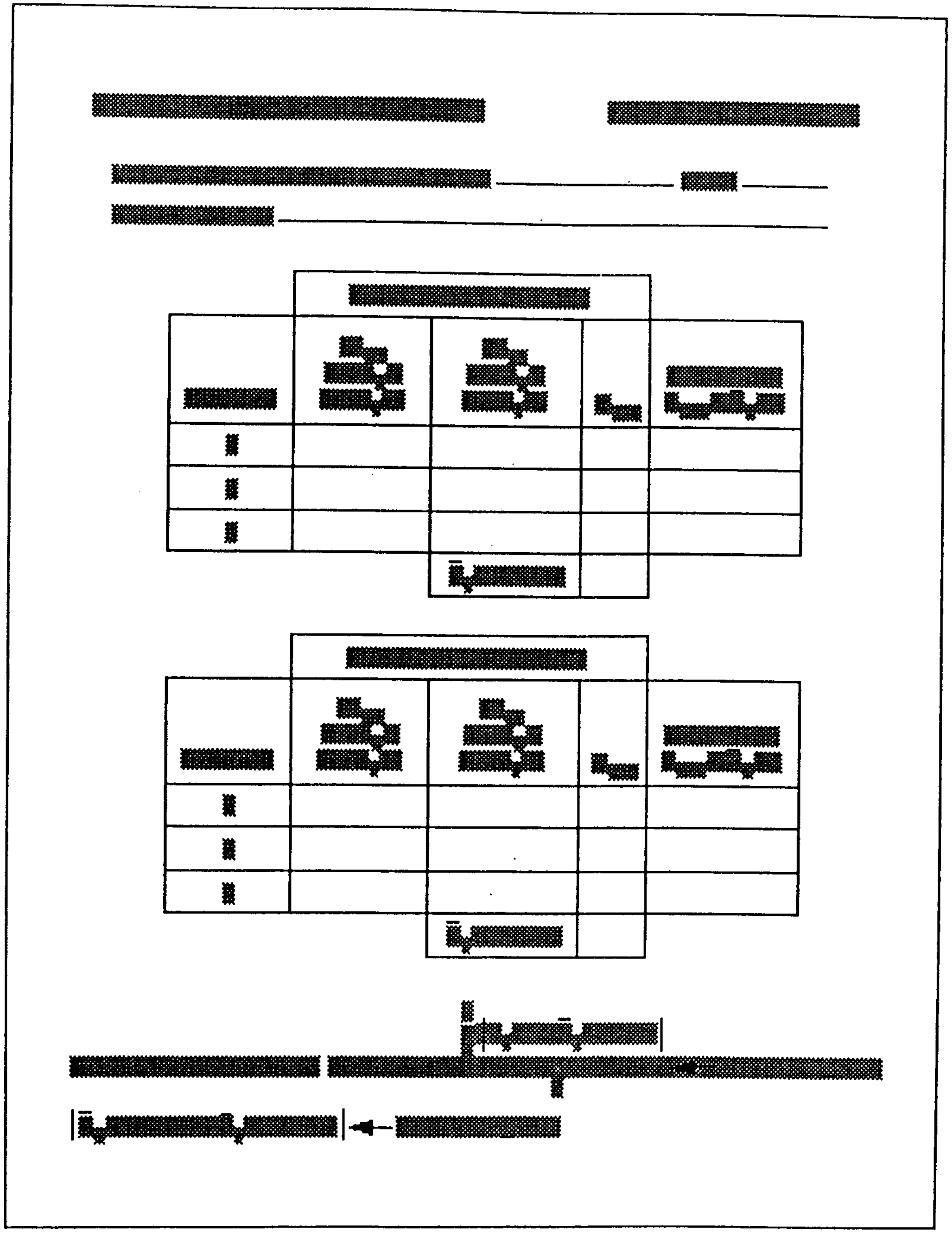
Type S Pitot Tube Calibration Using a Standard Pitot Tube and Wind Tunnel


D
Curved or mitered junction
Static holes (~0.1D)
Hemispherical tip
3D (min)
6D (min)

Calibration Duct



$$C_{p(s)} = \left[\frac{\Delta p_{std}}{\Delta p_s} \right]^{1/2} C_{p(std)}$$



Velocity Measurement Procedures

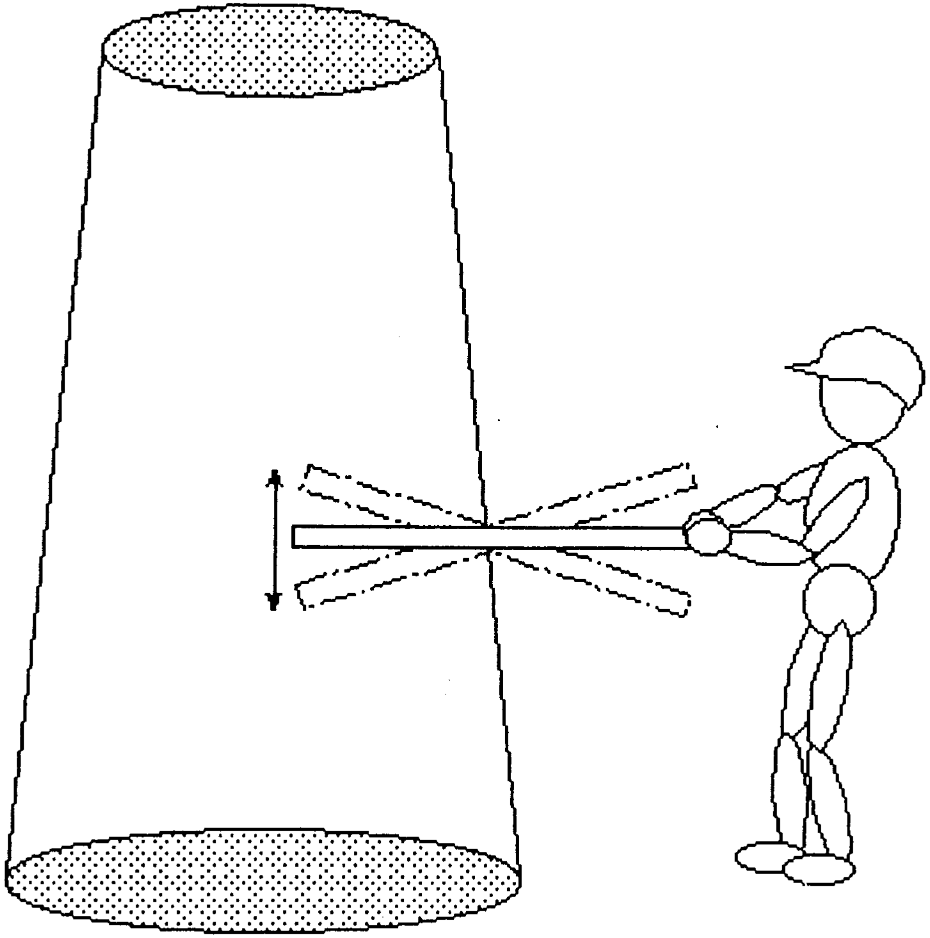
1. Leak-check pitot tube and differential pressure gauge.
2. For circular stacks less than 10 ft in diameter, two ports are sufficient. Use four ports when stack diameter is greater than 10 ft.
3. Pitot tubes longer than 10 ft should be structurally reinforced to prevent bending of tube and misalignment errors.
4. Identify each sample port and traverse point with a letter or number.
5. Read velocity head and temperature at least twice at each point and record the average.

Velocity Measurement Procedures

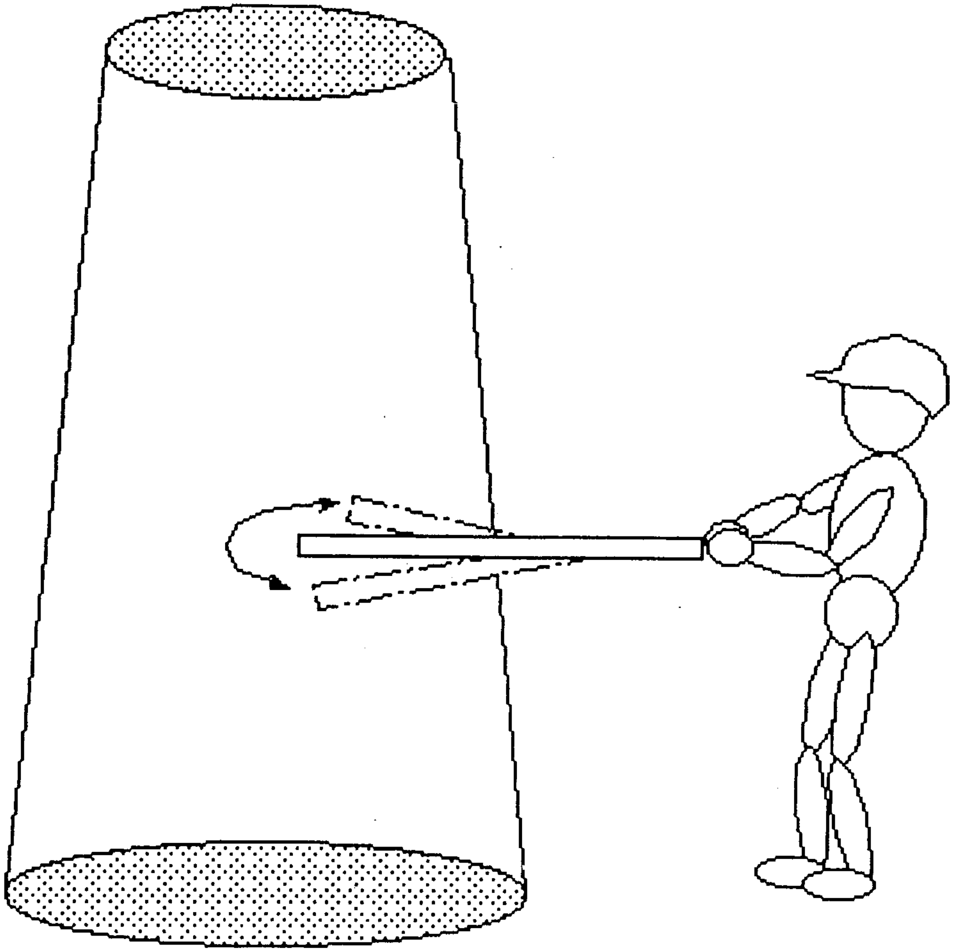
(cont.)

6. Care should be taken to prevent touching the pitot tube tip to the side of the stack.
7. Plug unused sampling ports and seal port being used as tightly as possible.
8. After traverse, check differential pressure gauge zero; repeat traverse if zero has shifted.
9. If liquid droplets are present, use a liquid trap in positive pressure leg of pitot tube.
10. A post-test leak check is required after each run of the pitot tube and velocity pressure system.

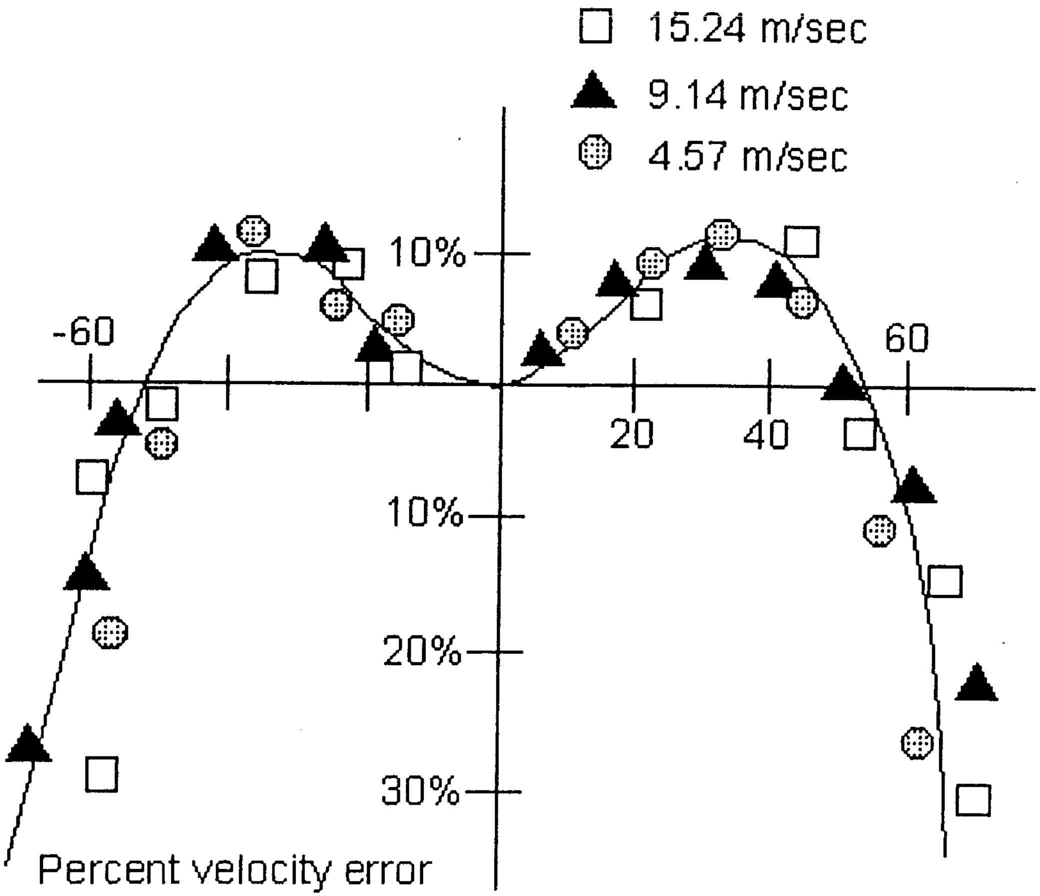
Pitch Angle

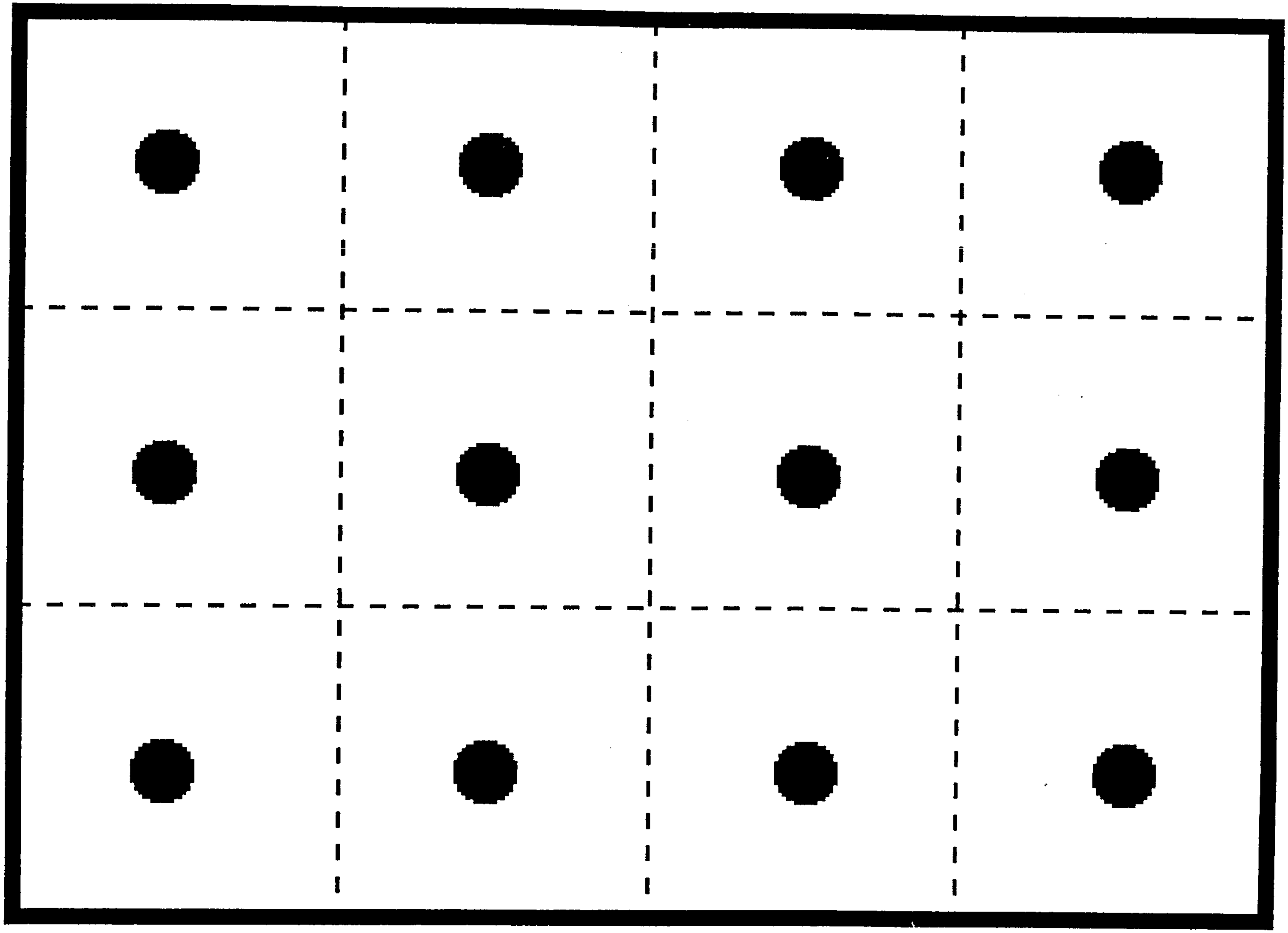


Yaw Angle



Velocity Error vs. Yaw Angle for a Type S Pitot Tube





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Average Velocity over the Cross-Section

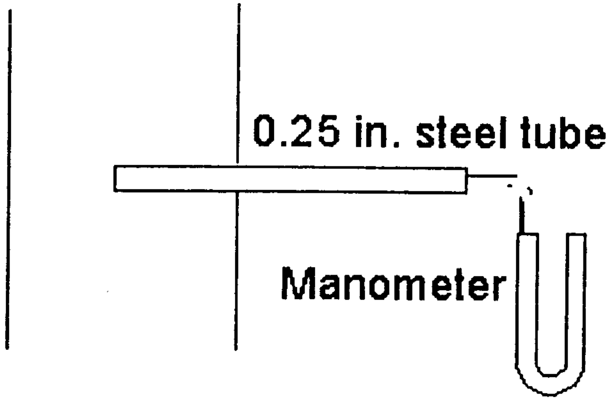
$$\bar{v}_s = K_p C_p \left(\sqrt{\Delta p}\right)_{avg} \sqrt{\frac{T_{s(avg)}}{M_s P_s}}$$

Average Stack Gas Dry Volumetric Flow Rate

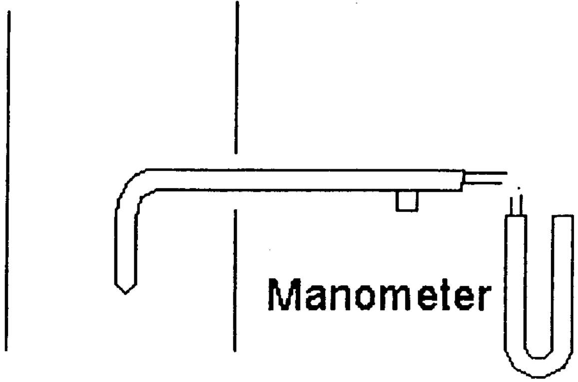
$$Q_{std} = 3600 \left(1 - B_{ws(avg)}\right) v_{s(avg)} A \frac{T_{std}}{T_{s(avg)}} \frac{P_s}{P_{std}}$$

Static Pressure Measurement (pg)

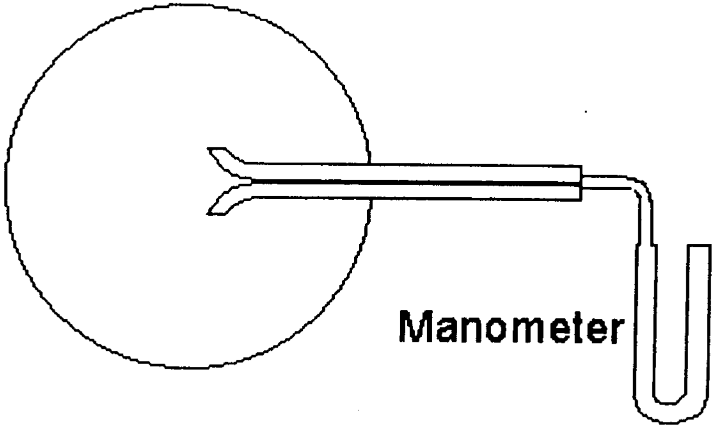
Pressure probe and gauge



Standard pitot tube



Type S pitot tube



$$P_s = P_b + \frac{p_g}{13.6}$$

Barometric Pressure

Barometric pressure during testing is obtained by:

Instrument

- Mercury, aneroid or other barometer (with required sensitivity)

Other

- Obtain barometric pressure from nearby National Weather Service station (station pressure) and adjust for elevation differences between sampling site and weather station.

  Note: The station pressure must be used not the pressure corrected to sea level.

Pressure Probe and Gauge

Static pressure measurement must be accurate to within 1 in. Hg (13.6 in. H_2O).

Pressure sensors typically used to measure static pressure during testing include:

- A piezometer tube and mercury or water-filled U-tube manometer
- The static tap of a pitot tube
- One leg of the Type S pitot tube

Applicability

Method 2 is applicable only at sites that:

- Meet the criteria of Method 1
- Do not contain cyclonic or non-parallel flow

Alternatives When Unacceptable Conditions Exist

(Subject to approval of the Administrator)

- Install straightening vanes.
- Calculate total volumetric flow rate stoichiometrically.
- Move to a measurement site at which flow is acceptable.
- Use procedures as described in Method 2 for cyclonic flow.

Method 3

Gas Analysis for Determination of Dry Molecular Weight

Principle

A gas sample is collected by one of the following methods:

- Single-point grab sampling
- Single-point integrated sampling
- Multi-point integrated sampling

Principle

The sample is analyzed for the following components:

- Carbon dioxide (CO_2)
- Oxygen (O_2)
- Carbon monoxide (CO)(if necessary)

Applicability

For determining dry molecular weight and excess air correction factor from fossil-fuel combustion sources

Sampling Procedures

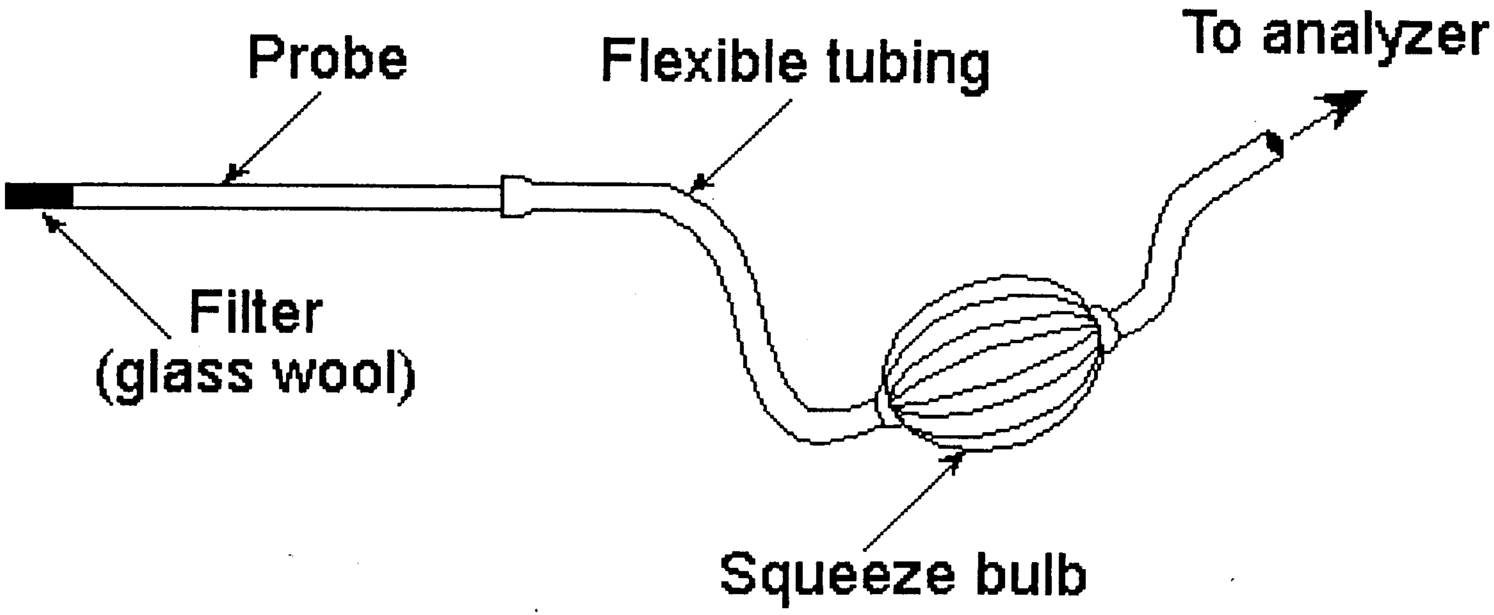
- Single-point grab
- Single-point integrated
- Multi-point integrated

Analytical Procedures

- Orsat (Method 3)
- Automated (Method 3A)

Sampling Methods

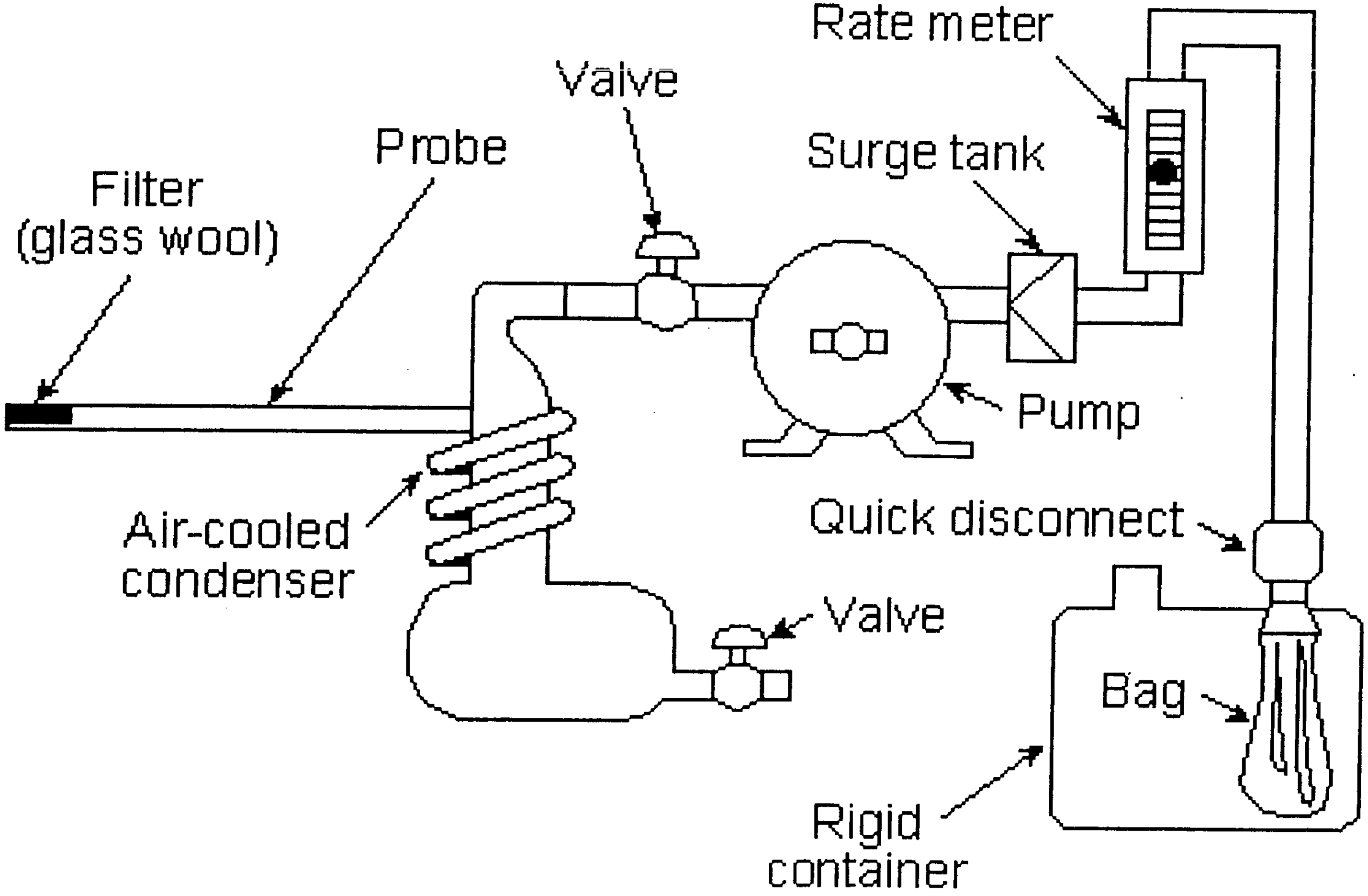
Grab-Sampling Train



Single-Point Grab Sampling

1. Sample point should be a centroid of the cross-section or at a point at least 1 m from the wall of a large stack.
2. Place probe securely in stack and seal sampling port to prevent dilution of stack gas.
3. Purge sample line and attach to analyzer.
4. Aspirate sample into analyzer.

Integrated Gas Sampling Train



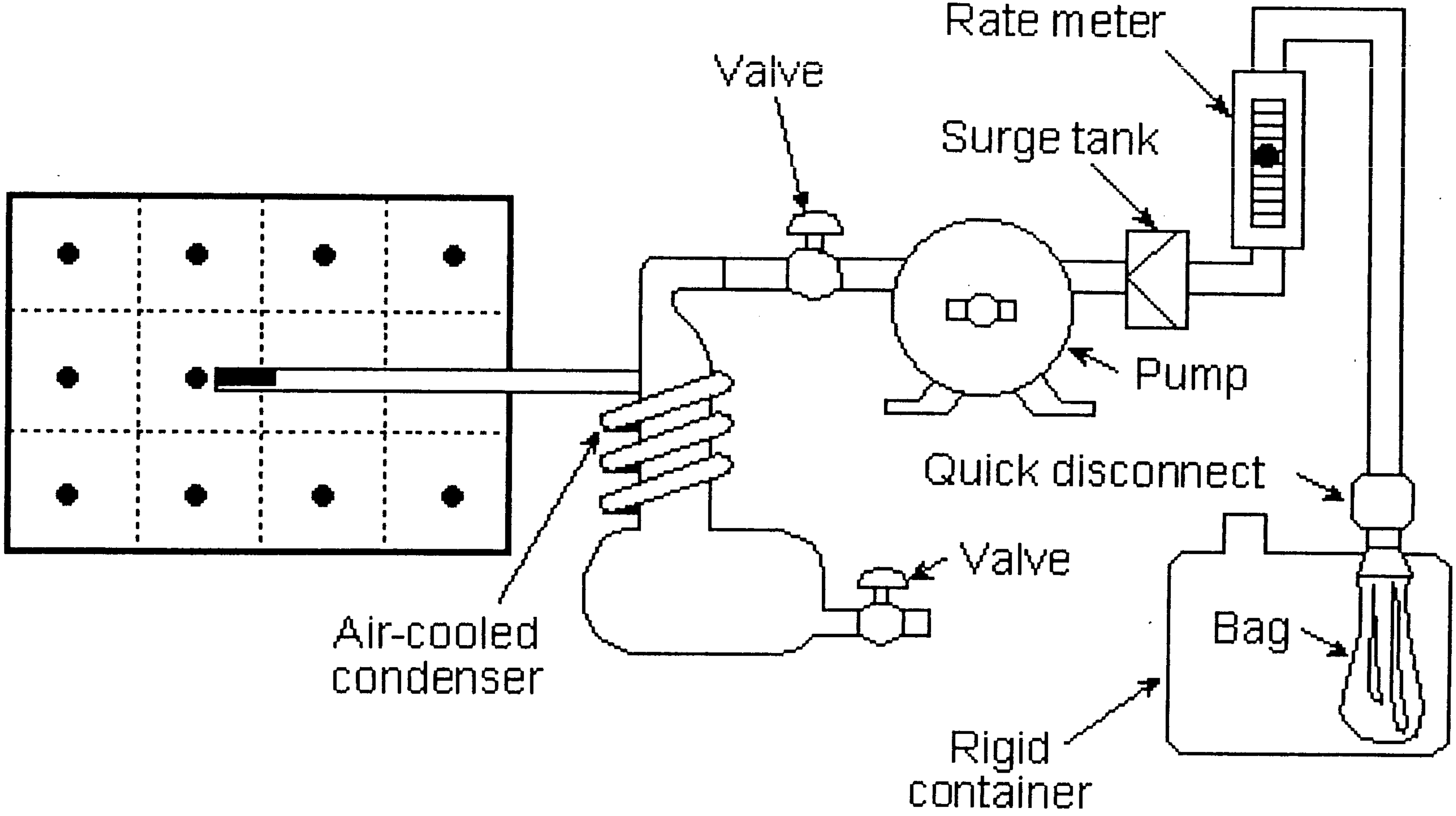
Single-Point Integrated Sampling

1. Sample point and probe placement is same as for single-point grab sampling.
2. Leak-check the flexible bag.
3. Leak-check the sampling train.
4. Connect probe to train and purge the system.
5. Connect evacuated flexible bag and begin sampling.
6. Sample at constant rate; collect 30 to 90 L of gas simultaneous with pollutant emission test.

Multi-Point Integrated Sampling

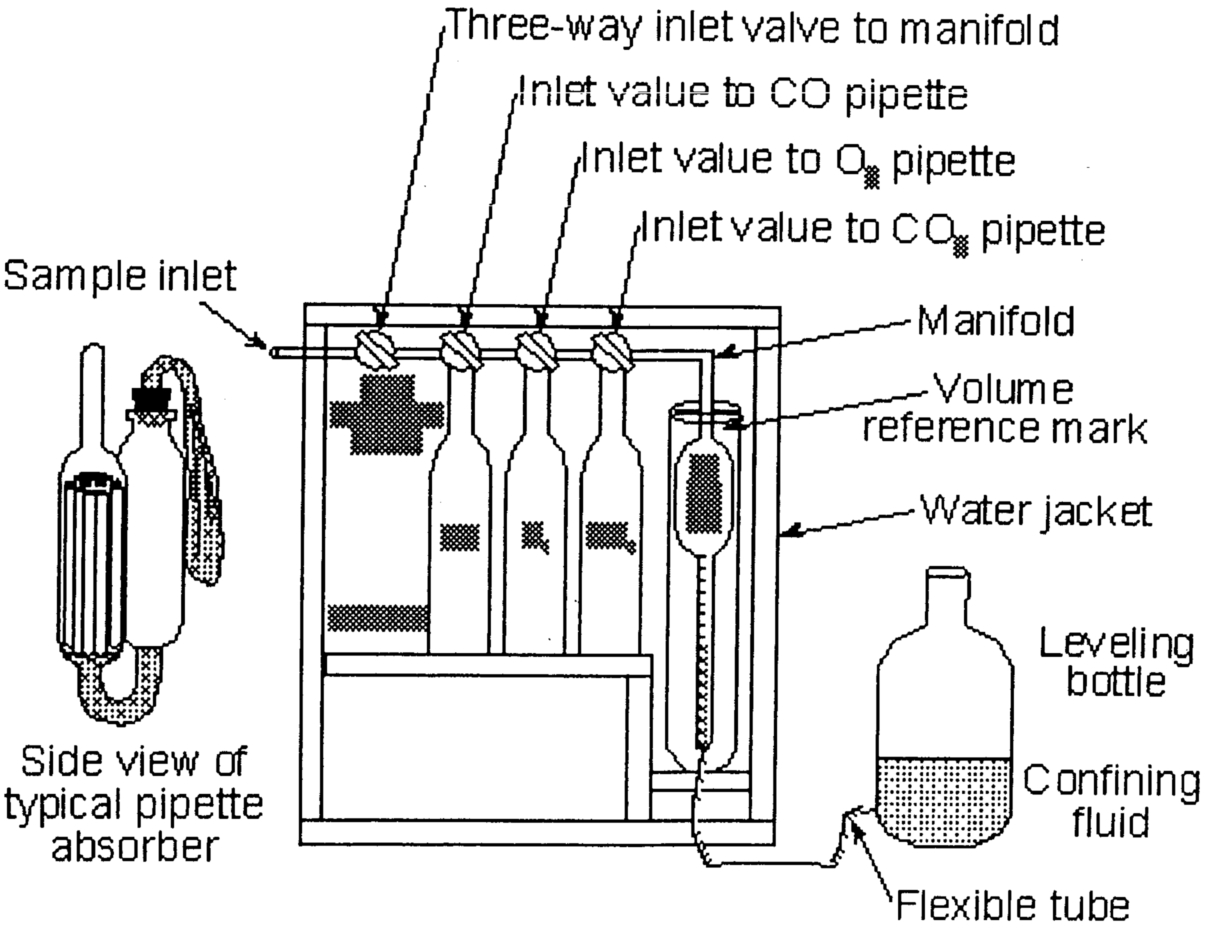
1. This procedure uses same sampling train and equipment preparation as the single-point integrated sampling method.
2. Locate sampling points according to Method 1.
3. Sample each point at the same rate and for the same time increment.
4. Collect 30 to 90 L of gas simultaneous with pollutant emission test.

Multi-Point Integrated Sampling



Analysis

Orsat Analyzer



Orsat Analyzer Reagents

Gas Confining Solution

A solution containing sodium sulfate, sulfuric acid and methyl orange

Carbon Dioxide Absorbent

A solution of potassium or sodium hydroxide

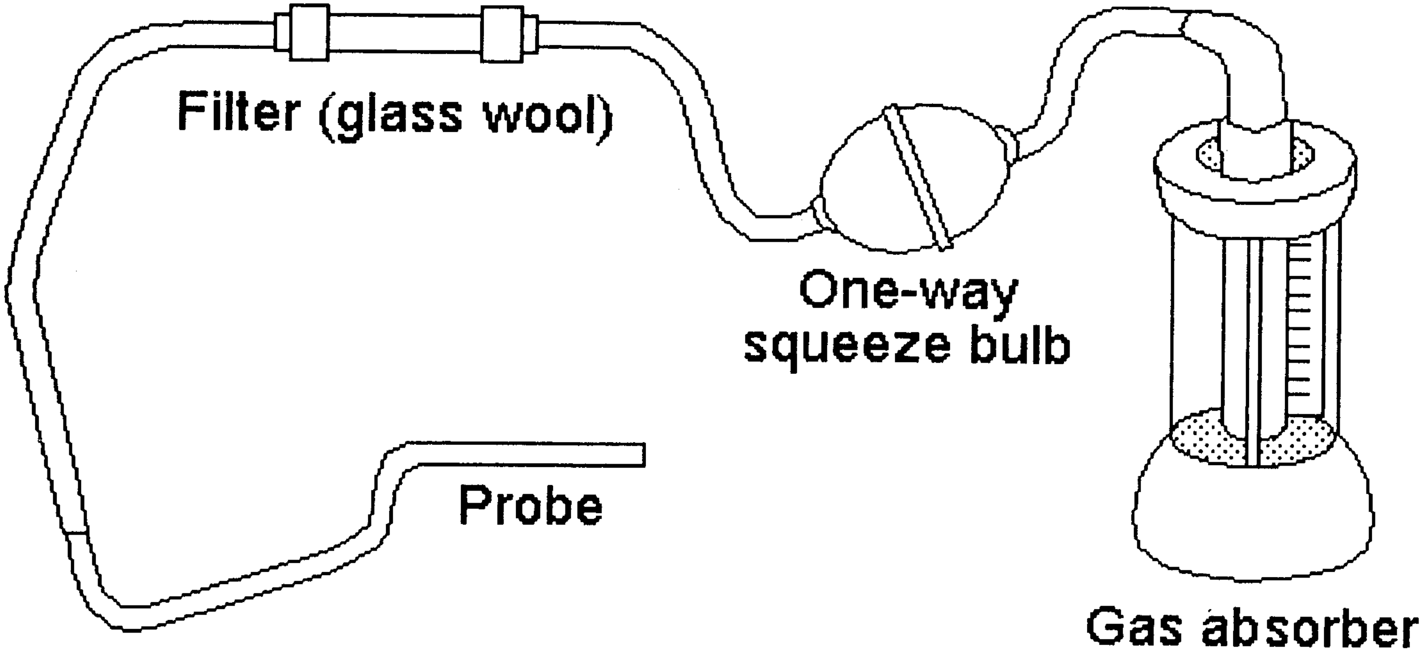
Oxygen Absorbent

A solution of alkaline pyrogallic acid or chromous chloride

Carbon Monoxide Absorbent

A solution of cuprous chloride or a sulfate solution

Fyrite Analyzer



Dry Molecular Weight Equation

$$M_d = 0.44(\%CO_2) + 0.32(\%O_2) + 0.28(\%N_2 + \%CO)$$

Where: M_d = dry molecular weight
$\%CO_2$ = percent CO_2 by volume (dry basis)
$\%O_2$ = percent O_2 by volume (dry basis)
$\%CO$ = percent CO by volume (dry basis)
$\%N_2$ = percent N_2 by volume (dry basis)
0.44 = molecular weight of CO_2 divided by 100
0.32 = molecular weight of O_2 divided by 100
0.28 = molecular weight of N_2 divided by 100
0.28 = molecular weight of CO divided by 100

Method 3A

Determination of O_2 and CO_2 Concentrations in Emissions from Stationary Sources

(Instrumental Analyzer Procedure)

Applicability

For the determination of O_2 and CO_2 only when specified within the regulations

Principle

A sample is continuously extracted from the effluent stream. A portion of the sample stream is sent to an instrumental analyzer(s) for the determination of O_2 and CO_2 concentrations.

Analyzer Operating Principles

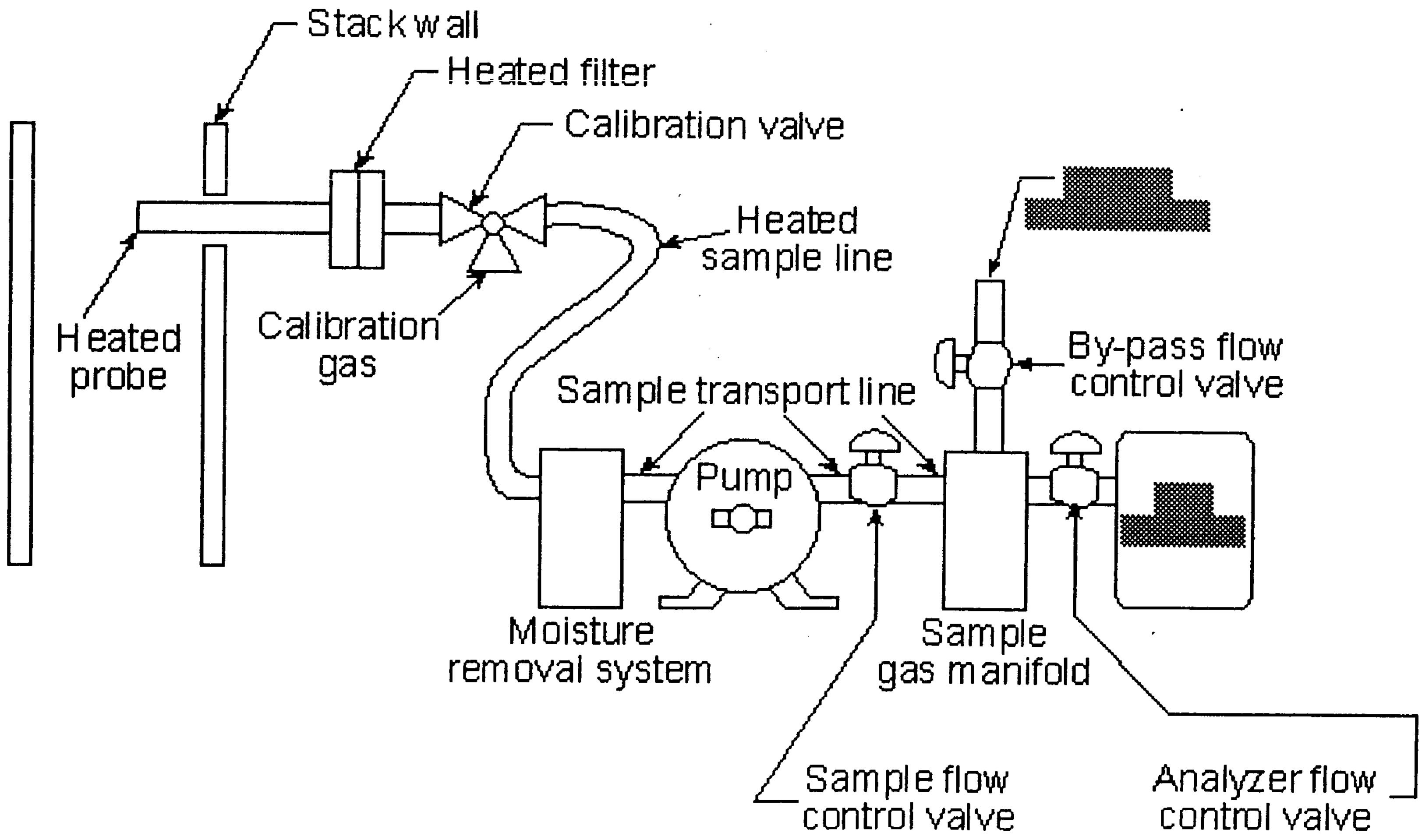
CO_2 Analyzers

- Nondispersive infra-red
- Polarography

O_2 Analyzers

- Paramagnetism
- Polarography
- Electrocatalysis

Measurement System Schematic



Performance Test Procedures

- Calibration error check
- Sampling system bias check
- Interference response check

Performance Test Criteria

Calibration Error -

- < ± 2% of span for zero, mid, high range gases
- (0) (40-60) (80-100) % of span

Sampling System

Bias Check -

- < ± 5% of span for zero and high range gases

Performance Test Criteria

Interference Response

< ± 2% of span

For CO @ 500 ppm
SO_2 @ 200 ppm
CO_2 @ 10%
O_2 @ 20.9%

Method 3A

Test Procedure

- Sample collection
- Zero and calibration drift test

Method 3B

Gas Analysis for the Determination of Emission Rate Correction Factor or Excess Air Using the Orast Analyzer

Applicability

For determining CO_2, O_2, and CO from a gas stream from a fossil-fuel combustion process

The Fuel Factor

$$F_o = \frac{20.9 - \%O_2}{\%CO_2}$$

$F_{▒}$ Acceptable Ranges

Fuel Type	$F_{▒}$ range
Coal:	
Anthracite and lignite	1.016 - 1.130
Bituminous	1.083 - 1.230
Oil:	
Distillate	1.260 - 1.413
Residual	1.210 - 1.370
Gas:	
Natural	1.600 - 1.836
Propane	1.434 - 1.588
Butane	1.405 - 1.553
Wood	1.000 - 1.120
Wood bark	1.003 - 1.130

Percent Excess Air Equation

$$\%EA = \left[\frac{\%O_2 - 0.5\%CO}{0.264\%N_2 - (\%O_2 - 0.5\%CO)} \right] 100$$

Where: $\%EA$ = percent excessive air

$\%O_2$ = percent O_2 by volume (dry basis)

$\%CO$ = percent CO by volume (dry basis)

$\%N_2$ = percent N_2 by volume (dry basis)

0.264 = ratio of O_2 to N_2 in air, V/V

Method 4

Determination of Moisture Content in Stack Gases

Principle

A sample is extracted at a constant rate. Moisture is removed and determined volumetrically or gravimetrically.

Applicability

For determining moisture content of stack gas.

Approximation Methods

Used to estimate percent moisture to aid in setting isokinetic sampling rate

Wet bulb-dry bulb

Partial pressure technique
(at saturation)

Approximation sampling method

Wet Bulb - Dry Bulb Method

1. Measure the wet bulb temperature.
2. Measure the dry bulb temperature.
3. Estimate moisture content using psychrometric chart

or

Calculate moisture content.

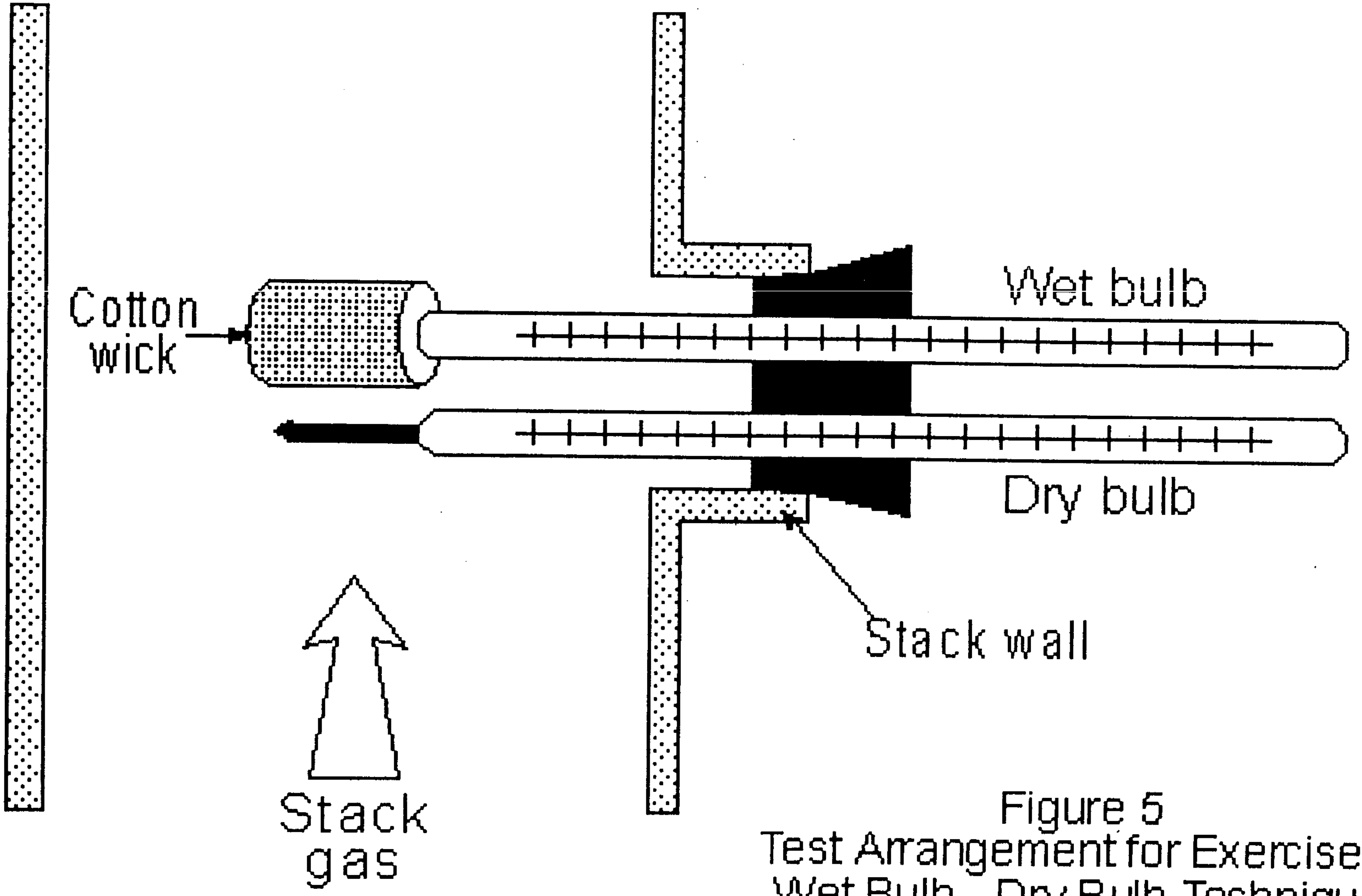
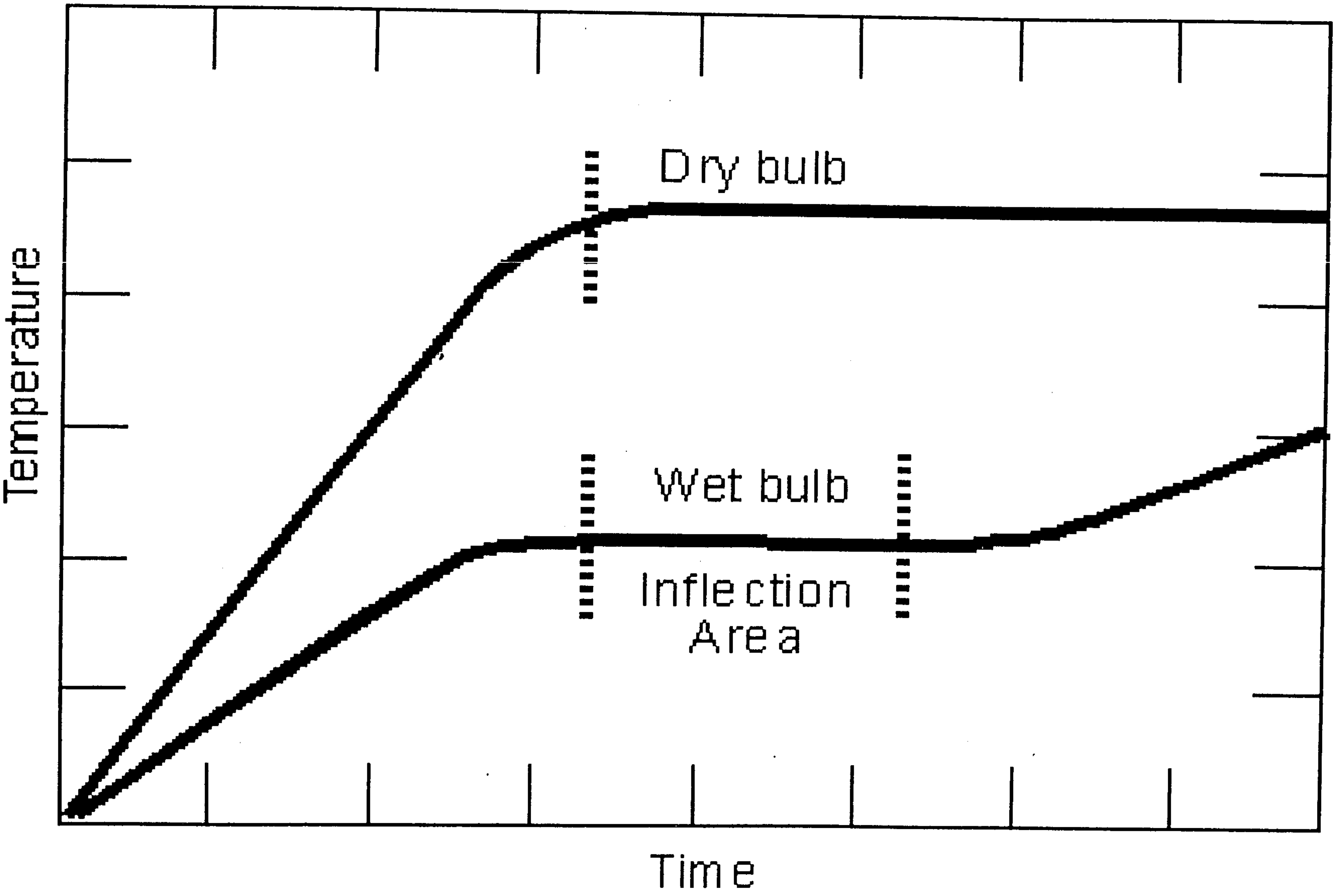


Figure 5
Test Arrangement for Exercise 3
Wet Bulb - Dry Bulb Technique
for
Moisture Measurement



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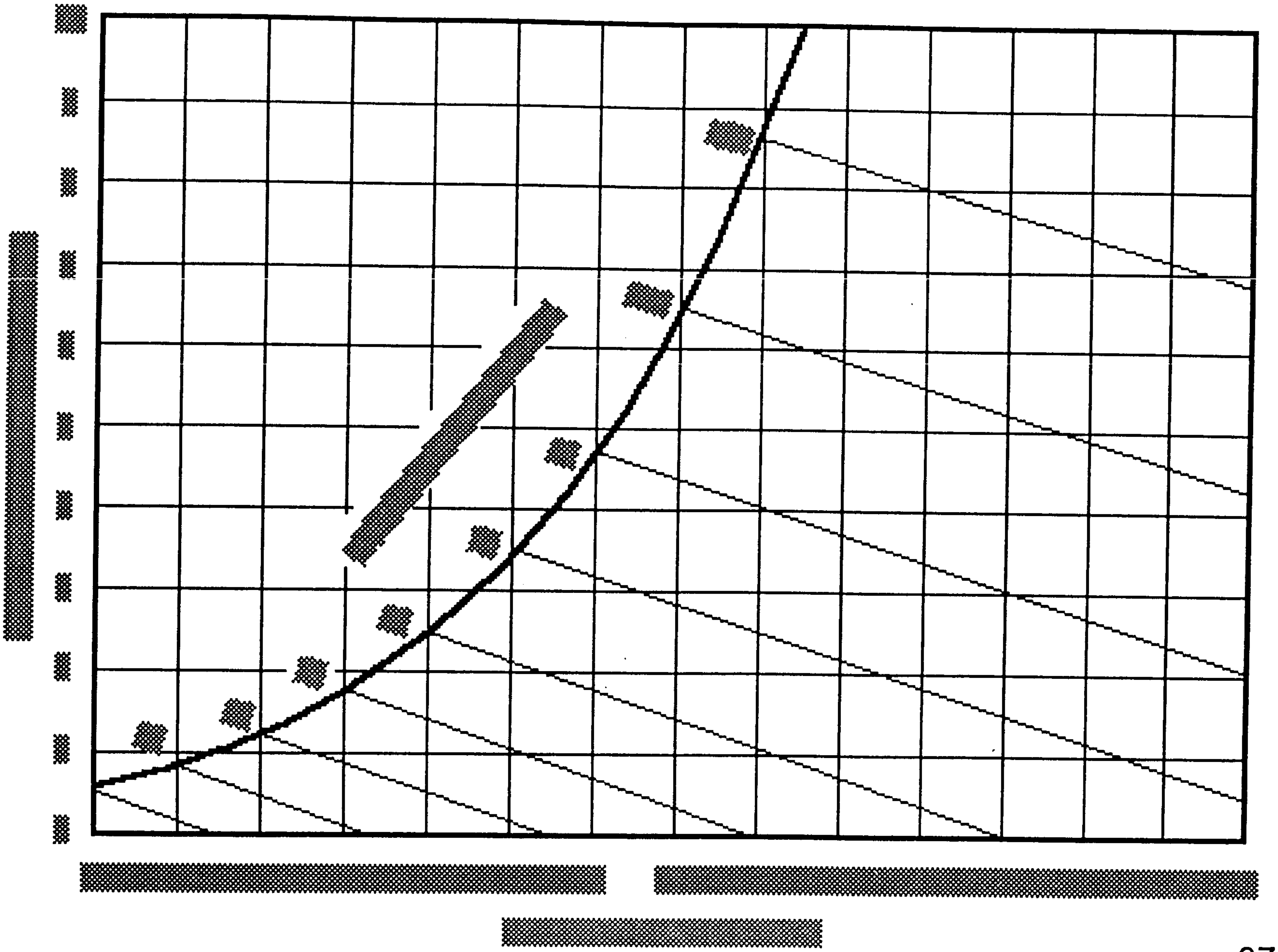

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Moisture Equation (Wet Bulb - Dry Bulb)

$$B_{ws} = \frac{v.p.}{P}$$

Where: v.p. = $s.v.p. - \left[(0.000367)(P)(t_s - t_p)\left(1 + \frac{t - 32}{1571}\right)\right]$

s.v.p. = saturated water vapor pressure at the wet bulb temperature

P = absolute pressure in the stack

t_s = dry bulb temperature

t_w = wet bulb temperature

v.p. = water vapor pressure

Partial Pressure Method

- Assume saturation.
- Attach temperature sensor to reference method probe.
- Measure stack gas temperature at each traverse point.
- Calculate the average stack gas temperature.
- Determine moisture fraction using saturation vapor pressure table.

Moisture Equation - Partial Pressure

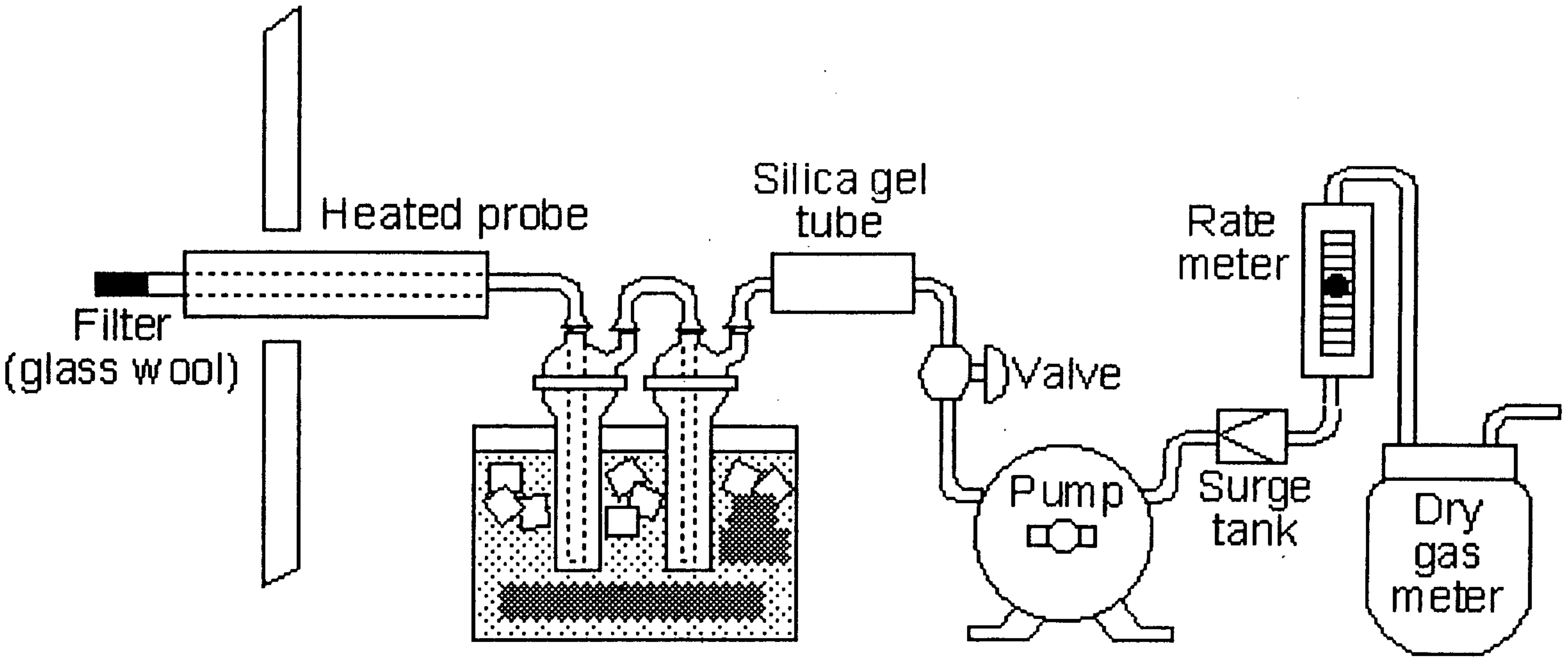
$$B_{ws} = \frac{s.v.p.}{P_s}$$

Where: B_{ws} = proportion (by volume) of water vapor in a gas mixture

s.v.p. = saturated vapor pressure of water at average stack temperature

P_s = absolute pressure of the stack

Moisture Sampling Train - Approximation Method



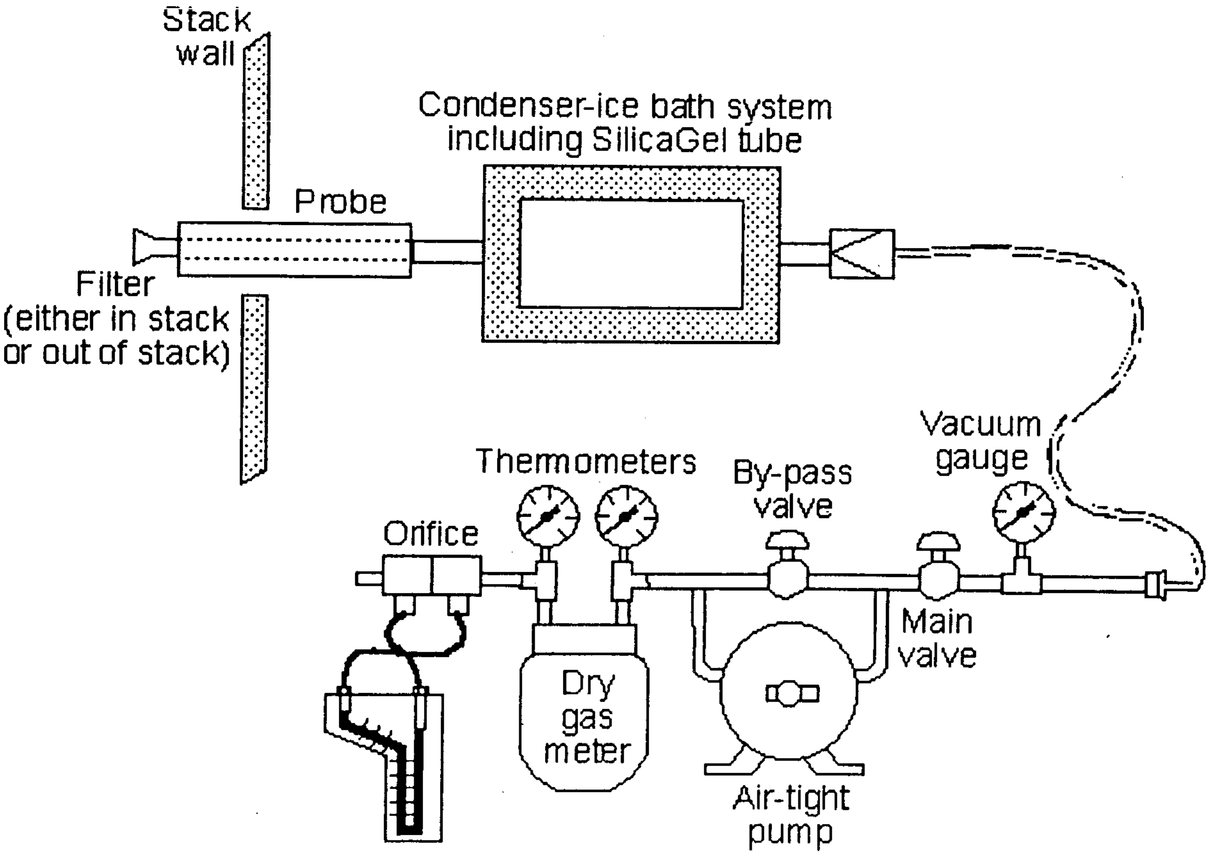
Procedure

1. Place 5.0 ml of distilled water in each impinger.
2. Assemble and leak-check sampling train.
3. Sample at a constant rate of 0.07 cfm until a sample volume of 1.1 ft^3 is obtained.
4. Combine contents of impingers and measure volume to nearest 0.5 mL.

Reference Method

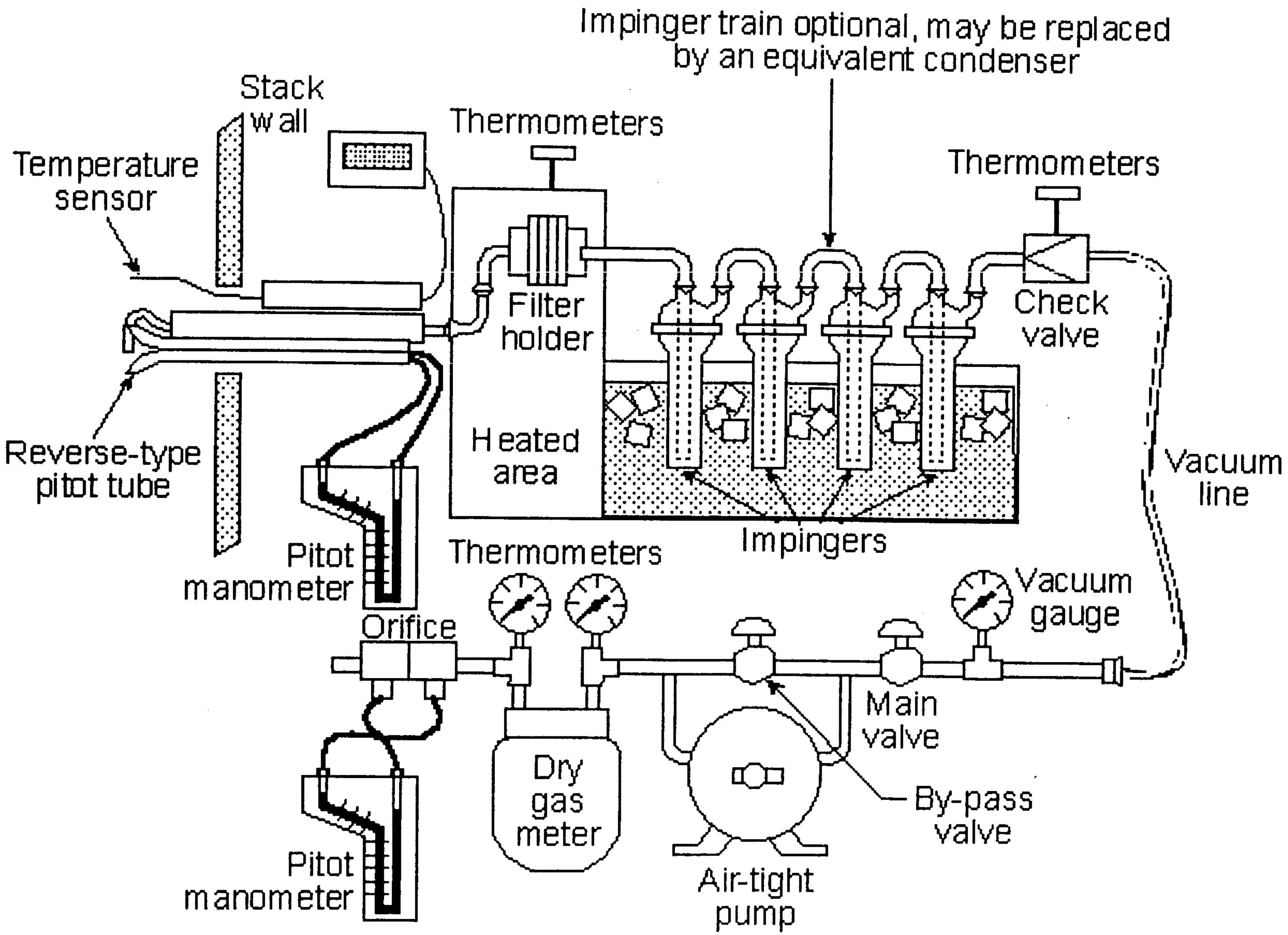
- Used for accurate determination of moisture content
- Usually conducted simultaneously with a pollutant measurement run
- Results used to calculate the percent isokinetic and pollutant emission rate

Moisture Sampling Train (Reference Method)



Procedure

1. Determine traverse points using Method 1.
2. Select sampling time such that minimum gas volume of 21 scf will be collected at rate no greater than 0.75 cfm.
3. Leak-check sampling train (optional).
4. Maintain sampling rate within 10% of constant rate.
5. After sampling, leak-check sampling train (mandatory).
6. Verify the constant sampling rate.


Impinger train optional, may be replaced by an equivalent condenser
Stack wall
Thermometers
Temperature sensor
Thermometers
Filter holder
Check valve
Reverse-type pitot tube
Heated area
Vacuum line
Pitot manometer
Thermometers
Impingers
Vacuum gauge
Orifice
Main valve
Dry gas meter
By-pass valve
Pitot manometer
Air-tight pump

Volume of Water Vapor Condensed

$$V_{wc(std)'} = \frac{(V_f - V_i)\rho_w R T_{std}}{P_{std} M_w}$$

$$= K_1 (V_f - V_i)$$

Where: K_1 = 0.001333 m^3/mL for metric units
= 0.04715 ft^3/g for English units

Volume of Water Vapor Collected in Silica Gel

$$V_{wsg(std)} = \frac{\left(W_f - W_i\right) R T_{std}}{P_{std} M_w}$$

$$= K_2 \left(W_f - W_i\right)$$

Where: K_2 = 0.001335 m^3/g for metric units
= 0.04715 ft^3/g for English units

Sample Gas Volume

$$V_{m(std)} = V_m Y = \frac{(P_m)(T_{std})}{(P_{std})(T_m)}$$

$$= K_3 Y \frac{V_m P_m}{T_m}$$

Where: K_3 = 0.3858 K/mmHg for metric units
= 17.64 R/in. Hg for English units

Moisture Content

$$B_{ws} = \frac{V_{wc(std)} + V_{wsg(std)}}{V_{wc(std)} + V_{wsg(std)} + V_{m(std)}}$$

Lesson 9

Course 450

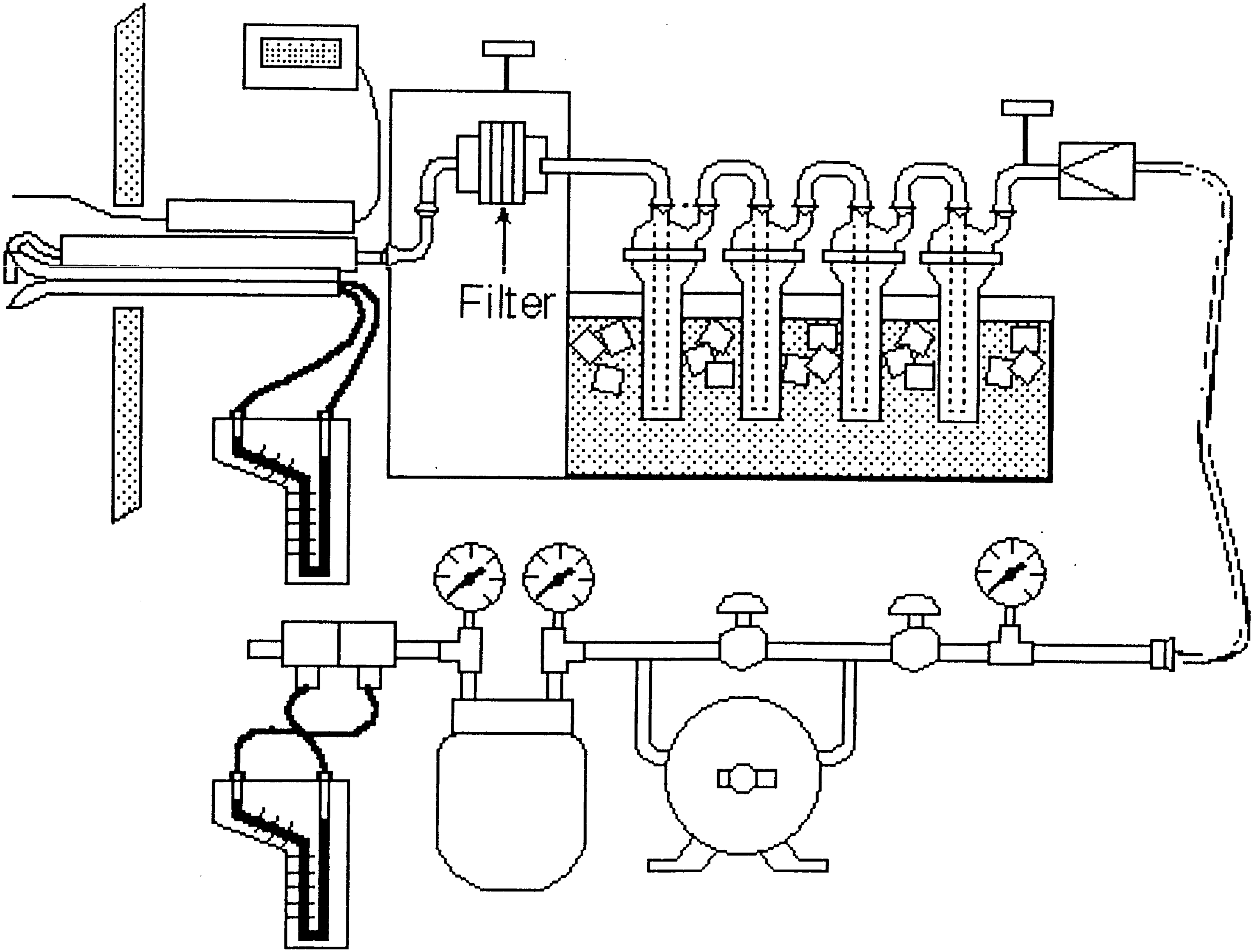
Definition of Particulate Matter Sampling Train Configurations

Filter Temperatures - Method 5

Method 5 - 248° F ± 25° F

Method 5A - 108° F ± 18° F
(Asphalt plants)

Method 5F - 320° F ± 25° F
(Nonsulfate parcticulate matter)



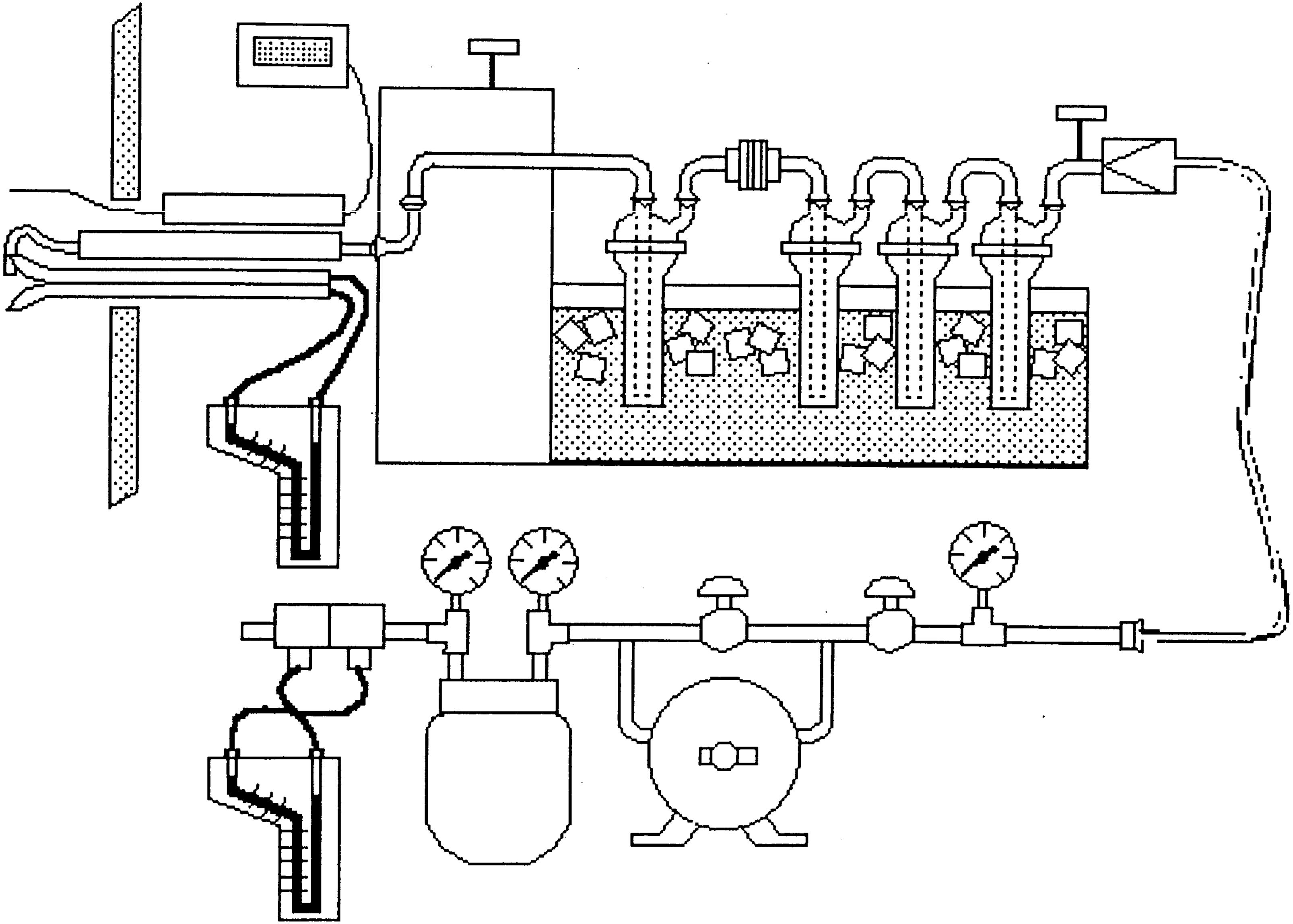
09-03

Method 8

Applicability

Determination of sulfuric acid mist and sulfur dioxide (acid plants)

Method 8

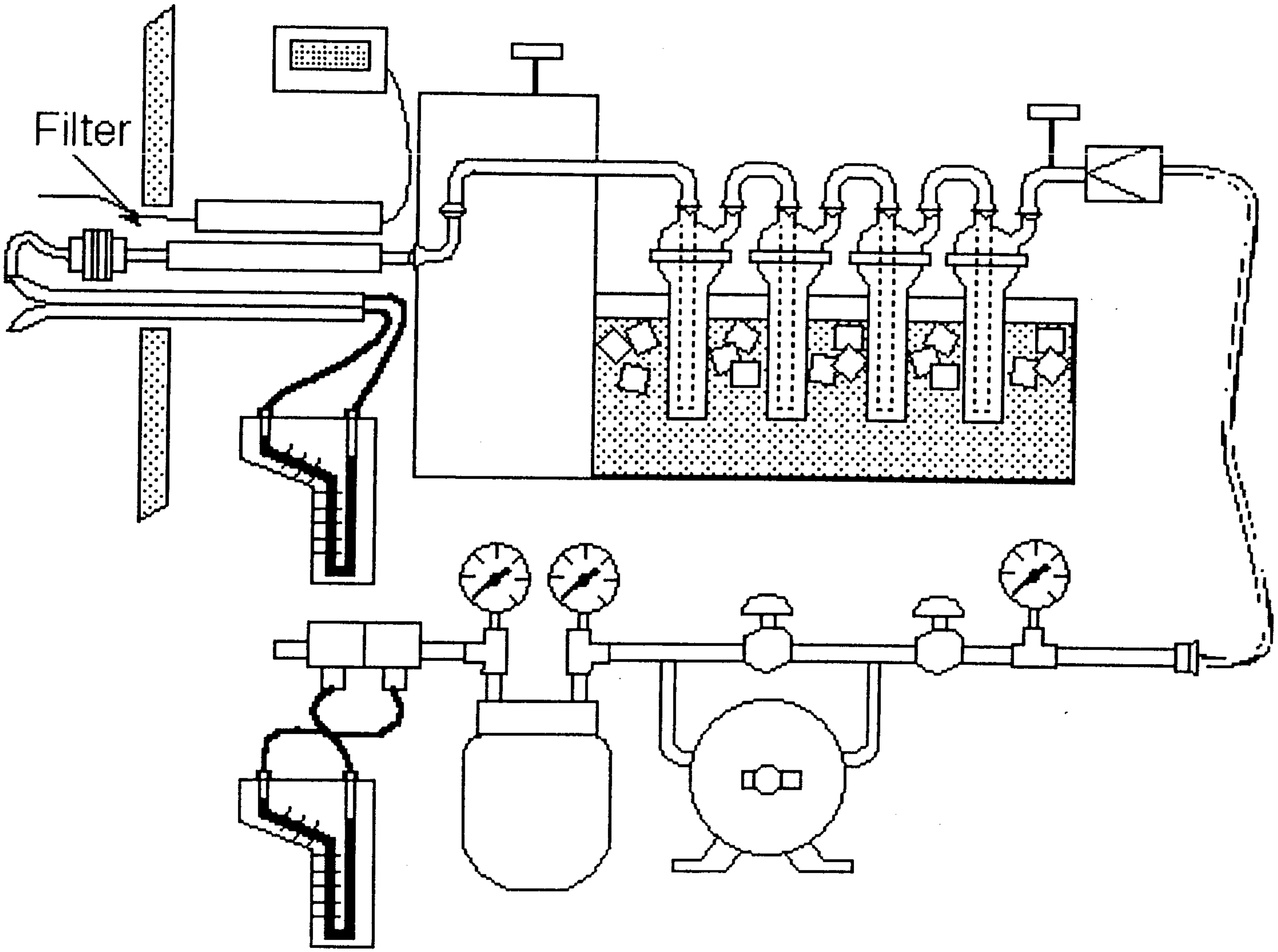


Method 17

In-stack Filter Applicability

In sources where particulate matter concentration is independent of temperature

Method 17

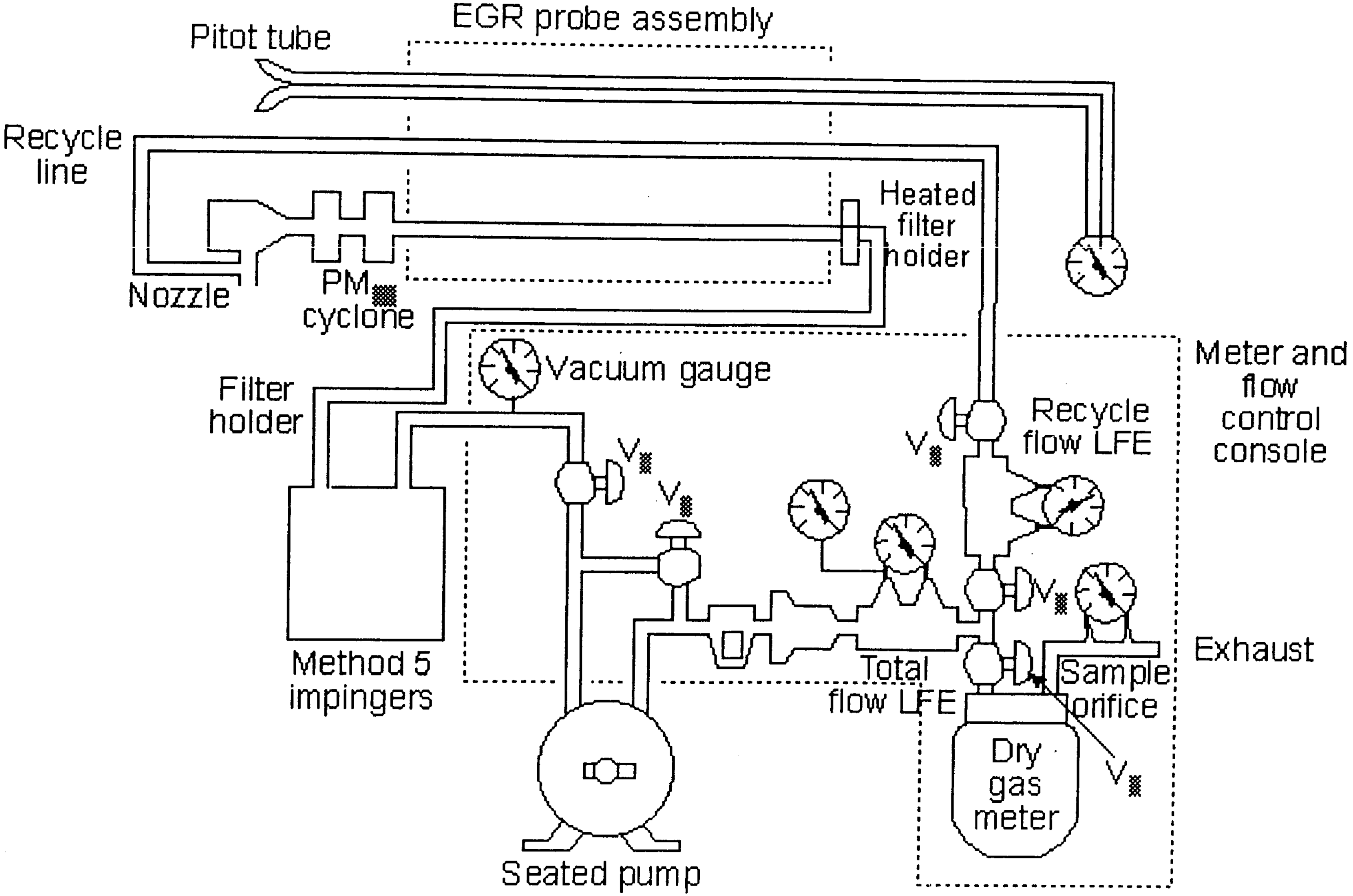


Method 201

PM_{10} Samping Train

Exhaust Gas Recycle Procedure (EGR)

40 CFR 51: Appendix M


EGR probe assembly
Pitot tube
Recycle line
Heated filter holder
Nozzle
PM▓ cyclone
Meter and flow control console
Vacuum gauge
Filter holder
Recycle flow LFE
V▓
V▓
V▓
V▓
Exhaust
Method 5 impingers
Total flow LFE
Sample orifice
Dry gas meter
V▓
Seated pump

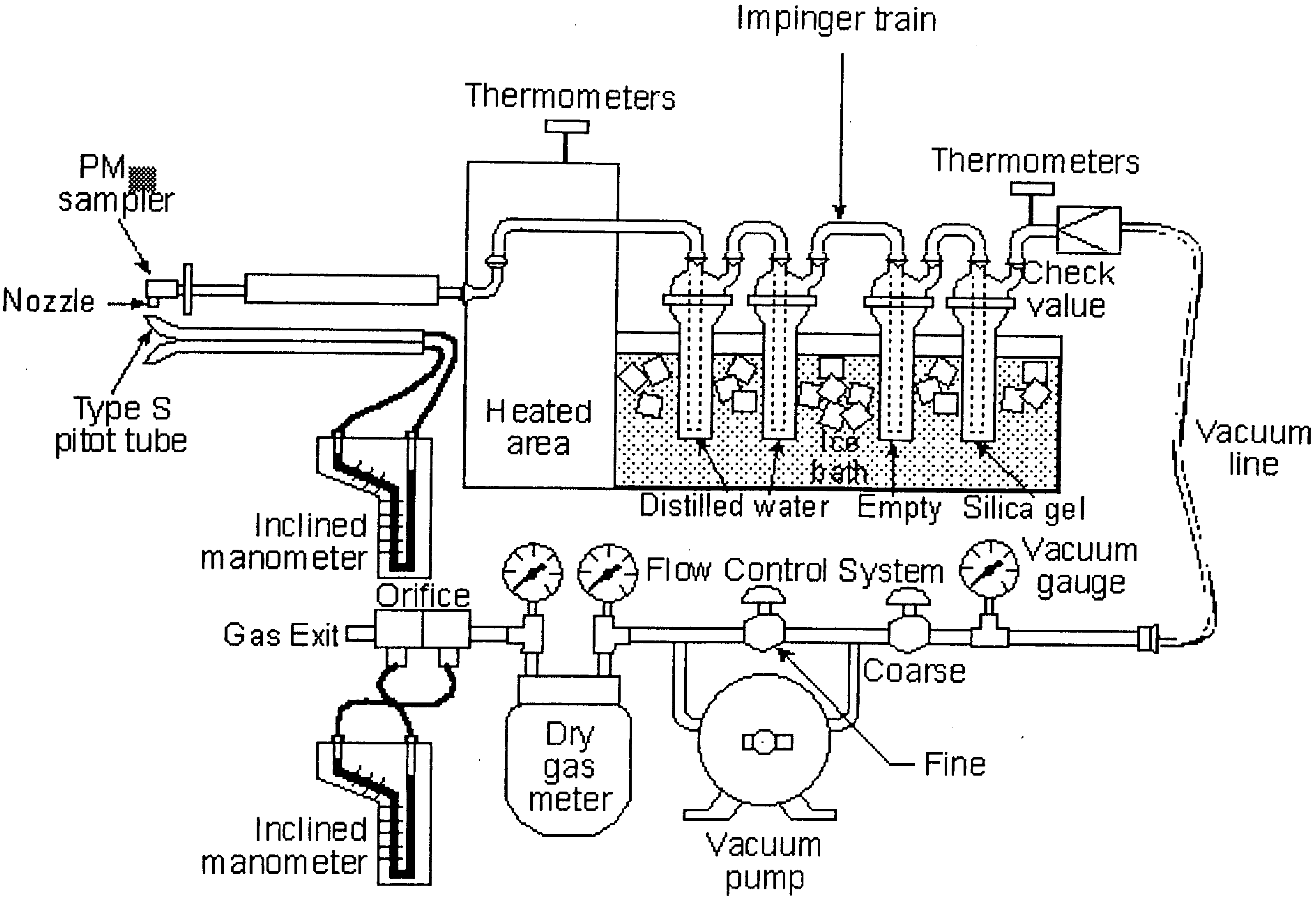
09-09

Method 201A

PM_{10} Samping Train

Constant Sampling Rate Procedure (CSR)

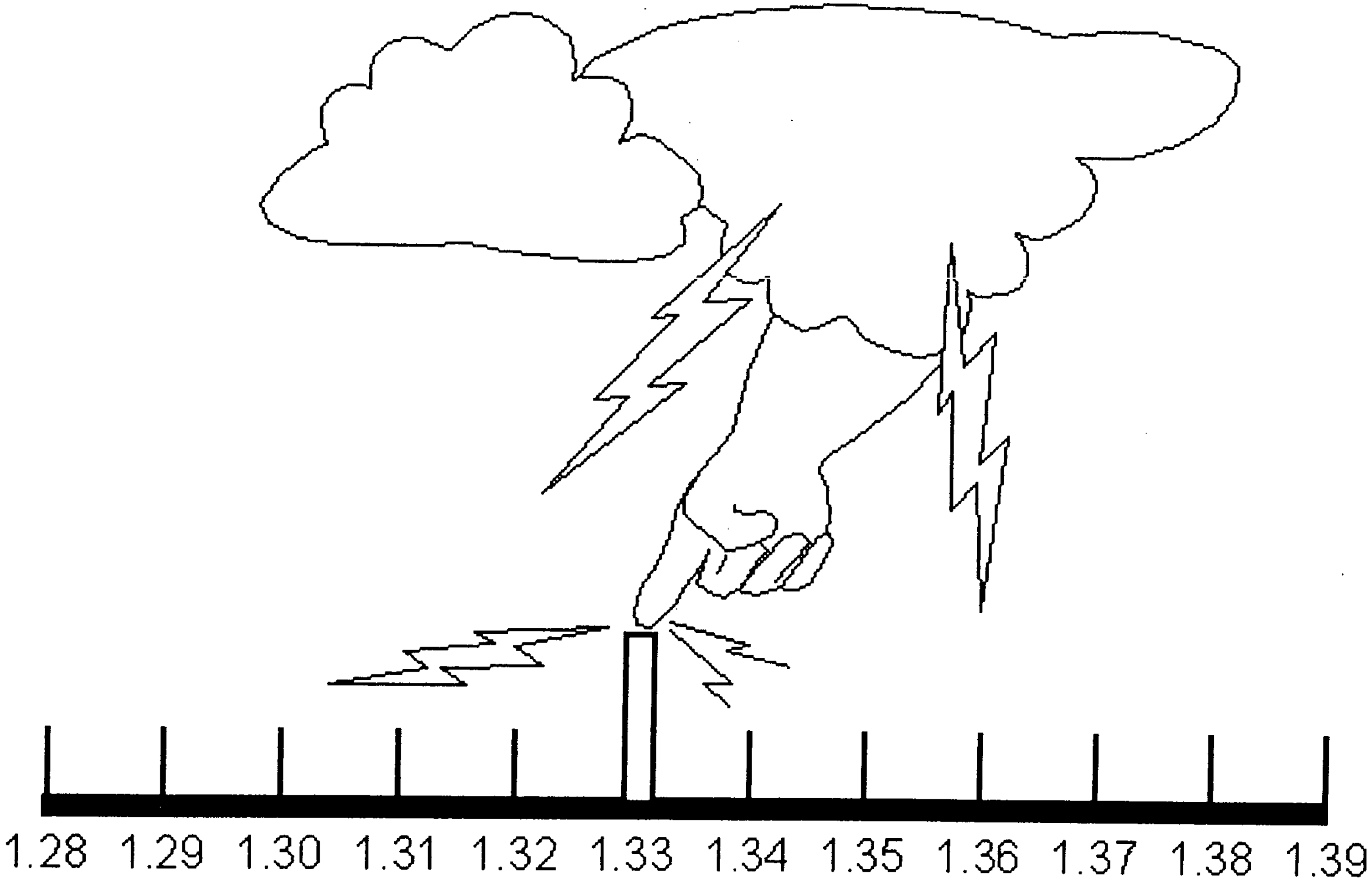
40 CFR 51: Appendix M


Impinger train
Thermometers
Thermometers
PM sampler
Nozzle
Type S pitot tube
Heated area
Check value
Ice bath
Distilled water
Empty
Silica gel
Vacuum line
Inclined manometer
Orifice
Gas Exit
Flow Control System
Vacuum gauge
Coarse
Fine
Dry gas meter
Vacuum pump
Inclined manometer

Lesson 11

Course 450

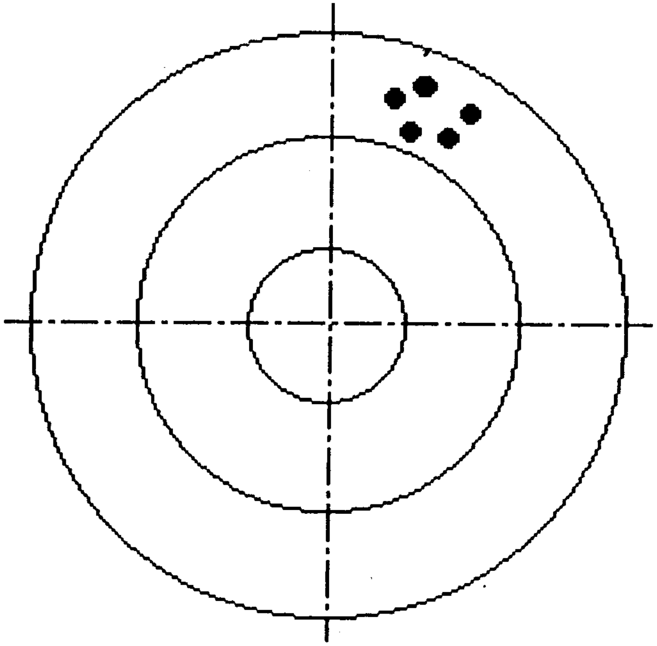
Error Analysis



The True Value

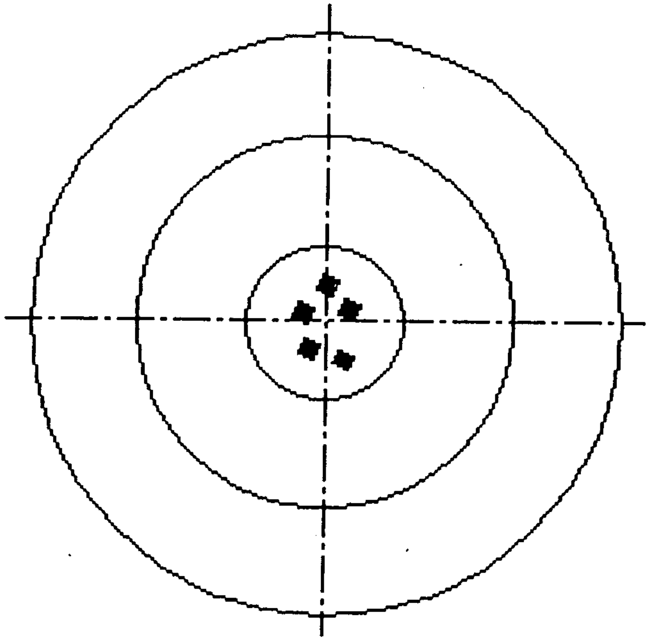
Precision and Accuracy

Precision refers to reproducibility.



A Precision is good but accuracy is poor.

Accuracy refers to correctness.



B Both precision and accuracy are good.

1 Systematic Errors

2 Random Errors

3 Illegitimate Errors

Lesson 12

Course 450

Reporting in Units of the Standard

$$c_{corr} = c_s \frac{P_{std} T_s}{P_s T_{std}}$$

$$\bar{c}_{s_{12}} = \bar{c}_s \frac{12}{\%CO_2}$$

$$\bar{c}_{s_{6\%O_2}} = \frac{\bar{c}_s\ [20.9 - 6.0]}{20.9 - \%O_2}$$

$$\%EA = \frac{V_{EA}}{V_{\text{required for complete combustion}}} \times 100$$

$$\%EA = \frac{\%\,O_2 - 0.5\,(\%CO)}{0.264(\%N_2) - [\%O_2 - 0.5\,(\%CO)]} \times 100$$

Method 19
F Factor Methods

$$E = \frac{pmr_s}{Q_H} = \frac{c_s Q_s}{Q_H} = \frac{\dfrac{\text{lbs}\ \cancel{\text{ft}^3}}{\cancel{\text{ft}^3}\ \cancel{\text{hr}}}}{10^6\ \text{Btu}/\cancel{\text{hr}}}$$

$$= \frac{\text{lbs}}{10^6\ \text{Btu}}$$

$$E = c_s F \begin{pmatrix} \text{dilution} \\ \text{correction} \\ \text{term} \end{pmatrix}$$

$$E = \frac{\cancel{\text{ft}^3}}{10^6\ \text{Btu}} \frac{\text{lbs}}{\cancel{\text{ft}^3}} = \frac{\text{lbs}}{10^6\ \text{Btu}}$$

Dilution correction term is dimensionless.

$$E = \bar{c}_s F_d \left[\frac{20.9}{20.9 - \%O_2} \right]$$

$$E = c_{ws} F_d \left[\frac{20.9}{20.9(1 - B_{ws}) - \%O_{2w}} \right]$$

$$E = \bar{c}_s F_c \frac{100}{\%CO_2}$$

$$E = \bar{c}_{sw} F_w \left[\frac{20.9}{20.9(1 - B_{ws}) - \%O_{2w}} \right]$$

Table 19-1-F: Factors for Various Fuels▒

Fuel Type	F▒		F▒		F▒	
	dscm/J	dscf/10▒ Btu	wscm/J	wscf/10▒ Btu	scm/J	scf/10▒ Btu
Coal:						
Anthracite▒	2.71x10-▒	10,100	2.83x10-▒	10,540	2.71x10-▒	1,970
Bituminous▒	2.63x10-▒	9,760	2.66x10-▒	10,640	2.63x10-▒	1,800
Lignite	2.65x10-▒	9,660	3.21x10-▒	10,950	2.65x10-▒	1,910
Oil▒:	2.47x10-▒	9,190	2.77x10-▒	10,320	2.47x10-▒	1,420
Gas:						
Natural	2.43x10-▒	8,710	2.85x10-▒	10,610	2.43x10-▒	1,040
Propane	2.34x10-▒	8,710	2.74x10-▒	10,200	2.34x10-▒	1,190
Butane	2.34x10-▒	8,710	2.79x10-▒	10,390	2.34x10-▒	1,250
Wood	2.48x10-▒	9,240			2.48x10-▒	1,830
Wood bark	2.58x10-▒	9,600			2.58x10-▒	1,920
Municipal Solid Waste	2.57x10-▒	9,570			2.57x10-▒	1,820

[redacted]

Lesson 13

Course 450

Source Sampling, Quality Assurance, and On-Site Safety

Quality Assurance Handbook for Air Pollution Measurement Systems

Volume III
Stationary Source
Specific Methods

EPA 600/4-77-027b

EPA APTI
Correspondence Course 414

EPA 450/2-82-003

Source Testing QA

- Calibrate
- Calibrate
- Calibrate

- Leak Check
- Leak Check
- Leak Check

Method 5
Quality Control
Procedures

Component Calibration

Probe Nozzle

- Measure three diameters of the nozzle.
- Calculate the average measurement.
- The difference between the high and low measurement shall not exceed 0.004 in.
- Nozzle should be uniquely identified.

Probe Heater Calibration

Calibrate probe heater if not constructed according to APTD - 0581 using procedure outlined in APTD - 0576.

Pitot Tube Calibration

Perform dimensional specification test

and/or

Calibrate in wind tunnel against standard pitot tube (preferably with NBS traceable coefficient).

Impinger Thermometer

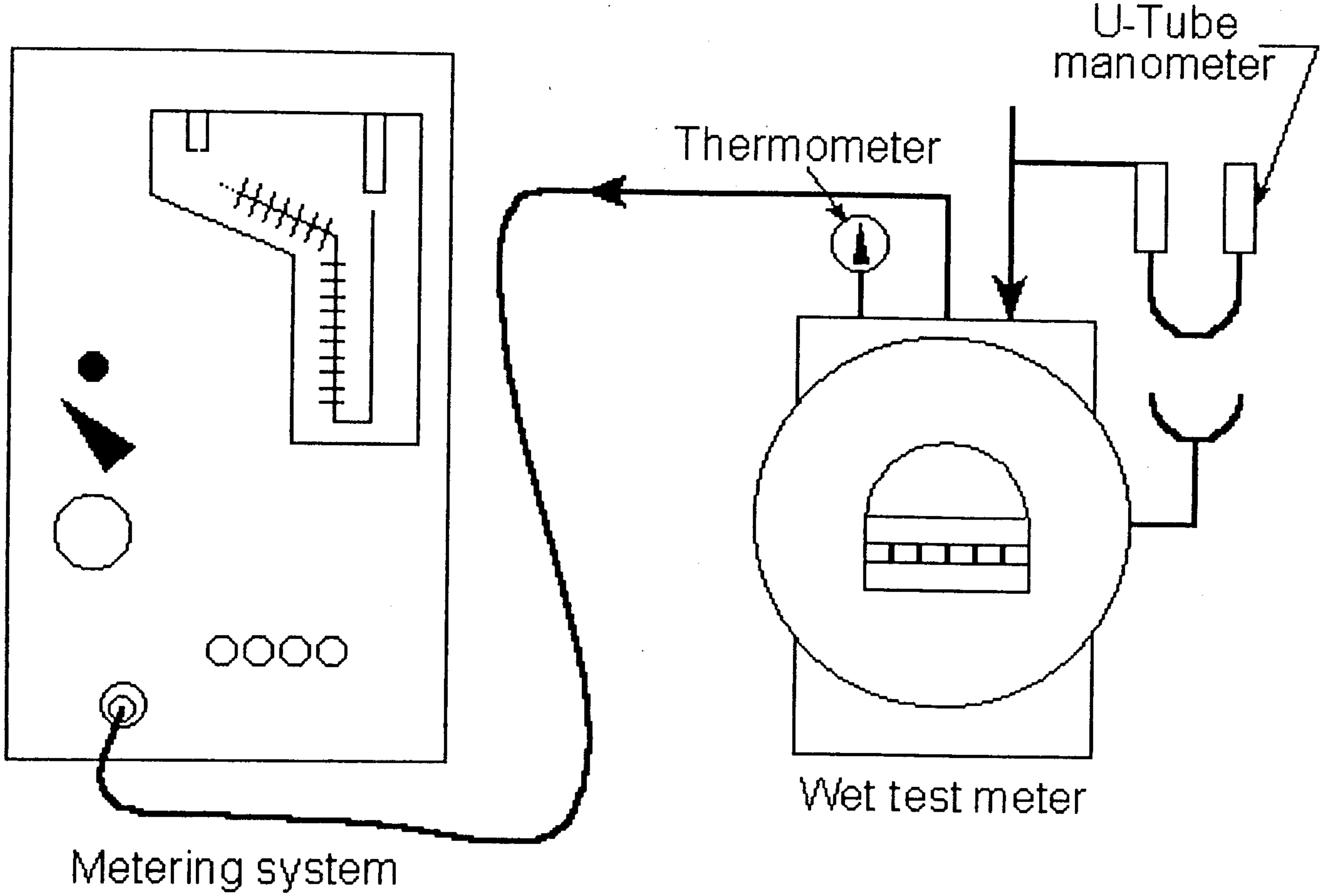
Calibrate with a mercury-in-glass thermometer that meets STM E-1 No. 63C or 63F specifications.

- Compare readings in ice bath.
- Compare readings at room temperature.
- Thermometer must agree within 2° F of the reference thermometer at both temperatures.

Dry Gas Meter Thermometer

Calibrate with a mercury-in-glass thermometer that meets ASTM specifications.

- Compare readings in hot water bath 105° - 122° F.
- Compare readings at room temperature.
- Thermometers must agree within 5.4° F at both points or differential at both points within 5.4° F.



Equipment arrangement for metering system calibration

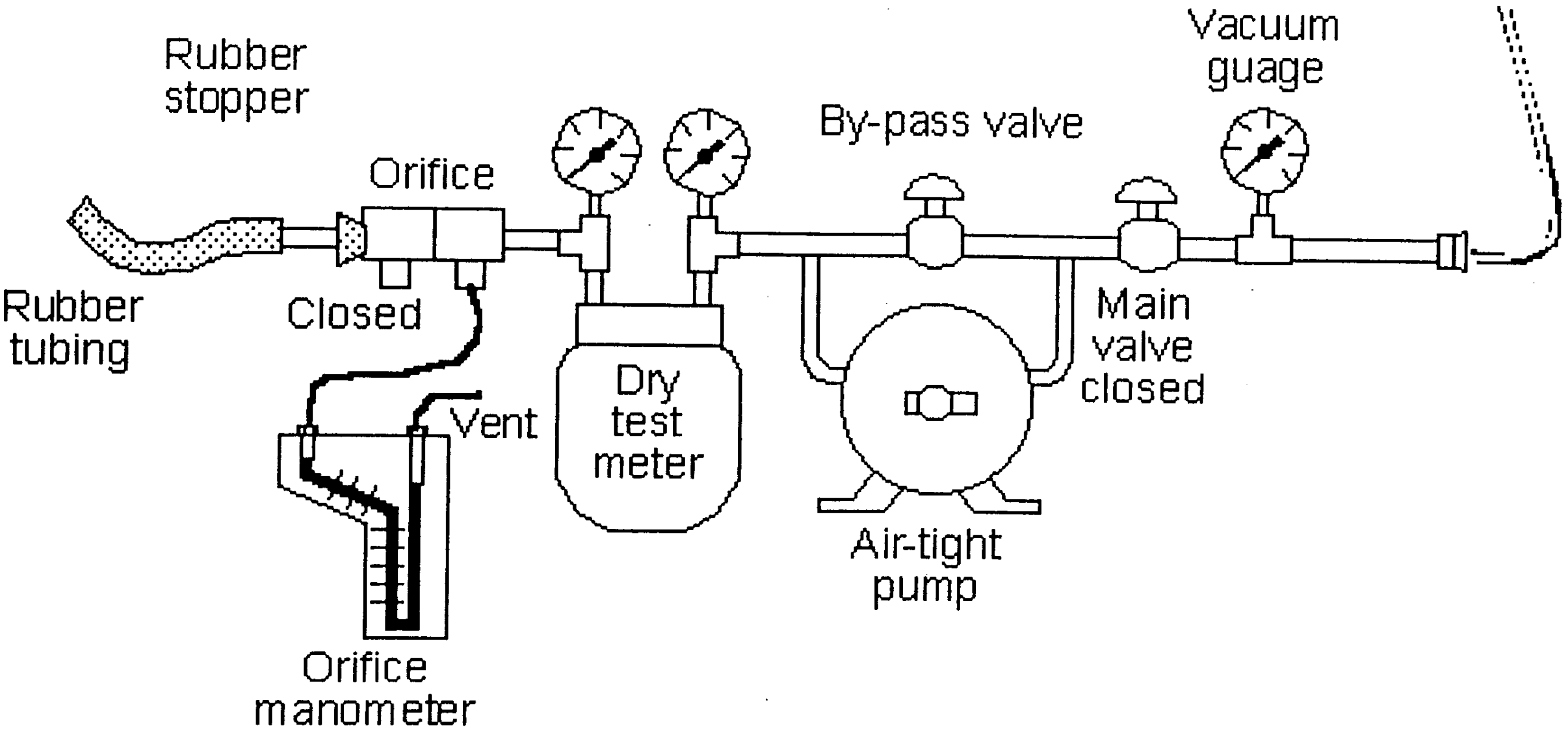
Balance Calibration

Analytical Balance

Calibrate using Class-S weights (balance should agree within ±2 mg).

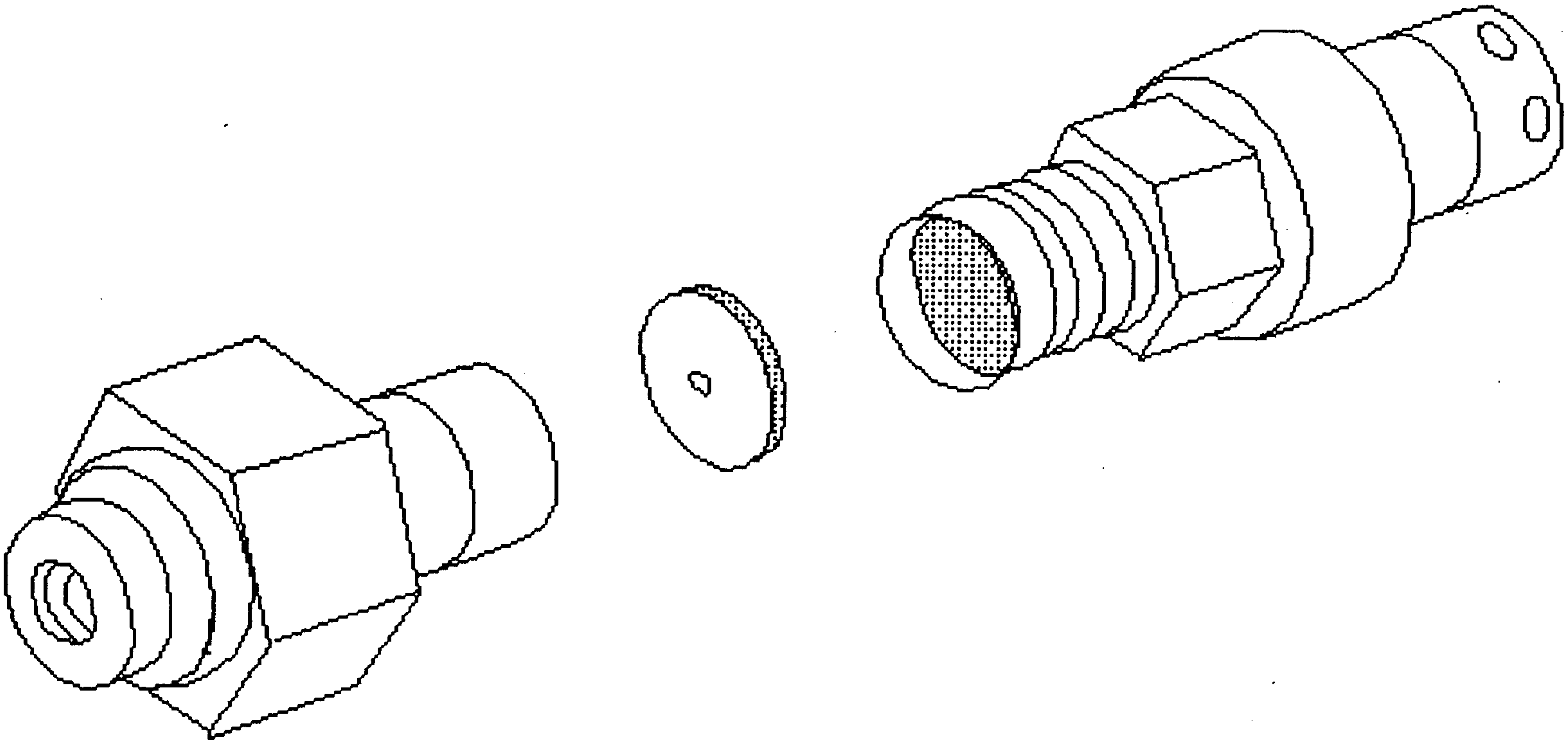
Trip Balance

Calibrate using Class-S weights (balance should agree within ±0.5 g).

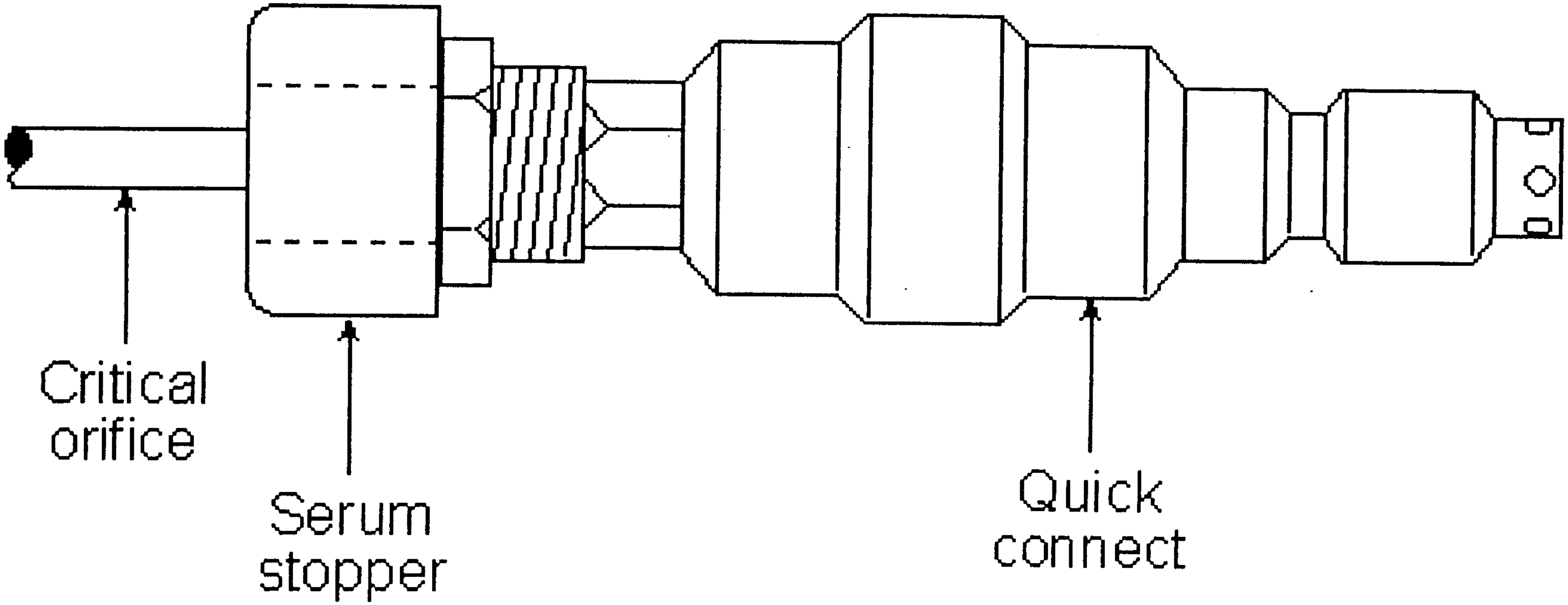


Leak check of meter box

Audit Device



Critical Orifice



Leak Checks

- Pitot tube lines
- Probe
- Sample lines
- Filter
- Metering system

Safety on the Sampling Site

The Importance of an Accident Analysis Program

Causes of Accidents

- Poor instruction
- Poor planning
- Improper design
- Proper equipment not provided
- Failure to follow instructions