United States
Environmental Protection
Agency

Air Pollution Training Institute
MD 20
Environmental Research Center
Research Triangle Park NC 27711

Air

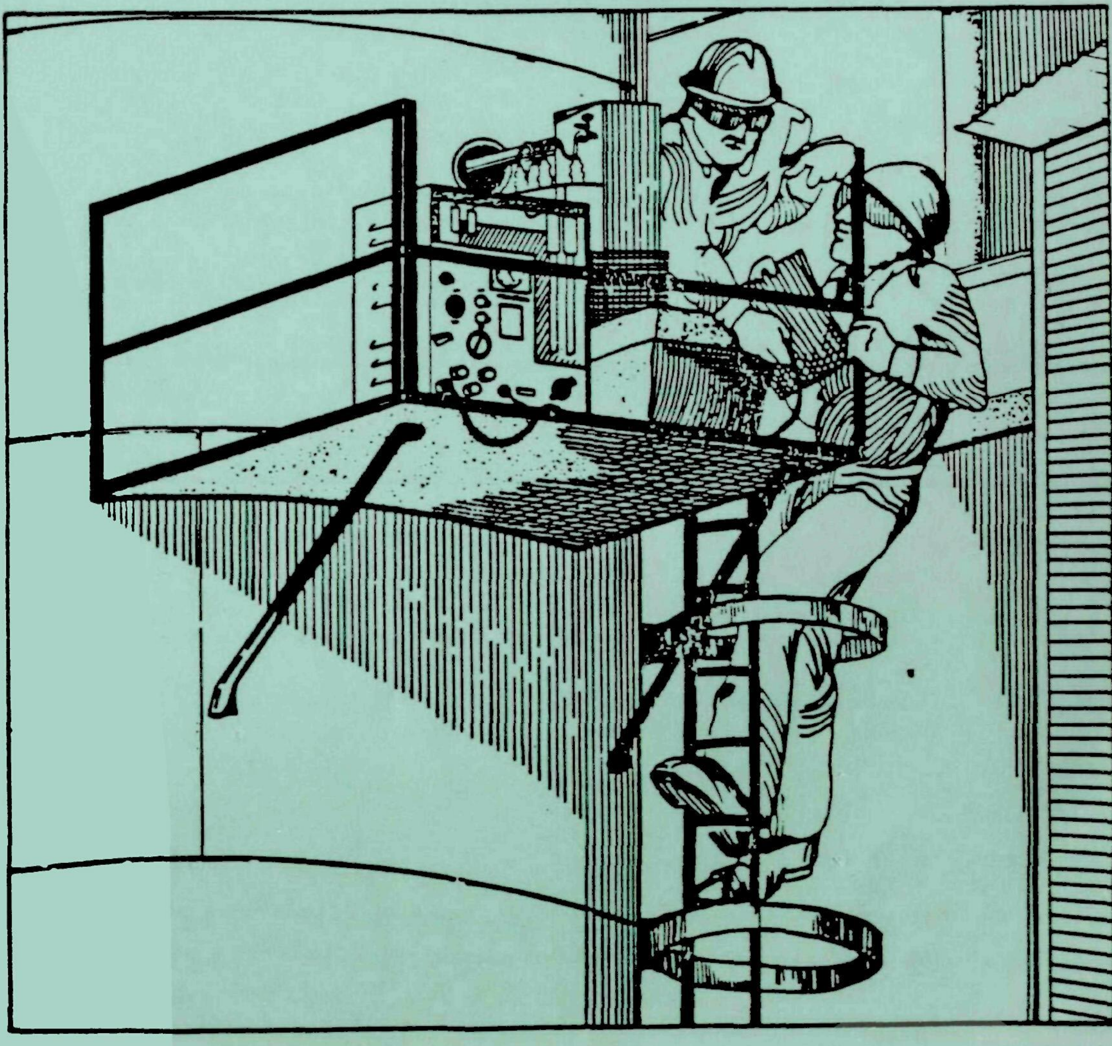
EPA

APTI Course SI:445

Introduction to Baseline Source Inspection Techniques

REFERENCE

FIELD INSPECTION NOTEBOOK



REVISED
OCTOBER 1983

FIELD INSPECTION NOTEBOOK

SOURCE

____

____

DATES

________________	________________
________________	________________
________________	________________

Prepared by

Engineering-Science
Durham, North Carolina
919-682-9611

for the

U.S. Environmental Protection Agency
Stationary Source Compliance Division
Contract 68-01-6312
Work Assignments 62 and 99

TABLE OF CONTENTS

Section	Page
Safety Guidelines	Front & Back Covers
Inspection of Air Pollution Control Systems	1
Inspection of Pulse Jet Fabric Filters	2
Inspection of Reverse Air and Shaker Fabric Filters	12
Inspection of Electrostatic Precipitators	21
Inspection of Cyclone and Multi-Cyclone Collectors	32
Inspection of Venturi Scrubbers	40
Inspection of Spray Tower Scrubbers	50
Inspection of Tray-type, Moving Bed, and Packed Bed Scrubbers	56
Selection of Measurement Ports and Use of Portable Instruments	65
Velocity Traverses	69
Measurement of Oxygen and Carbon Dioxide in Combustion Gas Streams	74
Checking the CO_2 and O_2 Measurements	75
Using the CO_2 and O_2 Measurements	75
Nomograph for Estimating Flue Gas Composition, Excess Air or Type of Fuel	76
Opacity Measurements - Slant Angle	77
High Temperature Psychrometric Chart	78
Fans	79
Fan Performance	80
Relative Air Density Factor	81
Density of Solids	82
Density of Liquids	83
Sieve Number vs. Particle Size	83
Selected Geometric Relationships	84
Conversion Factors	85

SAFETY GUIDELINES

Front Cover

1. The work should be interrupted IMMEDIATELY whenever the inspector experiences the nonspecific symptoms of exposure, including but not limited to the following: headache, eye or nose irritation, nausea, dizziness, drowsiness, vomiting, loss of coordination, chest pains, or shortness of breath. The inspector should proceed to a well ventilated area and reevaluate the potential inhalation hazards.

2. The inspection should be conducted at a controlled pace in order to avoid careless accidents. NEVER HURRY.

3. Hardhats and safety shoes should be worn during all inspections, even when not required by plant safety policies.

4. If necessary personal protective equipment such as a respirator is not available, areas of potential exposure should be avoided.

5. Hearing protection should be used whenever it is difficult to hear another person speaking in a normal tone of voice at a distance of 3 feet.

6. Contact lenses should NOT be worn during inspections. Eye protection must conform with plant requirements.

7. Internal inspections of air pollution control equipment should NOT be conducted unless the inspector has the proper training and equipment for confined space entry.

8. Areas of potentially high pollutant concentrations should be entered only if the proper personal protection equipment is available. A partial list of such areas includes weather enclosures above precipitators, walkways between control systems operating at positive pressure, pump houses, fan houses, and measurement ports on positive pressure ducts.

9. When climbing ladders, the horizontal rungs should be grasped. Both hands must be free for climbing - equipment should not be carried in either hand.

10. All portable sampling equipment should be properly grounded whenever there is possibility of static shock or explosion. A partial list of areas with high static electrical charge include solvent storage vessels, fuel storage facilities, and downstream of electrostatic precipitators.

11. Prior to walking across elevated horizontal walkways such as roofs and catwalks, the inspector should evaluate the potential exposure to steam and pollutant releases from the process below and the potential for falls due to structural problems with the walkway. The latter can be due to corrosion of the supports or excessive accumulation of solids on the roof.

12. Work clothes contaminated with materials such as inorganic lead or mercury should be washed separately from street clothes. Disposable shoe covers should be used when inspecting such facilities.

13. Insulated gloves should be used whenever handling sampling probes and equipment withdrawn from hot gas streams.

14. Inspectors should NOT smoke while conducting field work. Smoking should be done only in such areas designated as safe by plant policies.

15. The inspection should be interrupted immediately whenever a severely vibrating fan is found in the vicinity of the equipment being evaluated. Disintegration of fans can send shrapnel over a large area and even through walls in extreme cases.

16. The inspection should be terminated whenever the wind chill factor is below -20°F. Extreme caution is warranted whenever there is freezing rain or sleet.

17. Areas adjacent to damaged nuclear-type hopper level detectors and nuclear continuous weighing systems should be avoided.

18. Emergency phone numbers should be recorded in the front of the field notebook for each plant. Inspectors should be familiar with the plant emergency system including warning siren codes.

19. Inspectors should never be unaccompanied while in the vicinity of the process or air pollution control equipment.

20. All plant safety requirements and all agency safety procedures must be satisfied at all times.

NOTE: It should not be assumed that all acceptable safety measures are contained in this and other publications; other or additional measures may be required under particular or exceptional circumstances.

Purpose

Early diagnosis of emerging operating problems or air pollution control equipment is essential in order to minimize emissions and to minimize repair costs due to subsequent component damage. The inspection procedure is designed to identify ABNORMAL operating conditions which MAY be indicative of common system malfunctions.

The data and information compiled during an inspection does not provide a definite measure of the pollutant emission rate. This can only be provided by the applicable Reference Test Methods.

General Approach

The performance of air pollution control systems is dependent on numerous complex and interrelated variables. Accordingly it is necessary to evaluate performance on a UNIT-SPECIFIC basis. The procedure utilizes comparisons of present operating conditions against previous BASELINE levels of each variable.

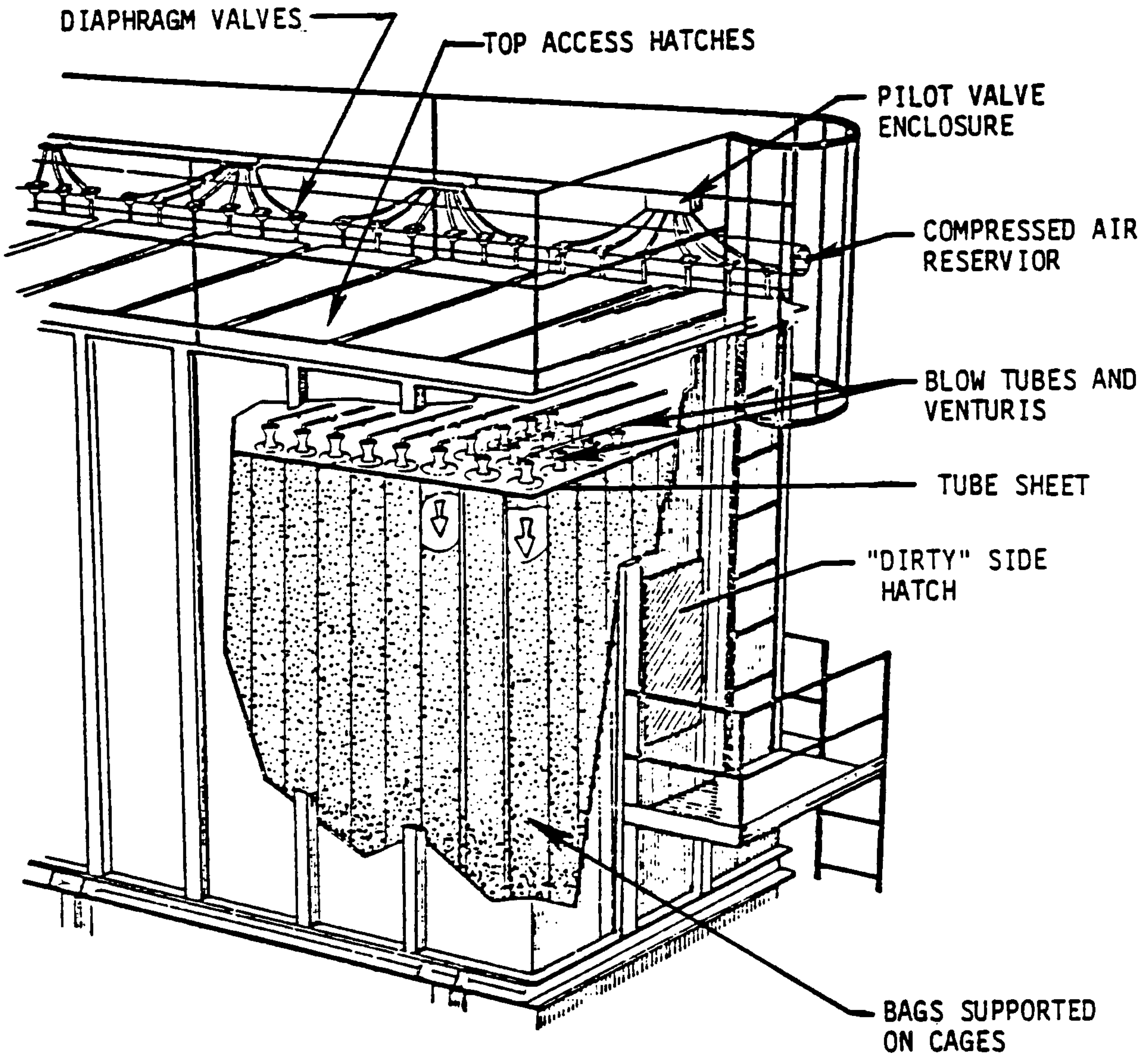
To maximize the accuracy of the inspection data, the inspector may occasionally need to use a number of portable instruments. These are used in lieu of permanently mounted instruments on control systems to the extent necessary. The measurements may be made by the agency inspector or by plant personnel in the presence of the inspector.

The inspection should be terminated whenever it is apparent that emissions have not increased significantly since the baseline period. If problems probably exist, the focus of the inspection should be narrowed to the GENERAL FACTORS which conceivably contribute to the increased emissions. The inspector must confirm that plant personnel recognize that a problem exists and that the proposed corrective actions have a reasonable chance for successful and timely repair. Due to the complexity of the interrelated performance variables and the lack of time, it is generally impractical for the inspector to positively identify the SPECIFIC operating problem.

Limits

The inspection procedures presented in the following sections are useful for a large number of common air pollution control systems. There are, however, a number of somewhat unique control systems which demand revised inspection techniques. The inspector should modify the inspection procedures to the extent necessary for such sources.

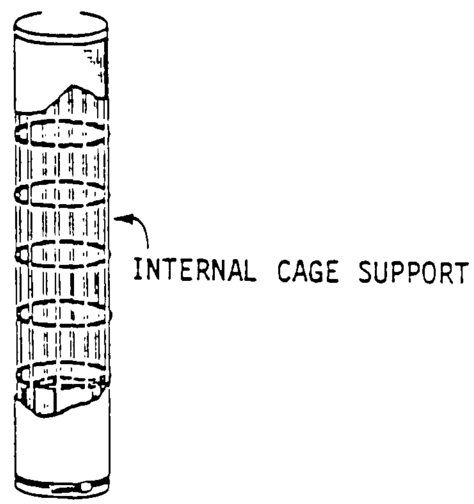
Nothing should be done which jeopardizes the health and safety of the inspector and/or the plant personnel. Furthermore, the inspector should attempt to minimize any inconvenience to plant personnel while accomplishing the assigned task in a timely manner.



SOURCE: Air Pollution Training Institute

Components and Operating Principles

Most pulse jet units have a felted fabric bag supported by an internal cage. The dust cake builds up on the outside of each bag. Clean gas passes up through the bags to a clean air plenum at the top of the baghouse. The bags are cleaned row-by-row using compressed air normally at pressures of 60 to 120 psig. Compressed air in the reservior is momentarily released through a diaphragm valve to the blow tube above each row of bags. Holes or nozzles above each bag allow a "pulse" to travel down the bag. The flexing of the fabric plus a modest reverse air action cause a portion of the dust cake on the outside of the bag to be dislodged and fall to the hopper.



SOURCE: Air Pollution Training Institute

A top access unit is shown in the figure above. A number of hatches on the top of this type of filter allow access to the clean side of the collector for checking and replacement of bags.

Another common design supports the bag and cage assemblies below the tube sheet. The main access hatch is usually on the side of the collector or in the hopper area.

When abrasive particulate matter is present, many pulse jet collectors utilize a "blast" plate or deflection plate so that much of this material is directed into the hopper and not against the fabric surface.

1. Components and Operating Principles (Continued)

One of the basic design parameters of a pulse jet filter is the "Gas-to-Cloth" ratio which is simply the number of cubic feet of gas (at actual conditions) passing through the average square foot of cloth per unit time. The normal units are $(Ft^3/Min)/Ft^2$ or simply Ft/Min. Most commercial units are in the range of 4 to 10 Ft/min. Remember that this is an average number and that the actual "velocities" through the cloth will vary throughout a baghouse even under normal conditions. If part of the bags are inadequately cleaned or if sticky/wet material blocks part of the fabric surface, then the local "velocities" through the remainder of the fabric may be much higher than desirable.

The pressure drop across the fabric filter is influenced by numerous factors including,but not limited to, the gas flow rate, the condition of the fabric, the presence of holes and tears, and the permeability of the dust cake. It is often difficult to evaluate the significance of changes from baseline pressure drops without taking into account other information.

Increased Pressure Drop - This is most often due to inadequate cleaning of the bags or to blinding of the fabric. The presence of water and oil in the compressed air supply can contribute to the blinding of the material. Improper start-up procedures and condensed aerosols can also blind the fabric.

When the pressure drop has increased from baseline levels, the process equipment and hoods should be checked to confirm that there is still adequate particulate matter capture.

Decreased Pressure Drop - This is often due to a decrease in the overall gas flow rate through the collector (check fan damper position, fan speed, or blockage of inlet duct to filter). Bag holes and tears can reduce pressure drop, however, the change is normally slight since the gas flow through the hole will simply increase until the pressure drop through the hole is equivalent to that across the rest of the fabric. Emissions often reach undesirable levels well before the overall pressure drop decreases substantially.

Other factors which can lead to a reduced pressure drop relative to baseline levels include an increase in the cleaning intensity (check the compressed air pressure) and an increase in the cleaning frequency. A change which increases the particle size distribution at the inlet to the pulse jet collector may also cause a decrease in the pressure drop.

Severe air infiltration across the top hatches of a pulse jet filter can significantly reduce the quantity of gas pulled from the process equipment through the baghouse. This results in a decreased pressure drop and increased fugitive emissions from the process.

2. Baseline and Diagnostic Inspection Data

Stack	Average Opacity Peak Opacity During Puffs Duration and Timing of Puffs
Fan	Inlet Gas Temperature Speed Damper Position Motor Current
Fabric Filter	Inlet Gas Temperature Outlet Gas Temperature Inlet Static Pressure Outlet Static Pressure Inlet O_2 and CO_2 Content (Combustion Sources) Outlet O_2 and CO_2 Content (Combustion Sources) Qualitative Solids Discharge Rate Air Reservior Pressure Frequency of Cleaning Presence or Absence of Clean Side Deposits Audible Air Infiltration

3. Routine Inspection Data

Stack	Average Opacity Duration and Timing of Puffs
Fan	None
Fabric Filter	Inlet and Outlet Gas Temperatures Inlet and Outlet Static Pressures Presence or Absence of Clean Side Deposits Air Reservior Pressure Audible Checks for Air Inleakage Qualitative Solids Discharge Rate

4. Inspection Methodology: The following sequence of inspection steps is often the most expeditious and effective means to identify abnormal operating conditions of typical pulse jet fabric filters. As with other types of air pollution control devices the inspector should respect the complexity of the interrelated operating variables.

A. Routine Inspections

Confirm Process Operation -	The sources controlled by the fabric filter should be very briefly checked to confirm that operation is representative.
Evaluate Plume Characteristics -	Determine average opacity. Most pulse jet collectors operate with less than 5% opacity, so values approaching 5% may suggest operating problems. If puffs are observed, the timing

4. Inspection Methodology (Continued)

should be noted so that it is possible to identify the row being cleaned just before the puff.

Fabric Filter -

The pressure drop across the collector should be noted. If there is an on-site gauge, proper operation of the gauge should be confirmed by observing meter response during the pulsing cycle. If there is some question about the condition of the gauge or its connecting lines, the inspector should request plant personnel to disconnect one line at a time to identify any plugged or crimped lines (disconnecting lines may not be possible if there is a differential pressure transducer connected to the gauge lines).

If the on-site gauge is not operational or not available, the static pressure drop should be measured using portable instrumentation. Preferably these measurements should be made at isolated ports installed specifically for the portable instrumentation. It is important to make the measurements on the inlet and the outlet one at a time so that plugged tap holes and lines can be identified.

Check operation of the cleaning system by noting the air reservoir pressure (DO NOT REMOVE THIS GAUGE). Check for air leakage around the ends of the reservoir, and the connections to each of the diaphragm valves. These valves are normally activated on a frequent basis, therefore, it is usually possible to observe a complete cleaning cycle. Each valve should have a crisp thud when activated. Valves which fail to activate or which produce a weak, wet newspaper splat are usually not working properly.

4. Inspection Methodology (Continued)

If too many of these are out-of-service it is probable that the local air-to-cloth ratios are high, causing excessive emissions through the baghouse and/or inadequate pollutant capture at the source. Even if all diaphragm valves are working properly, reduced cleaning effectiveness can result due to low compressed air pressures.

If the compressed air pressures are too high, especially for units with a high design air-to-cloth ratio, it is possible that the intense cleaning action will result in some seepage of dust through the fabric immediately after cleaning when the fabric crashes back into the support cage. This will cause a momentary puff of 5-10% opacity.

Holes and tears can lead to puffs of 5-30% during the cleaning cycle. During the pulse the material bridged over these areas is removed, thereby allowing particulate to leak through. As soon as the pulse dissipates, material tends to bridge over the holes again, eventually healing the area. As the size of the holes and tears grows, the duration of the puff increases. Continuous emissions results when the holes and tears become too large to bridge over.

The discharge of solids from the filter hopper should be observed if there is a safe and convenient means to do so. Solids are usually discharged on a fairly continuous basis (following each pulsing of a row).

4. Inspection Methodology (Continued)

B. Diagnostic Evaluation

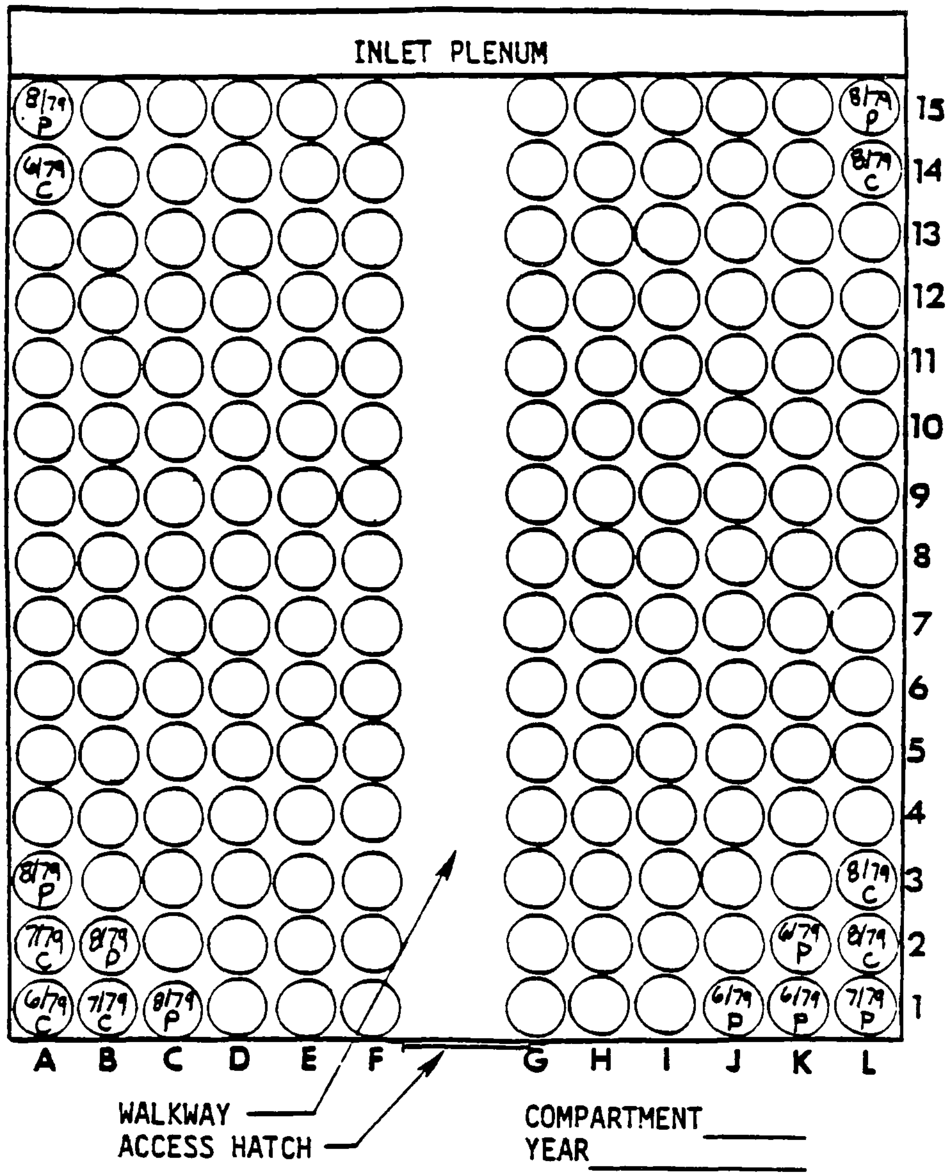
If the opacity is high (continuous or puffs).	For top load type designs check the clean side of several compartments - IF THESE CAN SAFELY BE ISOLATED BY THE OPERATOR AND IF NO POLLUTANT CAPTURE PROBLEMS WILL RESULT AT THE SOURCE ORIGIN. Even slight dust deposits can be a sign of major problems (most of the dust in the clean side plenum is carried out due to the relatively high gas velocities). Dust near one or more bag outlets may suggest inadequate sealing on the tube sheet. Holes and tears may disperse dust throughout the top side of the tube sheet thereby making it difficult to identify the bag with the hole. The operator may wish to use fluorescent dye at a later date to identify the problem.
If the pressure drop is high, opacity is high, and/or process fugitive emissions are noted.	For a top access type design, the possibility of blinding of the fabric can be checked from the top access hatch. Oil and water in the compressed air line is sometimes partially responsible for the blinding which takes part of the fabric area out of service. For conventional pulse jet collectors the possibility for blinding can only be checked at the dirty side access hatch. Safety requirements apply as above. A crusty cake is sometimes evidence of excessive moisture and/or sticky deposits on the bags.
Opacity is continuously high, frequent bag failures are reported, failures are primarily at the bottom.	For both types of pulse jet collectors, it is possible to suffer premature bag failure at the bottom if the support cages are slightly warped and the bags rub at the bottom. This can be checked from a dirty side access hatch.

Inspection Methodology (Continued)

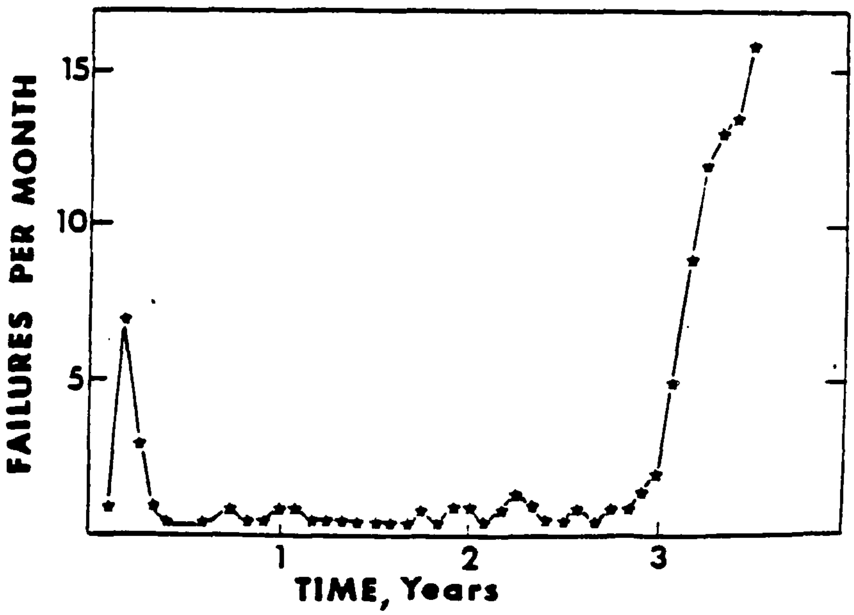
Note: The hatches at the tops of hopper areas should only be opened by the operator and then with extreme caution. Hot solids can flow rapidly out of these hatches.

If available, the bag failure charts for the baghouse should be examined. A sample chart is shown in the adjacent figure. The plan view sketch shows the pattern of bag failures since the last rebagging. If there is a distinct spatial pattern, it is quite possible that the damage is due to abrasion (inlet gas blasting, inlet swirling, and/or rubbing against internal supports). By including the date of the bag removal, and the elevation of the apparent damage (T-top, M-middle, B-bottom) it is possible to identify many common modes of failure. Operators using such charts have been able to minimize both excess emission incidents and bag replacement cost. A rapid increase in the rate of failure often suggests that there has been significant deterioration of fabric strength due to chemical attack, high temperature excursions, or simply normal exhaustion of the material (see lower figure).

If there are any bags which have been removed from service recently and will be discarded, a simple rip test should be performed. If it is possible to rip the cloth by inserting a screw driver and pulling, it is probable that the bag damage was the result of chemical attack, high temperature excursions, moisture attack, or routine fabric exhaustion. Most fabrics damaged by abrasion related problems can not be ripped, even near the site of the damage.

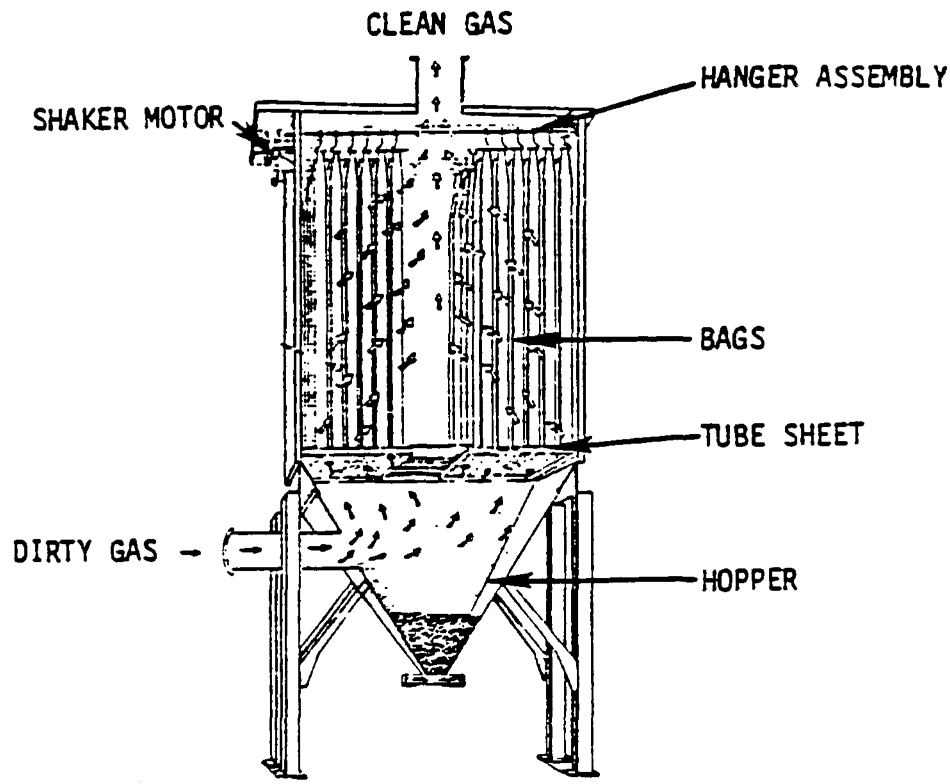


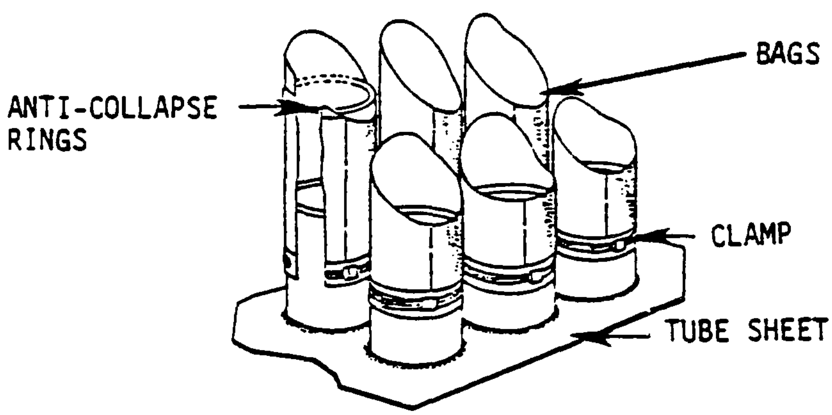
BAG FAILURE CHART



4. Inspection Methodology (Continued)

Opacity is high and there is a distinct pattern to the types of holes and tears.	Bag and cage assemblies which have been removed previously should be carefully inspected. Often the point of bag failure is next to a sharp point on the support cage. Premature failure may also be caused by cages which do not provide enough support for the fabric. If all the bags have failed at the top, there is a possibility that the compressed air nozzles are misaligned and therefore, the pulse is directed at a narrow area at the top of the bag.

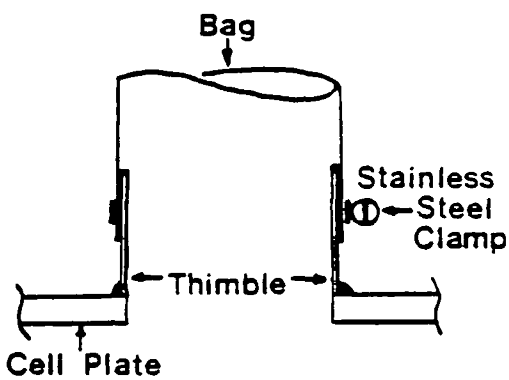




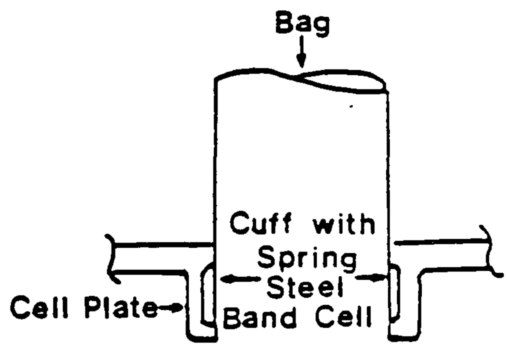
SOURCE: Air Pollution Training Institute

1. Components and Operating Principles

Most commercial units use a woven fabric bag which is suspended from the top of the compartment and clamped to the tube sheet below. The bags do not usually have interior cages, however, most have several sewn anti-collapse rings to facilitate discharge of collected dust. The particulate laden gas stream enters the baghouse below the tubesheet and passes up through the inside of each bag. The dust cake, which is responsible for most of the filtering, builds up on the inside surface. On a regular schedule, each of the compartments are isolated from the main gas stream and the bags are cleaned. In shaker units, the bags are gently shaken for 5 seconds to 2 minutes using a mechanical assembly with oscillations of approximately 4 cycles per second. For a reverse air collector, a fan is used to direct some filtered or ambient air through the bags from the outside to the inside thereby dislodging the dust cake. After each shake or reverse air cleaning period it is usually desirable to have a brief null period before restoring the effluent gas flow through the bags.



Thimble Connection



Snap Band Connection

Bags may be clamped to the bottom tube sheet either by clamping to a raised thimble or by expansion of the bag shape ring into a recess below the tube sheet. The thimble should be high enough to absorb some of the abrasive action of the entering gas stream. It also must have rounded edges to reduce the cutting of the bags during the cleaning cycle. The snap ring assemblies must be snug to reduce the chance of leakage. The tube recesses for the snap rings must be well cleaned before installing new bags and the bag snap rings must not be permanently disformed.

Tensioning of a bag is very important. For shaker units it is possible to check bag tension by grasping the bag between two fingers and twisting. If it is possible to rotate it more than 45 degrees, then the tension is probably too low. If the shaker bag is completely taut, then there is a risk that it will be pulled loose from the tube sheet during cleaning. The reverse air bag, on the other hand, should be completely taut in appearance.

1. Components and Operating Principles (Continued)

The useful life of bags is primarily dependent on the following: (1) proper fabric selection and baghouse design to minimize chemical attack and abrasive failure, (2) proper cleaning intensity and frequency, (3) proper start-up procedures to minimize acid dewpoint problems, and (4) operation below the maximum rated temperature of the fabric. Operation on a continuous basis should usually be approximately 50°F below the maximum rated temperature stated in the adjacent table. Short term temperature excursions more than 50°F above the maximum rated temperatures can lead to bag loss even when the duration of the incident is only 5 to 10 minutes.

The maximum rated temperatures and general performance characteristics of common commercial fabrics is listed in the following table.

The comments concerning the variability of pressure drop in pulse jet collectors are also applicable to reverse air and shaker collectors. The Air-to-Cloth ratios are usually between 1 and 3 ft/min. As with pulse jet collectors, the local "velocities" through a given compartment and between compartments may differ significantly.

PROPERTIES OF COMMON CC   CIAL FABRICS

Fabric	Generic name	Maximum Rated Temperature, °F	Acid resistance	Fluoride resistance	Alkali resistance	Flex and abrasion resistance
Cotton	Natural fiber cellulose	170	Poor	Poor	Fair-good	Fair-good
Wool	Natural fiber protein	170	Very good	Poor-fair	Poor-fair	Fair
Nylon	Nylon polyamide	200	Fair	Poor	Very good-	Very good-
Polypropylene	Polyolefin	200	Excellent	Poor	Excellent	Very good-excellent
Polyethylene	Polyolefin	200	Very good-excellent	Poor-fair	Very good-excellent	Good
Orlon®	Acrylic copolymer	225	Good-excellent	Poor-fair	Fair	Fair
Dynel®	Modacrylic	275	Good-very good	Poor	Good-very good	Fair-good
Dacron®	Polyester	275	Good	Poor-fair	Fair-good	Very good
Ryton®	Polyphenylene sulfide	375	Good-excellent	Good	Good-excellent	Excellent
Nomex®	Nylon arimid	400	Fair	Good	Excellent	Very good-excellent
Teflon®	Fluorocarbon	500	Excellent	Poor-fair	Excellent	Fair
Fiberglass	Glass	500	Fair-good	Poor	Fair	Poor
Stainless steel (type 304)		1500	Excellent	Excellent	Excellent	Good

2. Baseline and Diagnostic Inspection Data

Stack	Average Opacity Opacity During the Cleaning Cycles (for each compartment)
Fabric Filter	Date of Compartment Rebagging Inlet Static Pressure (Average) Outlet Static Pressure (Average) Minimum, Average, and Maximum Gas Inlet Temperatures Average O_2 and CO_2 Concentrations (Combustion Sources Only) Average O_2 and CO_2 Concentrations (Combustion Sources Only) Time to Complete a Cleaning Cycle of All Compartments Length of Shake Period Length of Null Period Bag Tension (Qualitative Evaluation) Rate of Dust Discharge (Qualitative Evaluation) Presence or Absence of Audible Air Infiltration Presence or Absence of Clean Side Deposits
Stack Test	Emission Rate Gas Flow Rate Stack Temperature O_2 and CO_2 Content Moisture Content
Fan	Fan Speed Fan Motor Current Gas Inlet and Outlet Temperatures Damper Position

3. Routine Inspection Data

Stack	Average Opacity Opacity During the Cleaning Cycles (for each compartment)
Fabric Filter	Inlet and Outlet Static Pressures Inlet Gas Temperature Rate of Dust Discharge (Qualitative Evaluation) Presence or Absence of Audible Air Infiltration Presence or Absence of Clean Side Deposits Ripping Strength of Discarded Bags

4. Inspection Methodology: The following sequence of inspection steps is often the most expeditious and effective means to identify abnormal operating conditions of typical pulse jet fabric filters. As with other types of air pollution control devices the inspector should respect the complexity of the interrelated operating variables.

A. Routine Evaluation

Confirm Process Operation -	The sources controlled by the fabric filter should be very briefly checked to confirm that operation is representative.

4. Inspection Methodology (Continued)

Evaluate Plume Characteristics - Determine the average opacity. Most reverse air and shaker collectors operate with less than 5% opacity. Values approaching this may suggest operating problems. If the opacity drops when a specific compartment has been isolated for cleaning it is a probable sign of holes or tears of bags in that compartment. Often shaker collectors have opacity spikes immediately following the cleaning cycle. Both conditions warrant further evaluation.

Fabric Filter - The pressure drop across the collector should be noted. If there is an on-site gauge, proper operation of the gauge should be confirmed. If there is some question about the condition of the gauge or its connecting lines, the inspector should request plant personnel to disconnect one line at a time to identify any plugged or crimped lines (disconnecting lines may not be possible if there is a differential pressure transducer connected to the gauge lines).

If the on-site gauge is not operational or not available, the static pressure drop should be measured using portable instrumentation. Preferably these meaurements should be made at isolated ports installed specifically for the portable instrumentation. It is important to make the measurements on the inlet and the outlet one at a time so that plugged tap holes and lines can be identified. Care must be exercised while rodding out tap holes since on some designs it is possible to poke a hole in the bag adjacent to the tap hole.

The pressure drop across each compartment should be determined during the cleaning cycle. In shaker collectors, the pressure drop during the cleaning of a compartment should be zero. Nonzero values indicate damper leakage problems. In reverse air collectors, back flow will cause a measurable pressure drop with a polarity opposite that of the filtering cycle.

4. Inspection Methodology (Continued)

If there is no on-site gauge and the unit operates at an elevated gas temperature, then the gas temperature should be measured. This can be done at a point on the inlet duct to the collector or at one of the tap holes (if direct access to the interior of the collector is possible).

The rate of solids discharge should be checked if this can be done safely and conveniently. Solids are usually discharged only during the beginning of the cleaning in each compartment.

Air inleakage through access hatches, solids discharge valves, hopper flanges, and fan isolation sleeves should be quickly checked by listening for the sound of inrushing air.

B. Diagnostic Evaluation

If air leakage is suspected, or gas outlet temperature is low, or pressure drop is low.

Check O_2 and CO_2 levels at the inlet and outlet of combustion source fabric filters. The measurement point on the inlet must be between the solids discharge valve and the tube sheet, so that the potential inleakage at this point is also taken into account. There should not be more than a 1% rise (e.g. in at 6% O_2, out at 7% O_2) in the O_2 levels going from the inlet to the outlet.

If the opacity is high continuously or during most of the operating period, or the pressure drop is much greater than the baseline, or the pressure drop is much lower than the baseline.

The presence and nature of the clean side deposits should be checked by viewing conditions from the hatch. Note: The compartment must be isolated by the operator before attempting to do the internal inspection. All safety procedures must be carefully followed. The inspector should not, under any circumstances, enter the compartment.

Inspection Methodology (Continued)

The presence of snap ring leakage is often indicated by enlarged craters in the clean side deposits around the poorly sealed bags. Holes and tears can sometimes be located by the shape of dust deposits next to the holes.

Poor bag tension is readily apparent from the access hatch. Improper discharge of material from the bags can often be confirmed by noting that the bags close to the hatch are full of material one or more diameters up from the bottom. Deposits on the bags should also be noted.

If there is more than a trace of material on the clean side tube sheet, it is probable that emissions from this compartment have been and may still be substantially above the baseline levels.

If available, the bag failure charts for the baghouse should be examined. A sample chart is shown in the section on pulse jet collectors. The plan view sketch shows the pattern of bag failures since the last rebagging. If there is a distinct spatial pattern, it is quite possible that the damage is due to abrasion (inlet gas blasting, inlet swirling, and/or rubbing against internal supports). By including the date of the bag removal, and the elevation of the apparent damage (T-top, M-middle, B-bottom) it is possible to identify many common modes of failure. Operators using such charts have been able to minimize both excess emission incidents and bag replacement cost. A rapid increase in the rate of failure often suggests that there has been significant deterioration of fabric strength due to chemical attack, high temperature excursions, or simply normal exhaustion of the material.

4. Inspection Methodology (Continued)

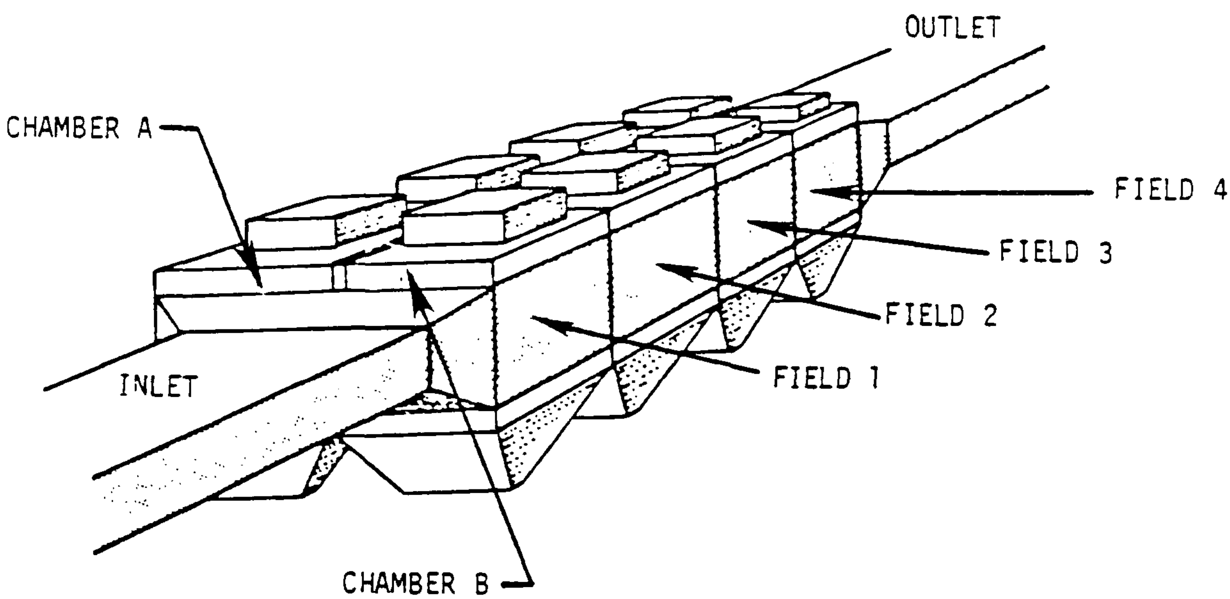
If there are any bags which have been removed from service recently and will be discarded, a simple rip test should be performed. If it is possible to rip the cloth by inserting a screw driver and pulling, it is probable that the bag damage was the result of chemical attack, high temperature excursions, moisture attack, or routine fabric exhaustion. Most fabrics damaged by abrasion related problems cannot be ripped, even near the site of the damage.

Components and Operating Principles

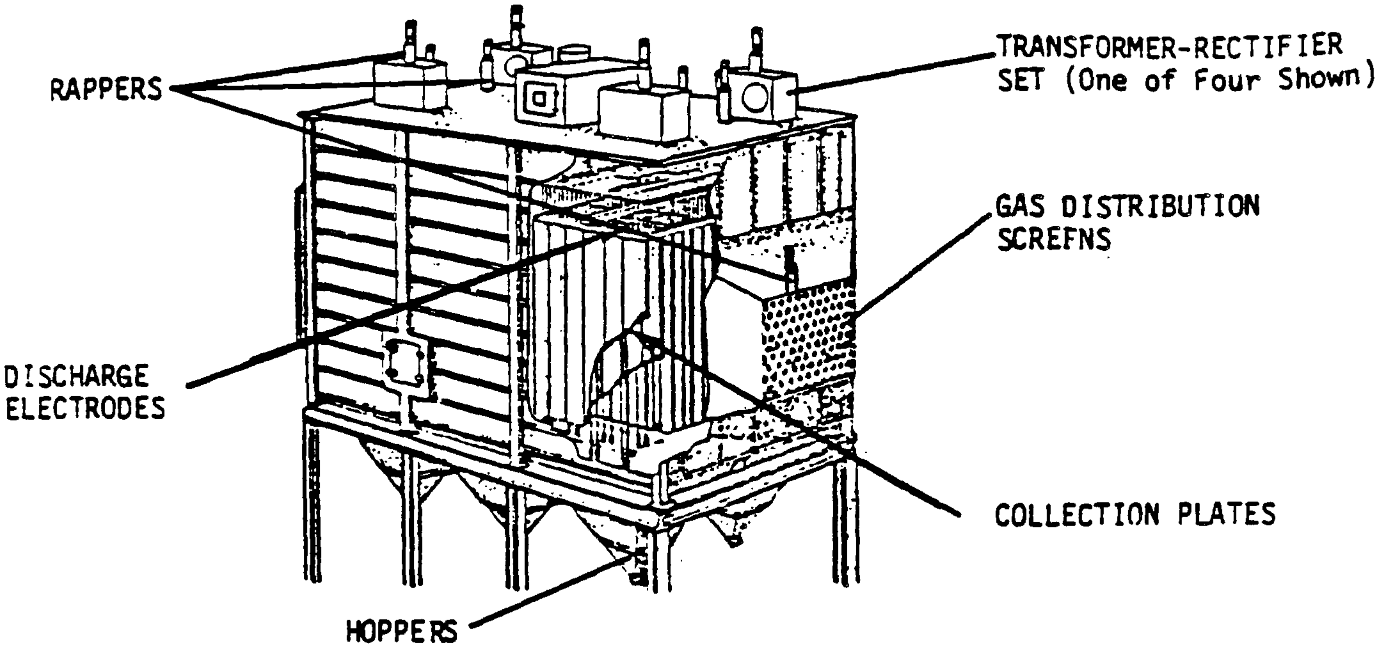
Gas entering the electrostatic precipitator is decelerated to an average velocity ranging from 2 to 8 feet per second. Gas distribution screens minimize the variability of local velocities at the precipitator inlet (see top figure on next page). There are a number of power supplies, termed transformer-rectifier sets, on the top of the precipitator to energize the various fields. Each transformerrectifier (T-R) set converts alternating current at 400 - 480 volts A.C. to a pulsed direct current at 15,000 to 60,000 volts. Each T-R set is connected to a set of the discharge wires or electrodes (see lower figure). The large collection plates and the precipitator shell are grounded.

Ions formed near the discharge wires impart an electrical charge on the particles causing the particles to migrate toward the collection plates at a rate dependent on the size of the particles and the strength of the electrical field.

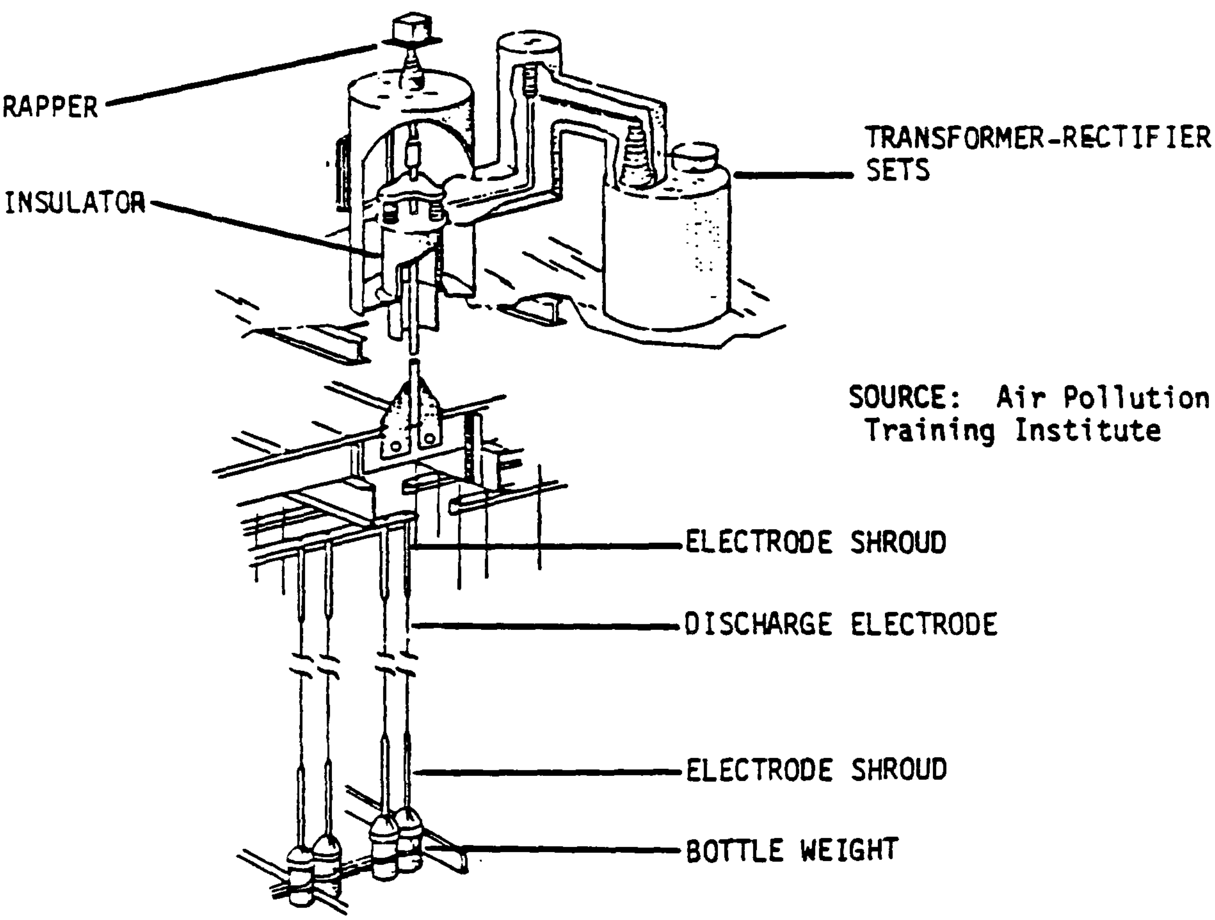
The rappers are used to routinely remove solids from the collection plates, discharge wires, and gas distribution screens.



SOURCE: Air Pollution Training Institute



SOURCE: Air Pollution Training Institute



SOURCE: Air Pollution Training Institute

1. Components and Operating Principles (Continued)

The T-R sets are arranged in series and operate independently. Each field removes 70%-85% of the particulate that enters, therefore most of the material is removed in the initial fields.

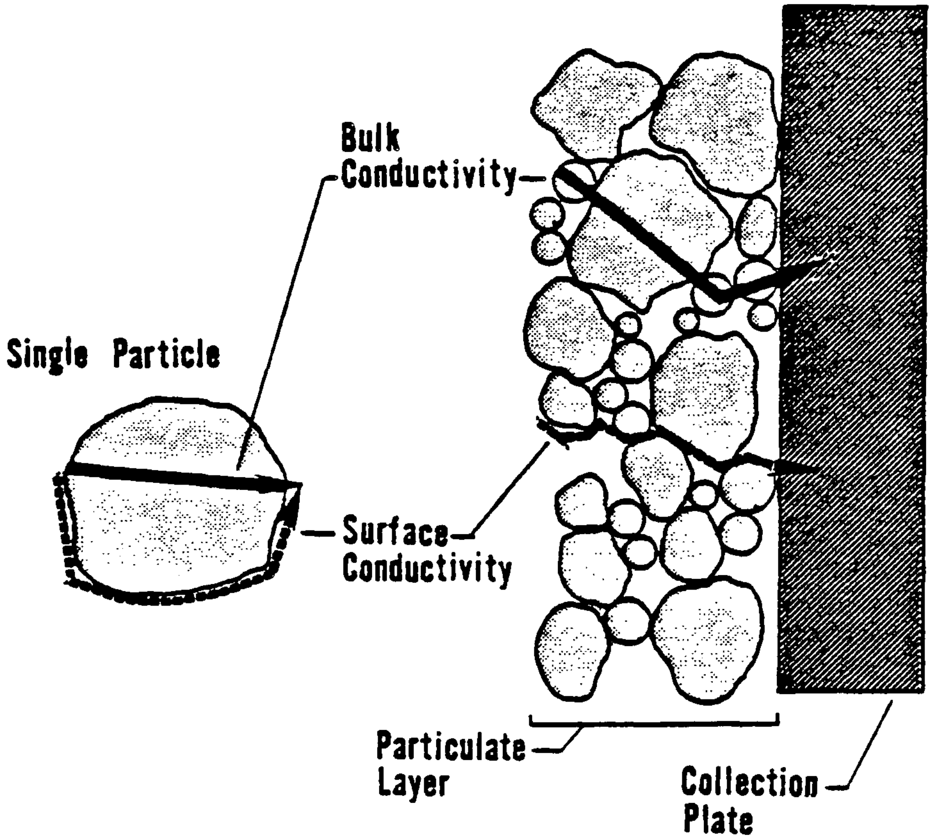
Many precipitators have parallel sets of fields termed chambers. Solid partitions prevent gas flow between chambers.

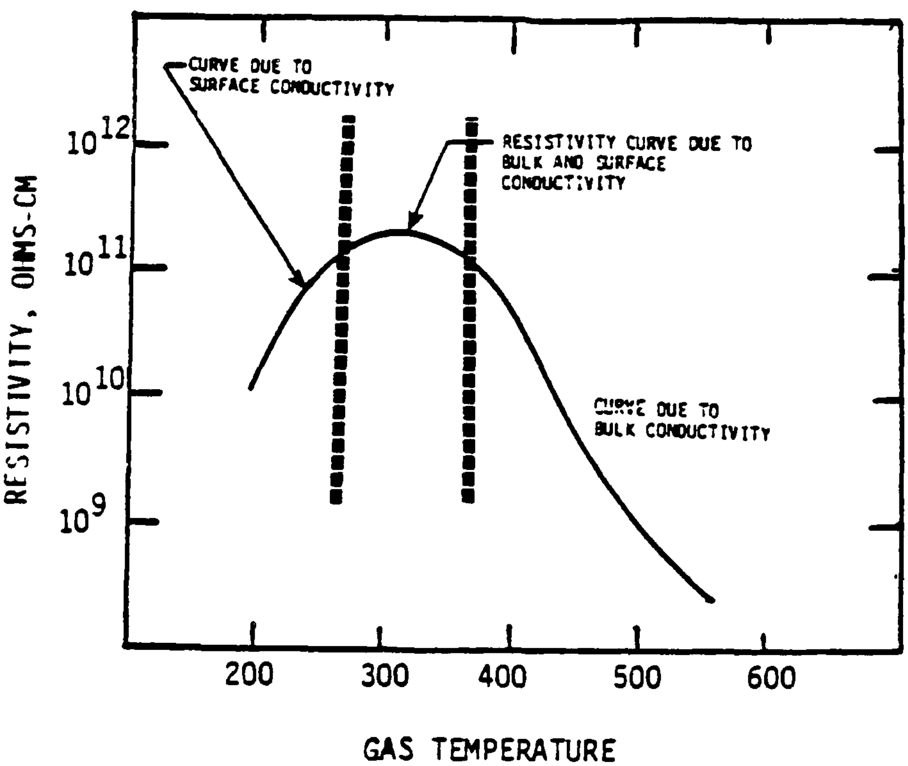
Once the particulate accumulates on the collection plates, the static electrical charge must be dissipated to the ground (see top figure). When the resistivity of the material is high, the dissipation of the charge is difficult. This charge on the particles tends to hold the dust layer on the plates thereby reducing the power input and increasing the necessary rapping intensity. Units with high resistivity rarely suffer rapping reentrainment, however the reduced power consumption can significantly reduce particle collection.

When the resistivity of the material is low, the dissipation of the charge is very rapid. The dust layer is only weakly held to the plates, thereby favoring reentrainment if rapping is too intense, if the gas distribution is poor, if the gas velocities are high in certain areas, and if the aspect ratio is high. Power inputs significantly above baseline levels may indicate increased emissions due to low dust resistivity.

The electrical charge can be conducted along the outer surface of the particles in the dust layer if the gas temperature is low enough to allow adhesion of water molecules, sulfur trioxide molecules, or similar charge carrying species. The effectiveness of this charge dissipation path is very sensitive to temperature (below 350°F) with shifts of only 10° to 20°F sufficient to cause major resistivity shifts.

If the temperature is high, the charge can be dissipated along a path through the bulk of the particle. The resulting resistivity-temperature curve is shown by the dark line. Between the zone of surface conductivity and the zone of bulk conductivity there is a peak resistivity value. The peak resistivity and the position of the peak relative to gas temperature may shift due to a variety of factors.


Bulk Conductivity
Single Particle
Surface Conductivity
Particulate Layer
Collection Plate


CURVE DUE TO SURFACE CONDUCTIVITY
RESISTIVITY CURVE DUE TO BULK AND SURFACE CONDUCTIVITY
CURVE DUE TO BULK CONDUCTIVITY
RESISTIVITY, OHMS-CM
10^12
10^11
10^10
10^9
200
300
400
500
600
GAS TEMPERATURE

Baseline and Diagnostic Inspection Data

Stack	Average Opacity Peak Opacity during Puffs Duration and Timing of Puffs Presence of Detached or Secondary Plumes
Precipitator	Primary Voltages (Volts, A.C., in all fields) Secondary Voltages (Kilovolts, D.C., in all fields) (Note: This is often not available) Primary Currents (Amps, A.C., in all fields) Secondary Currents (Milliamps, D.C., in all fields) Spark Rate (in all fields estimated by counting the fluctuations of the primary voltage meter) Air Inleakage through Hoppers and Hatches (Qualitative Evaluation) Rapper Frequencies and Intensities Gas Inlet Temperatures Gas Outlet Temperatures
Stack Test	Particulate Emission Rate Gas Flow Rate Gas Oxygen, Carbon Dioxide, and Moisture Concentrations
Process	Production Rate Raw Material Composition

Routine Inspection Data

Stack	Average Opacity Peak Opacity during Puffs Duration and Timing of Puffs Presence of Detached or Secondary Plumes
Precipitator	Primary Voltages (Volts, A.C., in all fields) Secondary Voltages (Kilovolts, D.C., in all fields) (Note: This is often not available) Primary Currents (Amps, A.C., in all fields) Secondary Currents (Milliamps, D.C., in all fields) Spark Rate (in all fields estimated by counting the fluctuations of the primary voltage meter) Air Inleakage through Hoppers and Hatches (Qualitative Evaluation) Gas Inlet Temperatures

4. Inspection Methodology: The following sequences of inspection steps are often the most expeditious and effective means to identify abnormal operating conditions of electrostatic precipitators. While the conclusions which may be reached regarding the general types of operating problems are often valid, the inspector should always respect the complexity of the numerous interrelated operating variables that affect

4. Inspection Methodology (Continued)

A. Routine Inspection

Confirm Process Operation - The source controlled by the electrostatic precipitator should be very briefly checked to confirm that operation is representative.

Evaluate Plume Characteristics - Determine average opacity and presence or absence of unusual plume characteristics such as detached zones or secondary formation. If puffing is observed, the timing and intensity of the puffing should be recorded.

Transmissometer - Determine shifts in average opacity during the previous 4 to 8 hours. The intensities and frequency of emission spikes should be carefully evaluated. If the instruments are accessible, the adequacy of the purge air blowers, optical alignment, and mounting should be confirmed.

Precipitator Electrical Cabinets - Record power data for each chamber, starting with the inlet field and proceeding in order to the outlet fields. The primary voltages and secondary currents should be plotted. If the resistivities are in the moderate range, the secondary currents will increase from inlet to outlet while the voltages will drop slightly. The spark rate (estimated by counting the fluctuations of the primary voltage meter) will usually decrease from inlet to outlet.

When the above trends are not apparent and/or all of the fields have shifted significantly from baseline levels, the most probable cause is a change in particle resistivity. This could be due to a change in gas temperatures, raw material/fuel composition, or process operation changes.

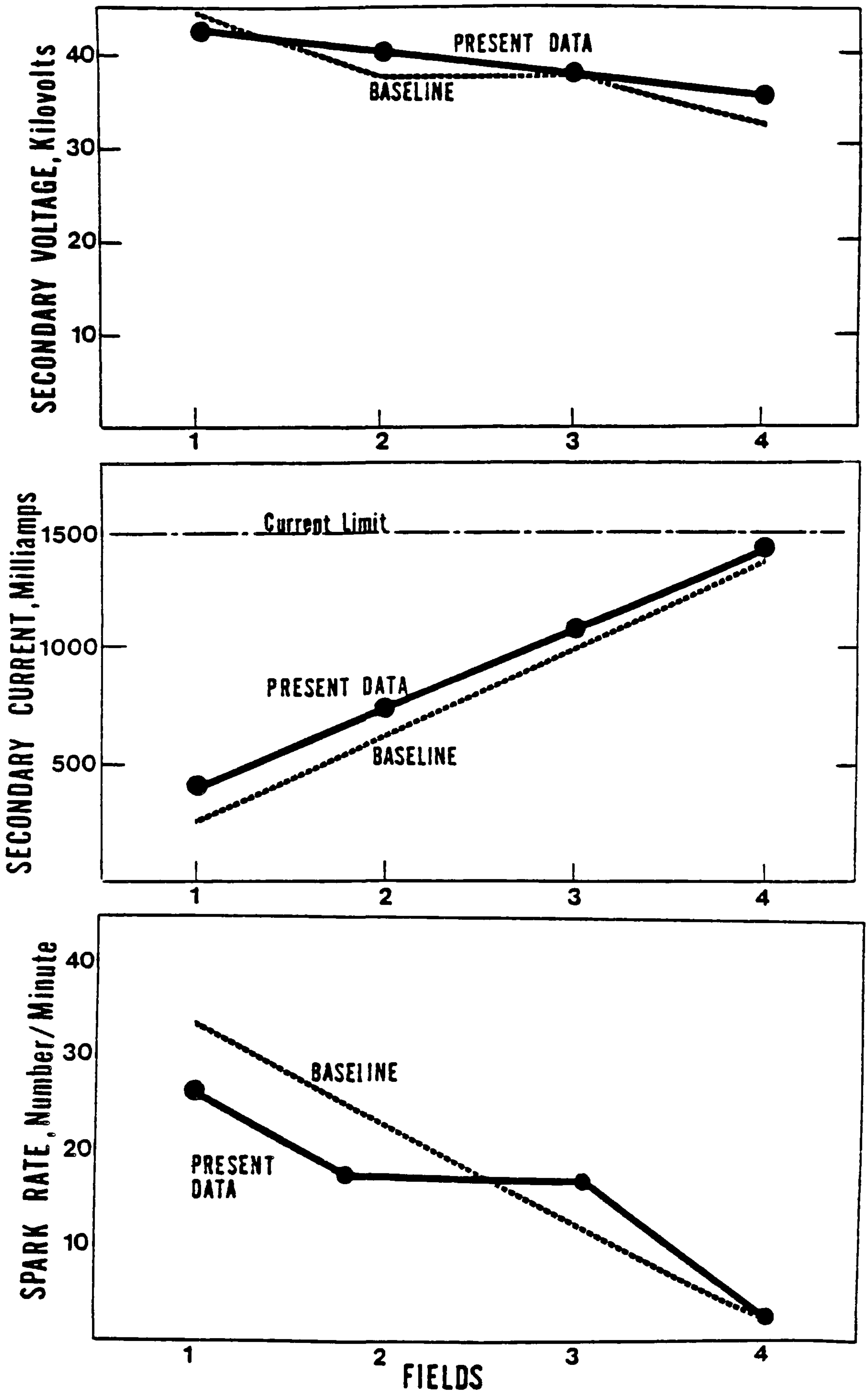
4. Inspection Methodology (Continued)

A typical set of curves for a unit (one chamber, four fields in series) having moderate resistivity is shown on the following page. If there is an increase in the resistivity the secondary currents in all fields will drop substantially, while the spark rate will increase even in the outlet field (field 4). Under low resistivity conditions, the secondary currents will increase substantially, limited only by the current limit of the T-R set. Sparking during low resistivity conditions will be very low even in the inlet field. While these curves are generally applicable, it should be noted that a number of practical opperational factors can alter the trends on a given unit. This can occur due to operation under manual control or due to undersized T-R sets.

By plotting the voltage, current, and spark rate curves in the vertical arrangement (see opposite figure), it is possible to quickly scan the data for shifts in the voltage/current ratio for a given power supply. This is a good indication of internal component problems and shifts in resistivity.

If only a small section of the precipitator exhibits unusual electrical readings, the most probable cause is one or more mechanical problems. This includes, but is not limited to, rapper failure, insulator failure, discharge wire movement and malalignment, hopper overflow, and air inleakage.

If the average opacity is close to baseline levels and the field-byfield trends are typical of moderate resistivity, and there are no observed puffs, then the


SECONDARY VOLTAGE, Kilovolts
40
30
20
10
PRESENT DATA
BASELINE
1
2
3
4
SECONDARY CURRENT, Milliamps
1500
1000
500
Current Limit
PRESENT DATA
BASELINE
1
2
3
4
SPARK RATE, Number/Minute
40
30
20
10
BASELINE
PRESENT DATA
1
2
3
4
FIELDS

Inspection Methodology (Continued)

inspection should be terminated since the precipitator is probably performing close to baseline levels. If abnormal operating variables are noted then the inspection should proceed with the Diagnostic Inspection.

B. Diagnostic Evaluation

If the power input to a large part of the precipitator has dropped, and the secondary currents (milliamps, D.C.) have dropped significantly, and the sparking rate has increased even in the outlet fields, then it is possible that the dust resistivity has increased since the baseline period.

Check for changes in the inlet gas temperature. For cold-side utility boiler units a shift upward may be significant. Also check fuel sulfur content of fuel. Any conditions which favor SO_3 formation should also be evaluated (such as excess air rates). For certain sources, the moisture content is important.

The degree to which the emissions have increased due to the increase in resistivity can be roughly estimated using the power input-mass emission correlation (See equations at end of the Section).

It is important to evaluate power input on a chamber by chamber basis. In some units there is a significant difference in the dust resistivities in the various chambers and this can have a large impact on emissions while the overall power input for the total system remains relatively unchanged.

If puffing is observed at the stack or on the transmissometer strip chart, and the secondary currents on most fields including the inlets have increased to values close to the T-R set ratings, and the sparking rate has decreased, then it is possible that the dust resistivity has decreased significantly since the base-line period.

If possible check for changes in the inlet gas temperatures (using plant instruments). For coldside utility boilers, a downward shift of only 10°-20°F may be significant. Also check fuel sulfur content, and the composition of collected material (carbonaceous material often reduces resistivity).

4. Inspection Methodology (Continued)

Units with excessive rapping intensities, low aspect ratios, and/or high gas velocities (such as greater than 5-6 fps) may be prone to reentrainment. The rappers should be checked for frequency and intensity.

Emissions generally increase as the power input is increased when the resistivity is low. The degree of problem can not be estimated using available correlations. The increase in opacity (averaging in the puffs) provides a more reliable rough estimate.

If the "normal" secondary current trends, primary voltage trends, and spark rate trends are observed, it is probable that the dust has a moderate resistivity.

If several fields are out of service on a unit with moderate resistivity, the increase in emissions from baseline levels can be roughly estimated using a power input-mass emissions correlation. If this is not available assume each field removes 75% of the particulate matter entering the field. Therefore, a single chamber unit with 3 fields would have a fractional penetration equivalent to 0.25 x 0.25 x 0.25 which is approximately 0.02. The same unit with one field out of service would have emissions of 0.25 x 0.25 or approximately 0.06.

If there are apparently low secondary currents in a small segment of the precipitator and the resistivity is in the moderate to high range, then it is possible that some of the collection plate rappers are not working.

Check rapper operation on the roof of the precipitator. Proper operation should be determined by listening to each rapper as it is activated. Do not touch the rappers since in some very unusual cases, the D.C. power may be on outer case of the rappers.

If voltages are low in one or more fields and the currents have increased the problem may be due to a high resistance short or to "tracking" on the high voltage insulator(s). This may result in insulator failure and T-R set trip out.

Check operation of insulator heaters (if present) by checking indicator light usually in precipitator substation. If penthouse purge air blowers are present, these should be checked. The blowers are usually on the precipitator roof.

Inspection Methodology (Continued)

If a number of fields are out of service due to wire failure, it is possible that the fundamental causes include: electrical erosion at "end-of-fields", electrical erosion at points of close clearance, corrosion and/or metal fatigue at crimps.

Often it is possible to examine a number of the wires which have already been removed. These are usually left on the precipitator roof and/or next to access hatches. To the extent possible, the mode of failure should be determined by checking the type and location of the failure. The operator's proposed corrective action to minimize future wire breakage should be discussed in some detail.

ESP APPROXIMATE ESTIMATE OF POWER INPUT

Using Secondary Voltages

$$\text{Watts} = \sum_{i=1}^{n} \begin{matrix}\text{Secondary}\\ \text{Voltge}\\ (\text{kv})\end{matrix} \times \begin{matrix}\text{Secondary}\\ \text{Current}\\ \begin{pmatrix}\text{ma}\\ \text{d.c.}\end{pmatrix}\end{matrix}$$

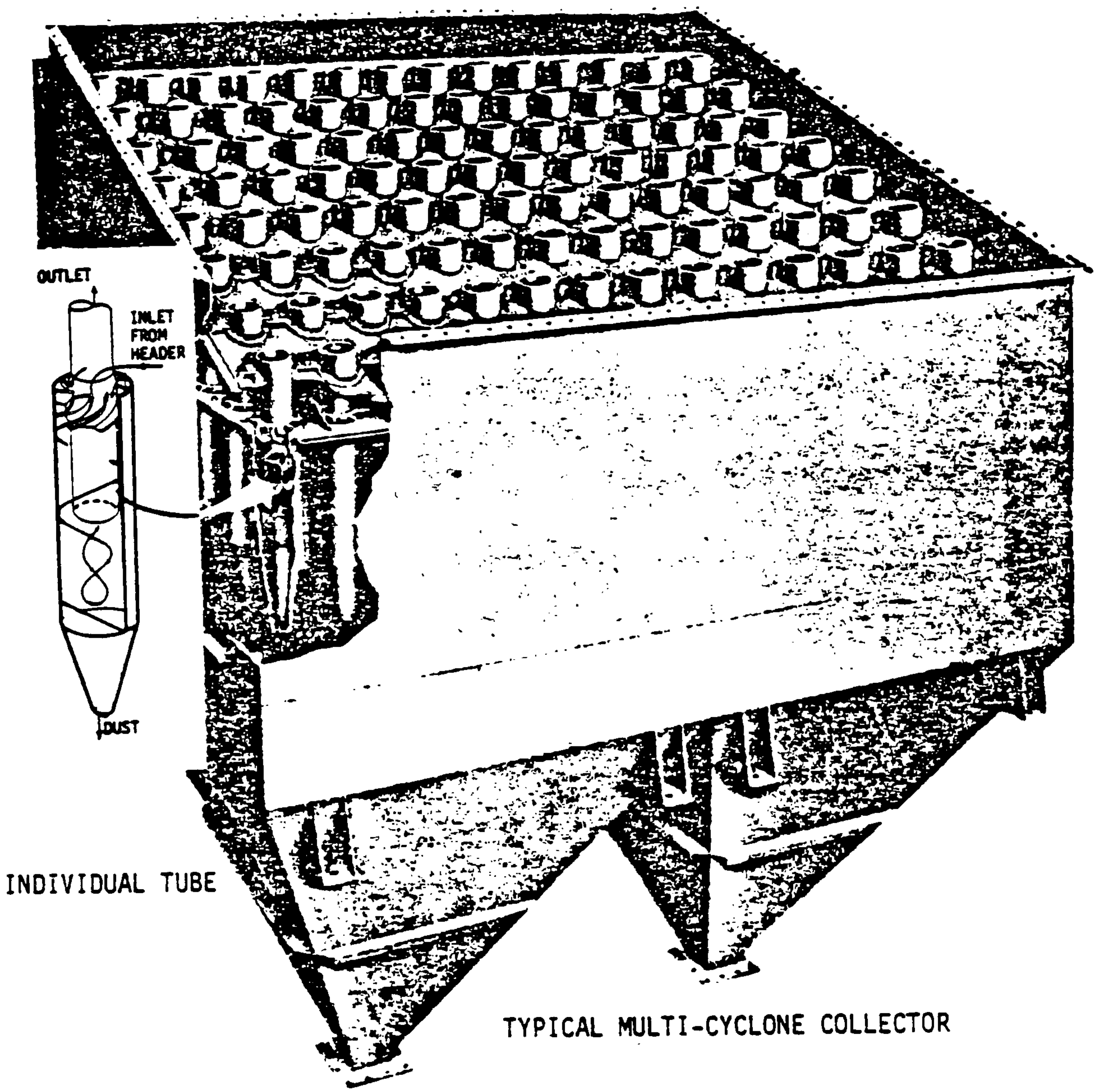
where: n = no. of fields in the chamber

$$\text{Power Input} = \frac{\text{Watts}}{\text{ACFM} \times 10^3}$$

Using Primary Voltages

$$\text{Watts} = \sum_{i=1}^{n} \begin{matrix}\text{Primary}\\ \text{Voltge}\\ \begin{pmatrix}\text{volts}\\ \text{a.c.}\end{pmatrix}\end{matrix} \times \begin{matrix}\text{Primary}\\ \text{Current}\\ \begin{pmatrix}\text{amps}\\ \text{a.c.}\end{pmatrix}\end{matrix} \times 0.75$$

$$\text{Corona Input} = \frac{\text{Watts}}{\text{ACFM} \times 10^3}$$



SOURCES: Howden, James & Co. Ltd. and Joy Manufacturing Co.

1. Components and Operating Principles

In a cyclone or a cyclone tube, a vortex is created within the cylindrical section by either injecting the gas stream tangentially or by passing the gas stream through a set of spinner vanes. Due to particle inertia, the particles migrate across the vortex gas streamlines and concentrate near the cyclone wall. Near the bottom of the cyclone cylinder the gas stream makes a 180 degree turn and the particulate matter is discharged either downward or tangentially into hoppers below. The treated gas passes upward and out of the cyclone.

1.1 Simple Cyclones

The simple cyclone consists of an inlet, cylindrical section, conical section, gas outlet tube, and the dust outlet tube. On some units there is a solids discharge valve such as a rotary valve or a flapper gate. A typical tangential inlet, axial outlet cyclone is shown in the adjoining figure.

Particle separation is a function of the gas flow throughout the cyclone cylindrical diameter. At higher gas flow rates and smaller cylinder diameters the particle inertia is greater thereby resulting in higher collection efficiency. There is an upper limit, however, where the increased turbulence caused by higher gas velocities can disrupt the particle collection.

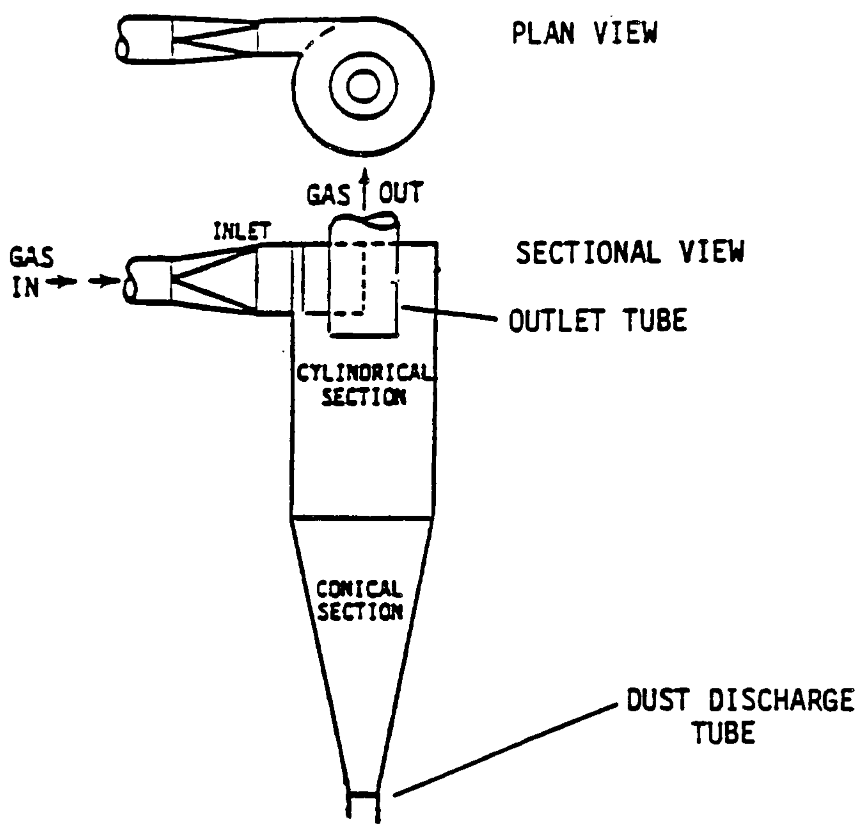
Medium efficiency single cyclones are usually less than 6 feet in diameter and opperate at static pressure drops of 1 to 4 inches of water. Overall collection efficiency is a function of the inlet particle size distribution.

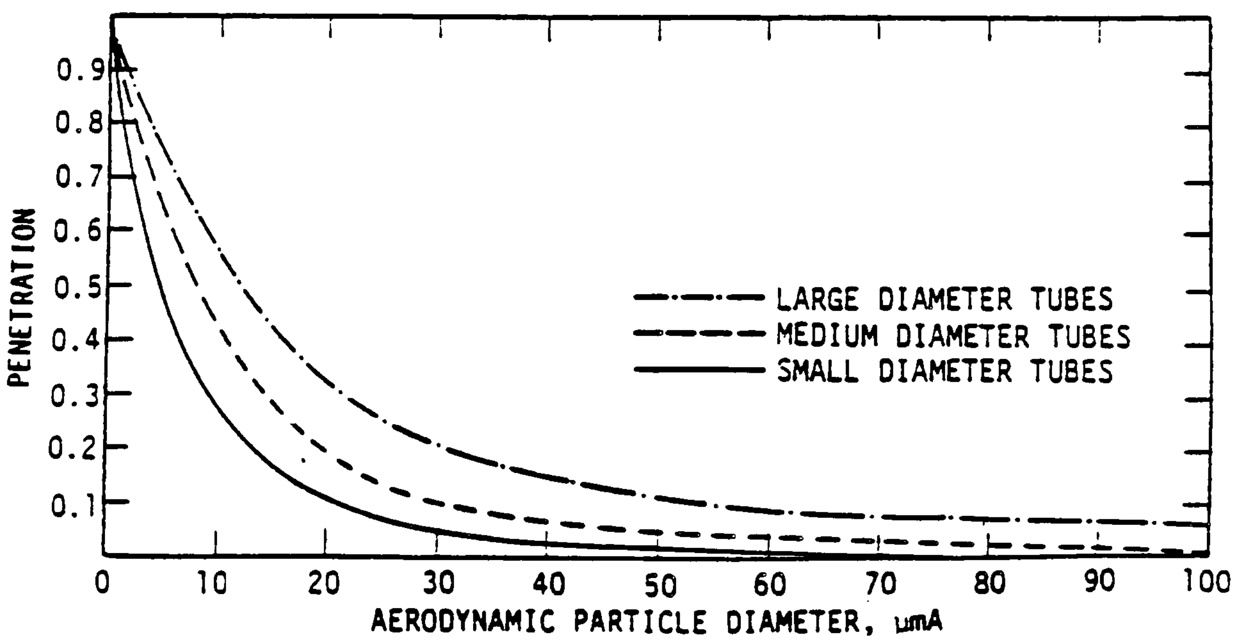
1.2 Multiple Cyclones

A multiple cyclone consists of numerous small-diameter cyclones operating in a parallel fashion. The high efficiency advantage of small-diameter tubes is obtained without sacrificing the ability to treat large effluent volumes.

The individual cyclones, with diameters ranging from 3 to 12 inches, operate at pressure drops from 2 to 6 inches of water. The inlet to the collection tubes is axial, and a common inlet and outlet manifold is used to direct the gas flow to a number of parallel tubes. The number of tubes per collector may range from 9 to 200 and is limited only by the space available and the ability to provide equal distribution of the gas stream to each tube. Properly designed units can be constructed and operated with a collection efficiency of 90 percent for particles in the 5 to 10 μmA range. The importance of particle size is illustrated in the collection efficiency curves shown in the figure. For any given particle size, the collection efficiency is a strong function of the gas flow rate. Multiple cyclones are less efficient at low flow rates than at the design flow rates.

It is important that the inlet duct to the multiple collector be properly oriented so there is no induced gas maldistribution among the cyclone tubes. There must also be allowances for the expansion of the ductwork and collector as the equipment heats up to normal operating temperatures.


PLAN VIEW
GAS OUT
INLET
GAS IN
SECTIONAL VIEW
OUTLET TUBE
CYLINDRICAL SECTION
CONICAL SECTION
DUST DISCHARGE TUBE


PENETRATION
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
LARGE DIAMETER TUBES
MEDIUM DIAMETER TUBES
SMALL DIAMETER TUBES
0
10
20
30
40
50
60
70
80
90
100
AERODYNAMIC PARTICLE DIAMETER, umA

Baseline and Diagnostic Inspection Data

Stack/ Discharge	Average Opacity Minimum and Maximum Opacities Duration and Timing of Puffs
Fan	Presence or Absence of Vibration Fan Speed Motor Current Inlet Gas Temperature
Cyclone/Multiple Cyclone	Inlet Static Pressure Outlet Static Pressure Inlet Gas Temperature Outlet Gas Temperature Inlet O_2 & CO_2 Concentrations (Combustion System) Outlet O_2 & CO_2 Concentrations (Combustion System) Gas Flow Rate (Pitot Tube or Process Estimate) Solids Discharge Rate (Qualitative Estimate)
Stack Test	Particulate Emission Rate Average Opacity Minimum and Maximum Opacities Stack Temperatures Stack O_2 & CO_2 Concentrations

Routine Inspection Data

Stack/ Discharge	Average Opacity Minimum and Maximum Opacities Duration and Timing of Puffs
Fan	Presence or Absence of Vibration
Cyclone/Multiple Cyclone	Inlet Static Pressure Outlet Static Pressure Inlet Gas Temperature (High Temperature Units) Outlet Gas Temperature (High Temperature Units) Inlet O_2 & CO_2 (Combustion Sources Only) Outlet O_2 & CO_2 (Combustion Sources Only) Gas Flow Rate (Pitot Tube or Process Estimate) Solids Discharge Rate (Qualitative Estimate) Integrity of Ducts and Collector Operation of Solids Discharge Valve (If Any) Audible Air Infiltration Apparent Deformation of Cyclone Shell Apparant Corrosion of Cyclone Shell

4. Inspection Methodology

A. Routine Inspection

Confirm Process Operation - The sources controlled by the cyclone/multiple cyclone should be briefly checked to confirm that process operation is representative.

Evaluate Plume Characteristics - Opacity spikes on an intermittant basis may be indicative of process releases of small particles which are beyond the capability of the collector. The duration and timing of the spikes should be recorded so that the process equipment can be inspected later.

On some units the average opacity is not very indicative of operating conditions since the particle size of the material being handled is too large to scatter light effective effectively. Therefore, the opacity can be low while the mass emissions are high. Dust deposits in the immediate vicinity of the discharge point often provide a useful indication of this condition.

Cyclones - Check the pressure drop across the cyclone using the onsite gauge. If this is not available or not operating, use a portable gauge. Lower than normal pressure drops are usually the result of a decrease in the gas flow rate. Erosion of the outlet tubes may cause a similar condition.

Evaluate the integrity of the cylindrical section and the conical section. Deformation of the conical section by a sledge hammer can cause a permanent reduction in the efficiency. Holes due to erosion and corrosion can allow air infiltration with resulting loss in efficiency and a reduction in the gas flow from the process hood.

Evaluate the rate of solids discharged from the conical section (if safe).

Inspection Methodology (continued)

Multiple Cyclones -

The check for air infiltration should be made first. If the collector serves a combustion source, air infiltration can be estimated by measuring the O_2 concentration before and after the collector (CO_2 measurements would also be made in order to confirm the O_2 tests). An increase of more than 1% O_2 indicates an undesirable level of infiltration.

If the unit is not on a combustion source, a general check for infiltration should be made. Audible leaks near the discharge valve, welds, ducts, and access hatches should be noted.

The stactic pressure drop should be measured using the on-site gauge or using portable gauges. At the same locations that the static pressures are measured, the gas temperature should be measured. The gas flow rate should either be measured with a pitot tube or estimated from a process parameter (such as the steam rate at a boiler). Using the equation below, the expected pressure drop should be calculated.

$$\Delta P_{insp} = \Delta P_{base} \left(\frac{(Q_{insp})^2}{(Q_{base})^2} \; \frac{(d_{insp})^2}{(d_{base})^2} \right)$$

where:

Q = flowrate, ACFM

d = density factor, dimensionless

The density factor can be obtained from the psychrometric chart in this notebook.

4. Inspection Methodology (continued)

If the calculated value is not within $\pm 25\%$ of the measured pressure drop, there has probably been a significant change in the resistance to gas flow. Internal problems which may cause this include pluggage of spinner vanes, pluggage of outlet tubes, erosion of outlet tube extensions, weld failures, and gasket failures.

If the oxygen concentration at the inlet to the collector has increased substantially (combustion units), then any observed increase in opacity may be due to combustion related problems.

Check the hopper area for any conditions which would inhibit proper solids discharge. This could include deformations due to sledge hammers, fires, or air infiltration.

B. Diagnostic Evaluation

Audible air infiltration or a measured O_2 increase of more than 1%.

To the extent possible, a check should be made to determine the source(s) of the infiltration. Some common areas include the solids discharge valve, hopper welds, shell welds, and access hatches.

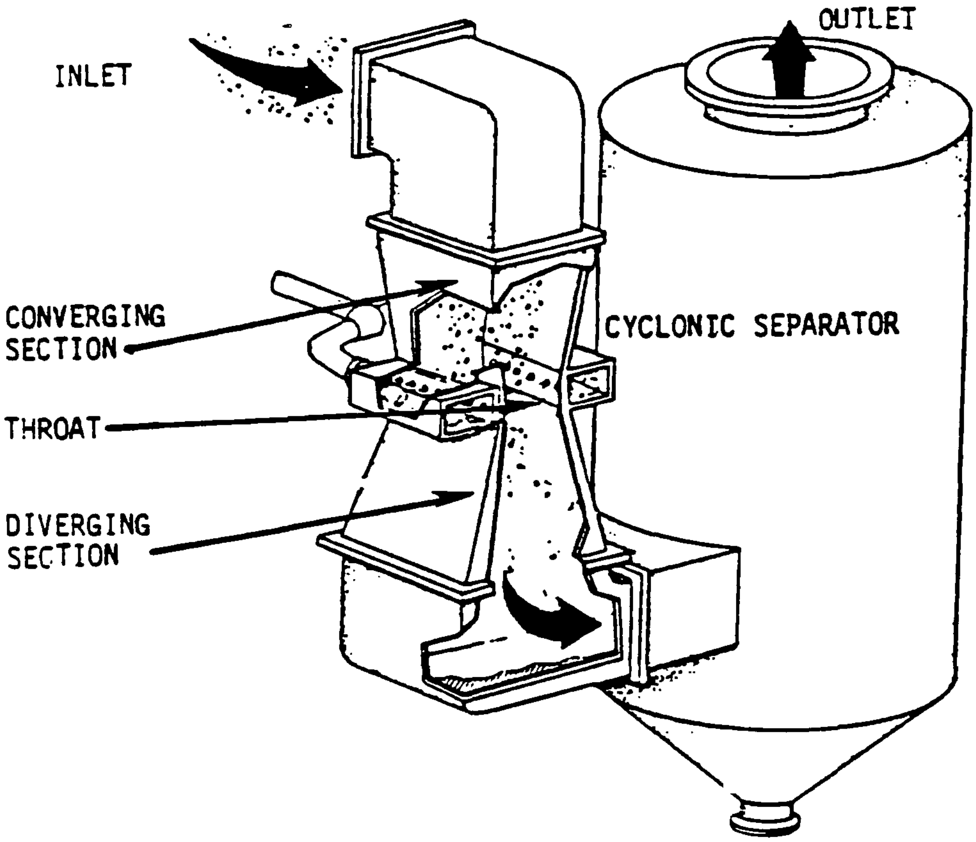
If the problem areas cannot be easily identified and corrected, plant personnel should perform smoke tests.

If the measured pressure drop is less than 75% of the estimated pressure drop and the opacity has incresed slightly.

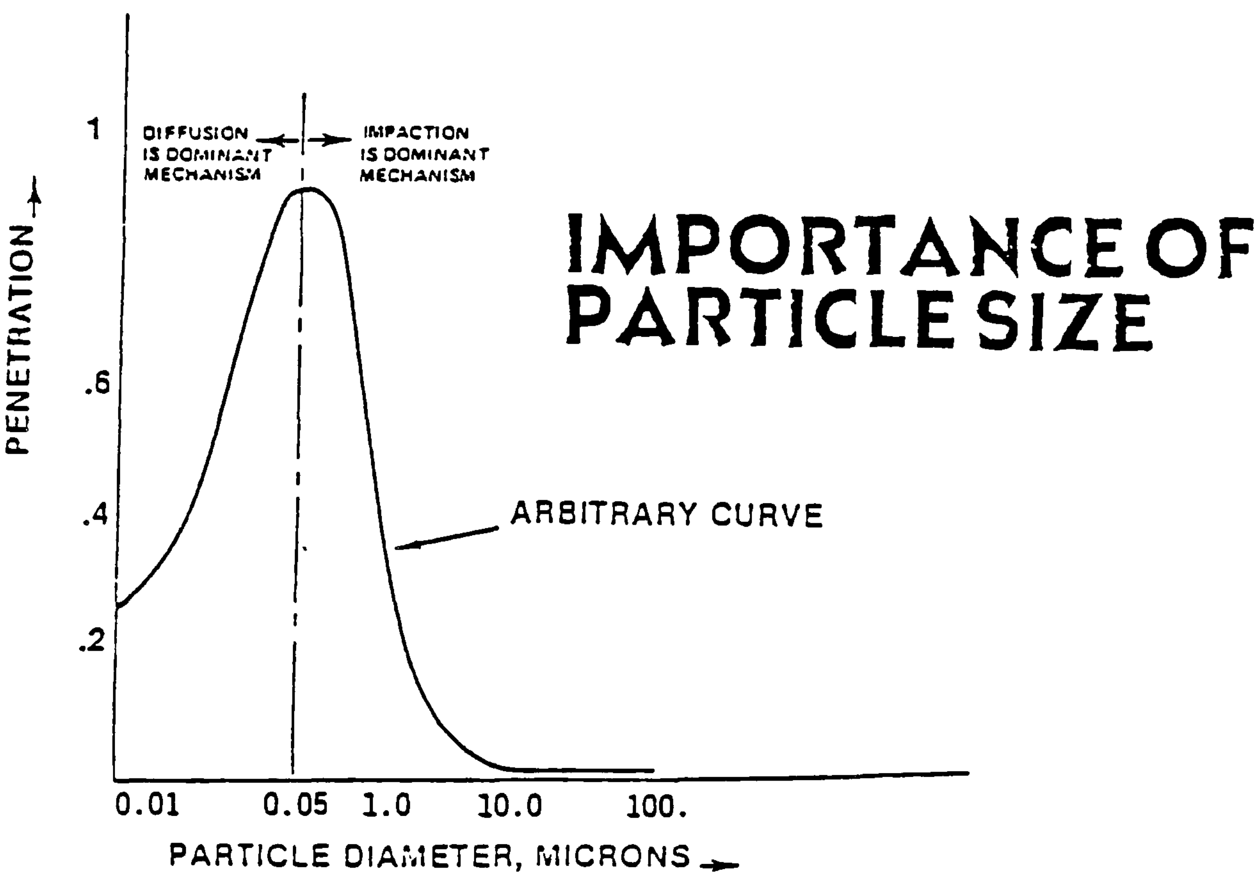
At the earliest opportunity, plant personnel should make an internal inspection to determine if the outlet tube extensions have suffered erosion damage or if any gaskets or tube sheet welds have failed.

Inspection Methodology (continued)

If the measured pressure drop is more than 125% of the estimated pressure drop and the opacity has increased slightly.	At the earliest opportunity, plant personnel should make an internal inspection to determine if there is partial or complete pluggage of the inlet vanes or outlet tubes.
If the opacity has increased slightly but there is no significant air infiltration and the calculated and measured pressure drops are almost equal.	At the earliest opportunity, plant personnel should make an internal inspection to determine if any of the following conditions exist: (1) pluggage of some of the dust outlet tubes, (2) erosion of the hopper baffle plate which inhibits hopper recirculation, or (3) build-up of deposits on the insides of the tubes which results in particle bounce back into the exit gas stream.



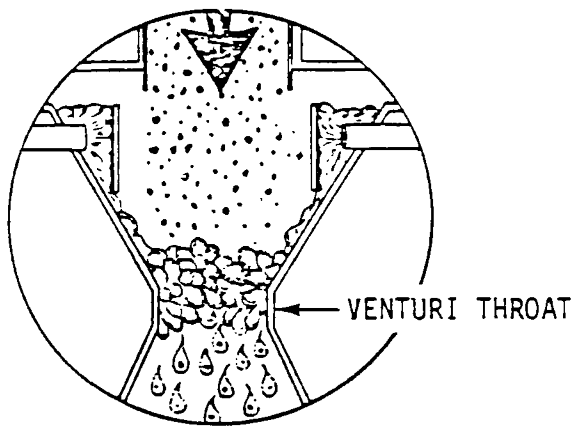
SOURCE: Air Pollution Training Institute



.. Components and Operating Principles

Particulate laden gas from the process source is often treated in a presaturator in order to reduce the inlet gas temperature to the scrubber. As the cooled gas enters the converging section of the venturi it is accelerated. Water injected at this point is atomized to a large number of fine droplets which then serve as targets for the particulate. The large difference between the gas stream and the water droplets' velocities results in impaction of the particles. The effectiveness of the particulate impaction is proportional to the gas velocity in the throat, the effectiveness of the liquor distribution across the throat, and the particle size distribution.

The pressure drop across the throat is directly related to the energy utilized to atomize the liquor and to impact the particles into the droplets. Since the pressure drop is very difficult to measure at this point this value is usually approximated by taking the pressure drop across the scrubber as a unit.



SOURCE: Air Pollution Training Institute

The importance of particle size is emphasized in the adjacent figure. For particles greater than 1 to 2 microns, impaction is so effective that the penetration (emissions) are quite low. Very fine particles in the less than 0.1 micron range are also collected efficiently due to the rapid diffusion of these particles. (Note: Diffusion collection is related to the surface area of droplets and the time available for collection, it is not a strong function of pressure drop). There is a particle range between 0.2 to 1.0 microns where neither impaction nor diffusion is highly effective. Particles in this size range are especially difficult to collect.

2. Baseline and Diagnostic Inspection Data

Stack	Average Opacity Minimum and Maximum Opacities During Process Cycles Mist Reentrainment
Scrubber	Inlet Gas Temperature Outlet Gas Temperature Inlet Static Pressure Inlet O_2/CO_2 Content Outlet Static Pressure Recirculation Liquor pH Recirculation Liquor Suspended Solids Recirculation Rate Recirculatioan Liquor Temperatures Adjustable Throat Mechanism Position Quantity of Surfactant, Flocculant, and/or Anti-foaming Agent Added Per Day Presaturator Total Solids
Stack Test	Emission Rate Gas Velocity and Flow Rates Stack Temperatures Stack O_2/CO_2 Content
Fan	Fan Speed Motor Current Gas Temperature Vibration (Minimal, Moderate, Severe)
Duct Work	Presence or Absence of Holes Hood Static Pressure

3. Routine Inspection Data

Stack	Average Opacity Minimum and Maxzimum Opacity During Process Cycles Presence or Absence of Fallout
Scrubber	Inlet and Outlet Static Pressures Inlet Gas Temperature Liquor Line Skin Temperatures Recirculation Liquor pH Recirculation Liquor Turbidity (Qualitative Evaluation) General Condition of Shell Presaturator Turbidity (Light, Moderate, Severe)
Fan	Vibration (Minimal, Moderate, Severe)
Duct Work	Presence or Absence of Holes Hood Static Pressure

4. Inspection Methodology

A. Routine Inspection

Stack - The opacity of the emissions from the scrubber is usually a good indicator of performance. Unfortunately, the opacity is often difficult to evaluate since the condensed water droplets from the scrubber obscure the light scattering particles. If the plume can be read at the point of discharge, the opacity can have diagnostic meaning.

The average opacity and cycles in the opacity should be determined to the extent possible (see above). The magnitude and timing of the opacity cycles can be of use in determining process operational factors which affect the particle size and quantity of particulate in the gas to the scrubber.

The presence of material fallout near the stack or the presence of a lip of crusted material at the stack mouth both may indicate carryover of material from the demister.

Fan and General System Condition - Excessive fan vibration due either to build-up of material on the blades or erosion of the blades can be a serious safety problem. When excessive vibration is present, the inspection should not be continued since there is a possibility of fan disintegration.

Scrubber Inlet Measurement Port - The port should be upstream from the point of liquor injection and at a position as free of immediate flow disturbances as possible. The static pressure should be measured using the portable static pressure gauge after ensuring that the port is clear. The gas temperature

4. Inspection Methodology (Continued)

should be measured at the same point with care to minimize air infiltration with cooling of the thermocouple probe.

Scrubber Throat - The skin temperatures of all liquor lines to the venturi throat should be checked. Low temperature of one line relative to the other lines may indicate pluggage of that line. This can severely affect emissions since the liquor to gas distribution is usually improper in such cases.

The position of the adjustable throat mechanism should be noted (manual systems only).

Outlet Measurement Port - The static pressure downstream of the throat should be measured. The port should be located after the diverging section of the venturi and preferably before any mesh pads or chevron demisters. These devices add several inches of pressure drop without appreciably affecting particulate efficiency.

Due to the high negative static pressures in this part of the scrubber (sometimes greater than -15 inches), care must be taken to prevent the problems related to air leakage during measurements, such as the aspiration effect.

Recirculation System - The pH for all scrubbers should be measured in a fresh sample of the recirculation liquor which should be requested from the plant representative. If the solution is highly colored or would chemically attack pH paper, a portable pH meter must be used.

4. Inspection Methodology (Continued)

The turbidity of the liquor should be qualitatively evaluated. High levels of suspended solids may result from a reduction of the purge and make-up flows or from higher levels of particulate coming into the system. Operation at very high pH levels (greater than 10) may cause precipitation of materials out of solutions thus causing the same condition. At high levels of suspended solids, nozzles are vulnerable to pluggage and or erosion.

Presaturator - The presaturator liquor turbidity should be checked. The liquor used here should appear very clear. If not, it is possible to reintroduce substantial quantities of material back into the gas stream as the spray droplets evaporate. This can have an adverse impact on the particulate removal efficiency since the particle size of the regenerated material is quite small.

Ducts and Hoods - The ducts leading to and from the scrubber should be checked for holes. Common problems include erosion at elbows, open cleanout ports, and weld failure. The hood static pressure should be recorded since this is related to the total gas flow up through the hood.

B. Diagnostic Evaluation

If the opacity is high or the static pressure drop is low. Check the liquor flow rate at the sump drain, check the pump discharge pressures, and recheck the skin temperatures of the liquor lines to the venturi throat. If possible, request that the operator isolate and rod out nozzles.

4. Inspection Methodology (Continued)

	Check the position of the adjustable throat mechanism. This affects the throat velocity which is a major factor in determining the pressure drop and collection efficiency.
	If liquor flow is close to baseline levels and the throat mechanism is unchanged (or is fixed by design), then reduced gas flow rate is the probable explanation. Check gas flow rate using a pitot tube.
Opacity is high, but static pressure drop is close to baseline levels.	Check for possible condensation of submicron aerosols from organic and/or metallic vapors evolving from the process equipment.
	Check for evaporation regeneration of particulate due to the use of high solids content liquor in quench chambers, presaturators, or atomizing venturi nozzles.
Corrosion damage apparent.	Review properties of materials used in the wet scrubber (see attached table). Depending on type of material, evaluate the specific chemical problems which most likely could occur. This evaluation normally involves liquor analyses for things such as chlorides. A cursory design review can be made to confirm the presence or absence of galvanic cells due to improper contact of dissimilar metals.
Mist reentrainment.	Check the pressure drop across the demister, if possible. An increase in the pressure drop suggests some pluggage of the demister which can lead to localized high velocities. The operation of the demister cleaning sprays should be checked by plant personnel.

4. Inspection Methodology (Continued)

pH less than 6.	A detailed check for corrosion should be made. If there is an alkaline additive system, this should be checked to determine why there is an inadequate addition rate.
Fugitive emissions at the process hood.	Air infiltration points in the scrubber, the fan (especially the isolation sleeves), and the ducts should be checked. On combustion sources, the extent of infiltration should be evaluated using O_2 and CO_2 measurements before and after the scrubber and at various locations along the ducts (if safely accessible). The total gas flow rate through the scrubber can be determined using the pitot tube.

PROPERTIES OF MATERIALS USED IN THE CONSTRUCTION OF WET SCRUBBERS AND AUXILIARY COMPONENTS

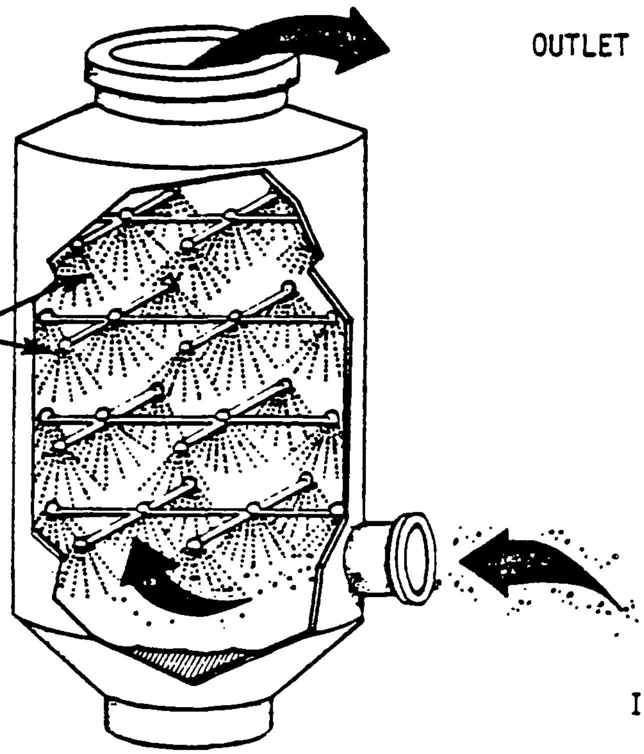
Material	Properties	Corrosion resistance	Uses
Cast iron	High strength; low ductility; brittle; hard; low cost	Gray or white case irons exhibit fair resistance to mildly corrosive environments; high-silicon case irons exhibit excellent resistance in a variety of environments (hydroflouric acid is an important exception); case irons are susceptible to galvanic corrosion when coupled to copper alloys, stainless steels	Pump casings, valve casings, piping; often used with linings in corrosive service
Carbon steel	Good strength, ductility, and workability; low cost	Fair to poor in many environments; low pH and/or high dissolved solids in moist or immersion service leads to corrosion; properly applied protective coatings give appropriate protection in many applications; susceptible to galvanic corrosion when coupled to copper alloys, stainless steels	General purpose in non-corrosive environments
Austenitic stainless steels (201, 202, 301, 302, 304, 310, 316, 317)	Iron-chromium-nickel alloy; not hardenable by heat; hardenable by cold working; nonmagnetic; cost 3 to 10 times more than carbon steel; alloys with "L" designation (e.g., 316L) have lower carbon content for improved weldability	Good in oxidizing environments; fair in non-oxidizing environments; susceptible to pitting and stress corrosion cracking in chloride solutions. Type 310 resists high temperature corrosion; types 316 and 317 contain molybdenum for better chloride and pitting resistance.	Scrubber vessels; fans; stacks and ductwork; mist eliminators; quench chambers

(Continued)

PROPERTIES OF MATERIALS USED IN THE CONST ION OF WET SCRUBBERS AND AUXILIARY COMPONENTS

Material	Properties	Corrosion resistance	Uses
Nickel alloys (Inconel[a], Incoloy[a], Monel[a], Hastalloys[b]-Chlorimet[c], and others)	Good strength, costs more than 10 times as much as carbon steel; also expensive to fabricate; commonly alloyed with chromium, iron or copper	Excellent resistance in most environments; not resistant in strong oxidizing solutions such as ammonium and HNO_2; most have good resistance to stress corrosion; some nickel-copper alloys have good resistance to hydrofluoric acid	Scrubber vessels, fans; stacks and ductwork; mist eliminators
Fiberglass-reinforced plastics (FRP)	Good chemical resistance; poor abrasion resistance; cannot be used in high-temperature service; low hardness	Excellent in many corrisive environments; actual results depend on type of plastic resin used	Scrubber vessels, piping, mist eliminators, ductwork and stacks
Wood	High tensile and shear strength perpendicular to grain; low tensile and shear strength parallel to grain; low hardness; poor abrasion resistance; cannot be used for high-temperature service	Good resistance in dilute acids (including hydroflouric acid); susceptible to biological attack under certain conditions; deteriorates in alkaline solutions	Scrubber vessels, tanks, especially in fluoride exposure; fir and cypress are popular species

[a] Registered trademark of Huntington Alloys, Inc.
[b] Registered trademark of the Stellite Division of the Cabot Corporation
[c] Registered trademark of the Duriron Company, Inc.



SIMPLE SPRAY TOWER SCRUBBER

SOURCE: Air Pollution Training Institute

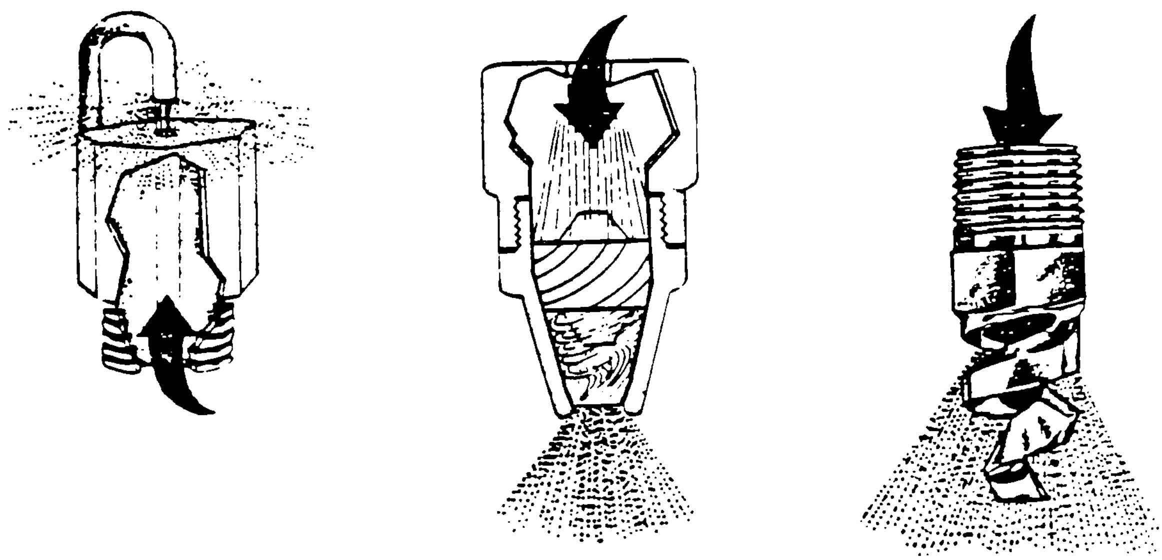
1. Components and Operating Principles

Spray tower scrubbers are the simplest type of wet scrubber and generally have the lowest overall particulate collection efficiency. They are not usually effective for particles below 5 µmA.

This type of scrubber normally consists of a vertical contact chamber with an array of spray nozzles as shown in the figure above. The particle laden gas stream enters near the bottom of the scrubber and passes upward at a velocity of 2 to 4 feet per second. The spray nozzles may consist of sophisticated liquid atomizing nozzles or may simply be small holes drilled into the spray header. The spray droplet size can vary from 200 microns to 1000 microns depending on the type of nozzle and the operating pressure. Particulate collection efficiency is a function of a number of variables including the gas velocity, the spray droplet velocity, the spray droplet size, the nozzle spray angle, the height of the scrubber, and the liquid-to-gas ratio.

Spray tower scrubbers are sometimes used for gaseous absorption and for odor control. In this case, important operating parameters include the liquid-to-gas ratio, the liquor pH (for some applications), and the residence time in the scrubber.

The major components which comprise this type of scrubber system include a demister, a recirculation pump, and a liquor recirculation and treatment circuit. The latter can include clarifiers and alkaline addition systems. In some cases there are no monitoring instruments for liquor pH, liquor flow rate, or gas stream temperature. The most common performance problems include pluggage of the liquor spray nozzles, erosion of the spray nozzles, corrosion of the shell, and mist reentrainment.



a. Impingement spray nozzle

b. Solid cone spray nozzle

c. Helical cone spray nozzle

Common Types of Commercial Spray Nozzles
SOURCE: Air Pollution Training Institute

2. Baseline and Diagnostic Inspection Data

Stack	Average Opacity Minimum and Maximum Opacities During Process Cycles Apparent Mist Reentrainment
Fan	Fan Vibration (Minimal, Moderate, Severe) Fan Speed Fan Motor Current Gas Inlet Temperature
Scrubber	Recirculation Liquor pH Recirculation Liquor Suspended Solids Recirculation Liquor Turbidity (Light, Moderate, Heavy) Recirculation Liquor Flow Rate Nozzle Operating Pressure Apparent Shell Erosion or Corrosion Inlet O_2 and CO_2 (Combustion Sources Only)
Duct Work	Presence or Absence of Obvious Holes Hood Static Pressure Hood Capture Effectiveness (Good, Moderate, Poor)
Stack Test	Emission Rate Gas Flow Rate Stack Temperature Stack O_2 and CO_2
Internal View from Access Hatch (If safe)	Nozzle Condition Presence or Absence of Deposits on Demisters

3. Routine Inspection Data

Stack	Average Opacity Minimum and Maximum Opacities During Process Cycles Mist Reentrainment
Fan	Vibration (Minimal, Moderate, Severe)
Scrubber	Recirculation Liquor pH Recirculation Liquor Turbidity (Light, Moderate, Heavy) Recirculation Liquor Flow Rate Nozzle Operating Pressure Apparent Shell Erosion or Corrosion
Duct Work	Presence or Absence of Obvious Holes Hood Static Pressure

Inspection Methodology

A. Routine Inspection

Stack -

Spray tower scrubbers are usually used only on sources generating large size particulate matter. Due to the low light scattering characteristics of large particulate, a low opacity does not always mean low mass emissions.

The presence or absence of mist fallout in the vicinity of the scrubber discharge should be noted. This is usually a symptom of demister failure. In some cases, this is accompanied by a small deposit of material at the stack discharge.

Opacity spikes on an intermittant basis may be indicative of process releases or small particle size material which is beyond the capability of the collector. The duration and timing of the spikes should be recorded so that the process equipment can be inspected later.

Fan -

Excessive fan vibration either due to build-up of material on the blades of the fan or erosion of the blades can be a serious safety problem. If excessive vibration is present, the inspection should be discontinued immediately because of the possibility of fan disintegration.

Scrubber -

The operation of the recirculation pump and the condition of the liquor piping and nozzles should be checked. An increase in the nozzle operating pressure often indicates partial or complete pluggage of the spray nozzles or spray header. If the nozzle pressure gauge is not operating (or available), the pump discharge pressure should be noted. The liquor flow rate should be checked using the on-site gauge (if available). If there is no gauge it is sometimes possible to estimate the flow rate by observing the discharge from the scrubber to the pond or the recirculation tank.

4. Inspection Methodology (continued)

The integrity of the scrubber shell should be evaluated. If there is apparent erosion or corrosion damage, it is likely that substantial air infiltration is occurring (negative pressure systems). This can reduce source capture effectiveness.

The pH of the recirculation liquor should be measured using a sample from the scrubber sump, the point of minimum pH. Rapid corrosion can occur if the pH in a carbon steel system drops below 6 (a magnet will stick to carbon steel).

Ducts and Hoods - The ducts leading to and from the scrubber should be checked for holes. elbows, open cleanout traps, and weld failure. The hood static pressure should be recorded since it is related to the total gas flow up through the hood.

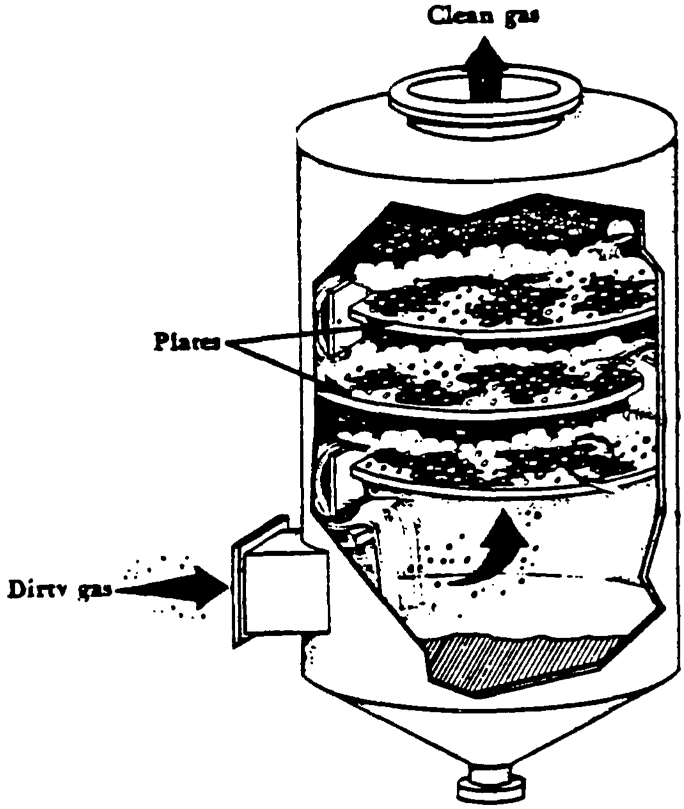
The liquor turbidity should be checked by drawing a sample from the sump discharge or the pump discharge. A high turbidity liquor can cause erosion or pluggage of the nozzles and headers.

B. Diagnostic Evaluation

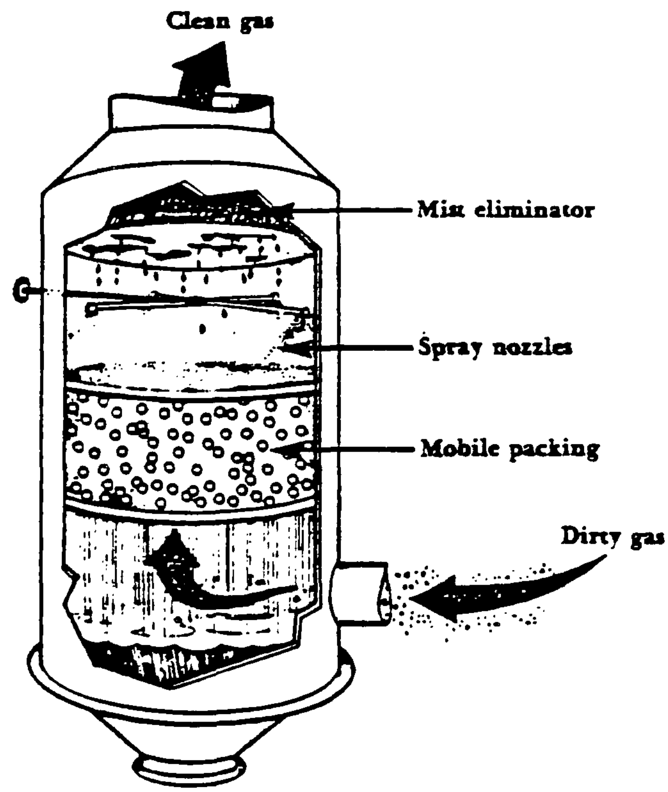
Apparent mist reentrainment. This can be caused by excessive velocities through the scrubber itself or by partial pluggage of the demister. The demister can be checked for pluggage when the scrubber is down and purged. The gas velocities can be checked by dividing the total actual cubic feet per minute (determined by a pitot traverse) by the cross sectional area of the scrubber (in square feet). An increase in the fan R.P.M. or an increase in the fan motor current (corrected to ambient conditions) also indicates an increase in gas flow rates relative to the baseline period.

Inspection Methodology (continued)

High opacity with an increase in the nozzle operating pressure.	The most probable cause of this performance problem is the partial or complete pluggage of spray nozzles or possibly the main supply header. At the earliest opportunity, plant personnel should shut down the unit, purge it, and observe the operation of the nozzles. A distorted spray angle indicates a partial pluggage. A drastically narrowed spray angle indicates almost complete pluggage. Plugged nozzles should be cleaned out or replaced. If there is evidence of frequent nozzle pluggage, the total and suspended solids content of the recirculation liquor should be determined. In the case of a high solids content the liquor treatment system may have to be modified.
Opacity high with a decrease in the nozzle operating pressure.	Nozzle erosion due to high suspended solids can cause these symptoms. The erosion of the nozzle orifice leads to a decrease in the spray angle with a resultingly poor spray distribution across the gas stream. The same symptoms may be caused by a reduction in the liquor flow rate which could occur with pump impeller wear.
pH below 6.	A detailed check for corrosion should be made. If there is an alkaline additive system, it should be checked to determine the cause of the inadequate addition rate.
Fugitive emissions at the process hood.	Check for air infiltration points in the scrubber, the fan (especially the isolation sleeves), and the ducts. On combustion sources, the extent of infiltration should be evaluated using O_2 and CO_2 measurements at various locations along the ducts (if there is safe accessibility) and before and after the scrubber. The total gas flow rate through the scrubber can be determined using the pitot tube.



TRAY-TYPE SCRUBBER
SOURCE: Air Pollution Training Institute



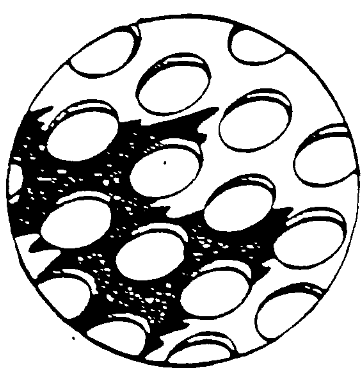
MOVING BED SCRUBBER
SOURCE: Air Pollution Training Institute

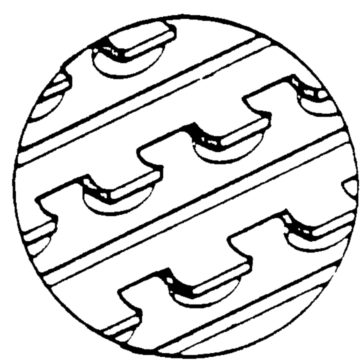
1. Components and Operating Principles

Tray-type, moving bed, and packed bed scrubbers are used primarily for particulate control, however the moving bed and packed bed scrubbers are also frequently used for control of mists and gaseous pollutants. For all three categories of scrubbers, the gas stream is usually introduced into the scrubber near the bottom and passes up through the scrubber in a counterflow manner with respect to the liquor (there is one common packed towever scrubber which is oriented horizontally with the liquor flowing down the packing by gravity). Particulate removal is due primarily to impaction on liquor droplets and liquor sheets. The effectiveness of impaction is proportional (1) to the relative velocity between the particle and the target (droplet or sheet), (2) to the particle density, and (3) to the square of the particle diameter. In some cases, the liquor surface tension and the particle surface characteristics can modify the effectiveness of the impaction capture mechanism. Important parameters with relation to gas absorption include liquor surface area, residence time, and liquor chemical characteristics such as the pH.

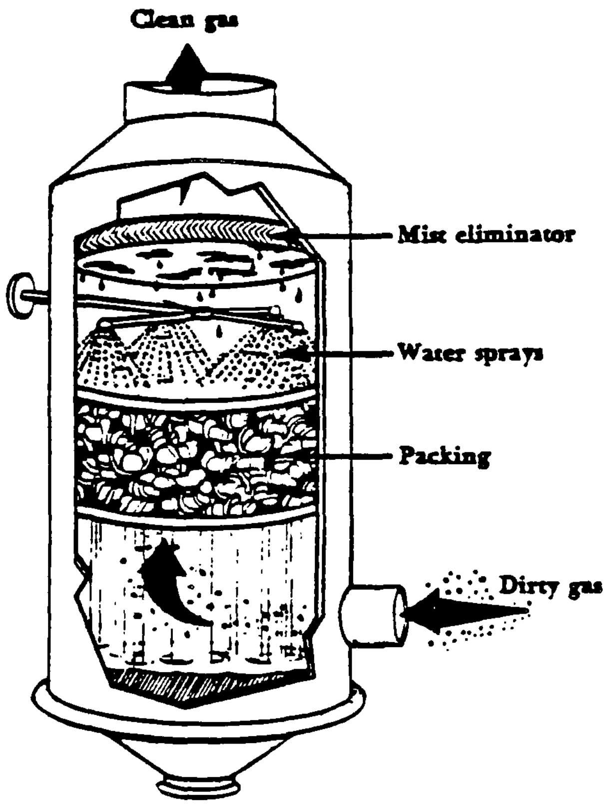
1.1 Tray-Type Scrubbers

Tray-type scrubbers consist of a vertical shell with one or more plates mounted horizontally. The liquor is introduced near the top of the scrubber, below the demister. It flows across the top tray and then down to the lower tray(s) by means of downcomers. (In some units the liquor drains down directly through the tray orifices). As the liquor passes across each stage, it is exposed to the high velocity gas streams passing up through the orifices in the trays. Impaction of the gas entrained particulate occurs on the sheets of liquor and on the droplets which are atomized by the gas stream as it passes up through the tray. The most common types of tray-type scrubbers are the sieve plate and impingement plate scrubbers. The differences in the tray design for these scrubbers is illustrated in the figure below:

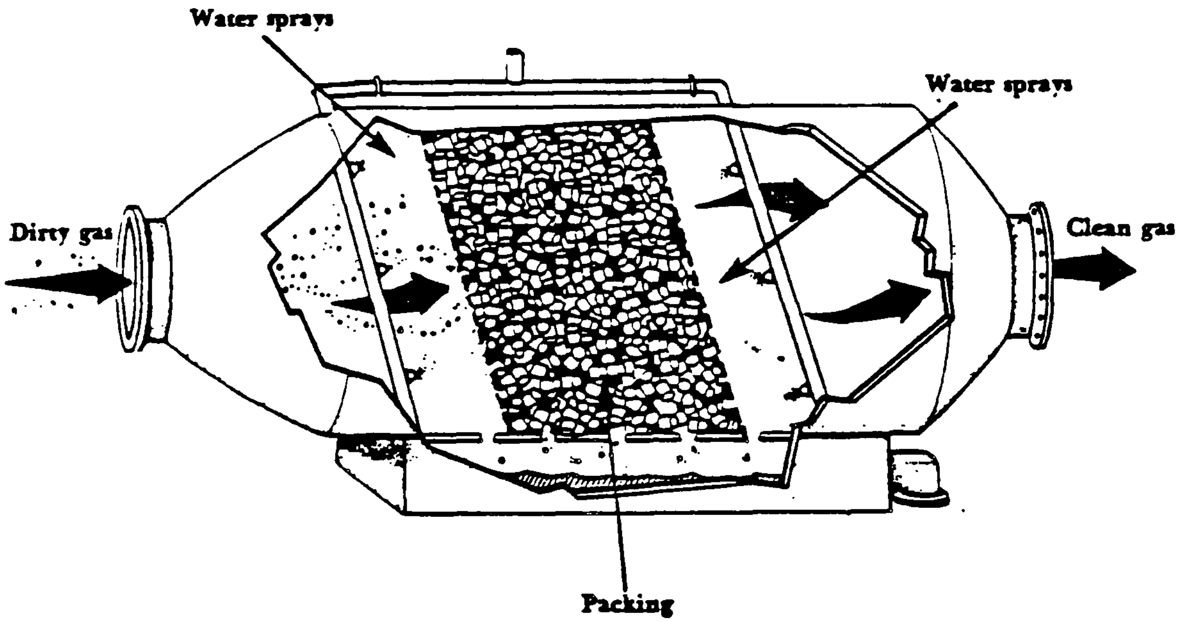




The sieve plate scrubber has moderately large orifices and in some cases the liquor drains down directly through these holes without the need for downcomers. The impingement plate has numerous very small holes and impingement targets above each. The impingement plate scrubber is prone to pluggage problems due to these very small holes.



COUNTERCURRENT PACKED TOWER
SOURCE: Air Pollution Training Institute



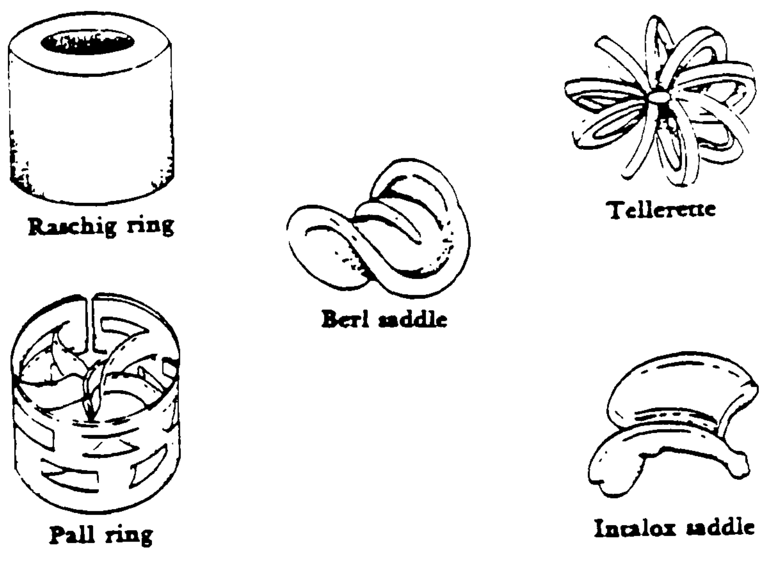
CROSSFLOW PACKED TOWER
SOUREC: Air Pollution Training Institute

1.2 Moving Bed Scrubbers

This type of scrubber includes one or more trays of light weight packing usually consisting of polypropylene or fluorocarbon spheres. This packing is free to move within the bed which is only 20% to 40% full. The packing is restrained by screens above and below the bed. The pollutant laden gas stream passes up through the beds, thereby fluidizing the packing. Particulate and gaseous absorption occurs on the droplets and liquor sheets formed in the turbulent bed. The liquor is introduced near the top (below the demister) using a set of spray nozzles. The demister can be mesh pads, chevrons or an unirrigated bed of packing. The removal efficiencies for particulate matter are very high, even in the 1 to 2 micron size range.

1.3 Packed Tower Scrubbers

A packed tower scrubber is similar to the moving bed scrubber with the exception that the packing is firmly restrained. The liquor is introduced immediately below the demister and passes down through the bed as sheets. The primary purpose of the packing is to maximize the surface area available for absorption of gaseous material. Nozzle pluggage, nozzle erosion, and scaling can all lead to channeling of the liquor (poor liquid-gas distribution). These units are not intended for high efficiency collection of particulate matter in the less than 3 micron range or for sources with high inlet mass loadings; they are better suited for gaseous absorption. Some common types of packings are illustrated below. In some units, gravel has also been successfully used.



Common types of Packing Material
SOURCE: Air Pollution Training Institute

2. Baseline and Diagnostic Inspection Data

Stack	Average Opacity Minimum and Maximum Opacities During Process Cycles Apparent Mist Reentrainment
Fan	Fan Vibration (Minimal, Moderate, Severe) Fan Speed Fan Motor Current Gas Inlet Temperature
Scrubber	Static Pressure Drops Across Each Tray or Bed Presaturator Liquor Total Solids Presaturator Liquor Turbidity (Light, Moderate, Heavy) Recirculation Liquor pH Recirculation Line Pressure at Nozzles (If Any) Inlet and Outlet Gas Temperatures Inlet O_2 and CO_2 (Combustion Sources Only) Apparent Shell Erosion or Corrosion
Duct Work	Presence or Absence of Obvious Holes Hood Static Pressure Hood Capture Effectiveness (Good, Moderate, Poor)
Stack Test	Emission Rate Gas Flow Rate Stack Temperature Stack O_2 and CO_2

3. Routine Inspection Data

Stack	Average Opacity Minimum and Maximum Opacities During Process Cycles Mist Reentrainment
Fan	Vibration (Minimal, Moderate, Severe)
Scrubber	Static Pressure Drops Across Each Tray or Bed Presaturator Liquor Turbidity (Light, Moderate, Heavy) Recirculation Liquor Turbidity (Light, Moderate, Heavy) Recirculation Liquor pH Recirculation Line Pressures at Nozzles (If Any) Apparent Shell Erosion and Corrosion
Duct Work	Presence or Absence of Obvious Holes Hood Static Pressure

Inspection Methodology

A. Routine Inspection

Stack - The opacity is usually a good indicator of scrubber performance. Unfortunately, the opacity is often difficult to evaluate since condensed water droplets obscure light scattering particulate. If the plume can be observed at a point before the condensation of water droplets (preferably at the stack discharge point), the opacity can have diagnostic meaning.

The presence or absence of mist fallout in the vicinity of the scrubber discharge should be noted. This is usually a symptom of demister failure. In some cases, this is accompanied by a small deposit of material in the area of the stack discharge.

Fan - Excessive fan vibration, due either to build-up of material on the fan blades or erosion of the blades, can be a serious safety problem. If excessive vibration is present, the inspection should be discontinued immediately because of the possibility of fan disintegration.

Scrubber - The static pressure drops across each tray or bed should be evaluated using operational on-site gauges or portable instruments. It is important to confirm that the measurement ports are not plugged regardless of which instrumentation is used. The static pressure drops should be be compared with baseline values. A reduction in the static pressure over time is usually due to a decrease in the gas flow rate. An increase could be due

4. Inspection Methodology (continued)

to increased gas flow rate or partial pluggage of the trays or beds.

On combustion sources, the inlet oxygen concentration should be measured and compared with the baseline values. An increase in the O_2 concentration can signal a deterioration in the combustion process and the consequent generation of more particulate than can be adequately controlled in the scrubber.

The recirculation liquor turbidity should be checked. If the turbidity appears high there is the potential for pluggage of the tray orifices (impingement plate scrubber) or build-up within the packing (packed bed scrubber).

The presaturator (if present) liquor turbidity should be checked. The liquor used here should appear very clear. If not, it is possible to reintroduce substantial quantities of material back into the gas stream as the spray droplets evaporate. This can have an adverse impact on the particulate removal efficiency since the particle size of the regenerated material is quite small.

The pH of the liquor leaving the scrubber should be determined by using either the on-site meter of a portable pH meter (or indicator paper). Low pH can have an adverse effect on the ability of the system to absorb gases like HF and SO_2 and may also result in accelerated corrosion of the scrubber shell. A high pH (above 10) indicates

4. Inspection Methodology (continued)

the possibility of precipitation of calcium and magnesium compounds, with a resulting build-up on the packing materials or the walls of the scrubber vessel which ultimately can lead to the gas-liquor maldistribution.

The line pressure at the nozzles should be checked. This is to confirm that there has not been any pluggage or erosion of nozzles themselves which could result in maldistribution of the gas and liquor streams. An increase in the nozzle operating pressure suggests pluggage. A decrease in the pressure relative to the baseline values suggests either a reduction in the liquor flow rate or erosion of the nozzles.

Ducts and Hoods - The ducts leading to and from the scrubber should be checked for holes. Common problems include erosion at elbows, open cleanout ports, and weld failure. The hood static pressure should be recorded since this is related to the total gas flow up through the hood.

B. Diagnostic Evaluation

Opacity is high and static pressure drops across trays or beds are lower than baseline values. - Check the gas flow rate through the scrubber. Confirming symptoms of low gas flow rate include a reduction in the fan motor current (corrected to standard conditions) and a reduction in the scrubber inlet static pressure. The flow rate can be measured using a pitot tube.

4. Inspection Methodology (continued)

	In the moving bed and tray-type scrubbers, the low pressure drops can also be due to a reduced liquor flow rate. This can be confirmed by rechecking the on-site meter, by visually checking flow out of the scrubber sump, or by checking the recirculating liquor nozzle operating pressure.
Opacity is high, but static pressure drops are close to baseline values.	Check for possible condensation of submicron aerosols from organic and/or metallic vapors evolving from the process equipment.
	Check for evaporation regeneration of particulate due to the use of high solids content liquor in presaturators, or quench chambers. To confirm solids levels, analyze liquor samples.
Opacity is high, but static pressure doprss are greater than baseline values or gas flow rates appear to be less than baseline values.	In impingement plate scrubbers, an internal check should be made by plant personnel at the earliest opportunity to determine if there is some pluggage of the tray orifices.
Mist reentrainment.	Check the pressure drop across the demister if possible. An increase in the pressure drop may suggest some pluggage of the demister which can lead to localized high velocities. The operation of the demister cleaning sprays should be checked by plant personnel.
Apparent corrosion damage.	Recheck the liquor pH measured and inquire about start-up and shut-down procedures.

1. General Guidelines

(a) Make measurements only when necessary and with the full knowledge and consent of the operator.

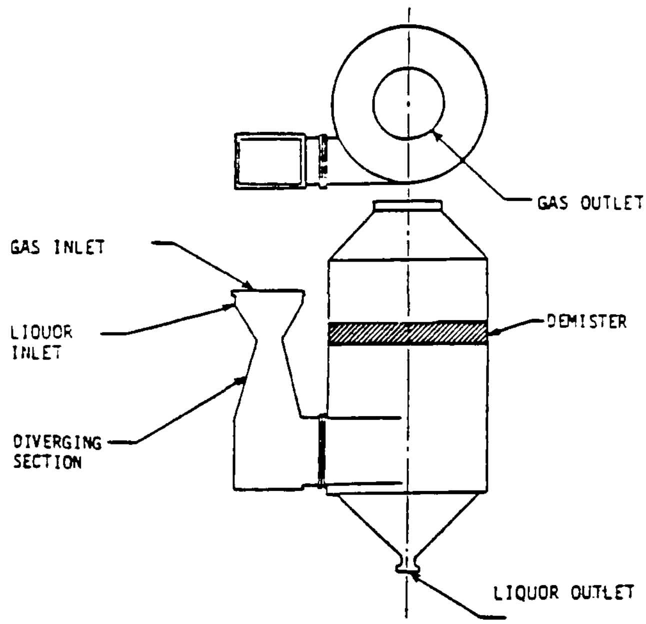
(b) Conform to all union-company policies regarding measurements.

(c) Do not disconnect static pressure lines which lead to a differential pressure (D/P) transducer.

(d) Only measurement ports which are safe and convenient to reach should be used. If appropriate ports are not presently available, modifications can be requested for future inspections. New ports can usually be easily installed at the next major outage. Heroic efforts should not be made to reach improperly located existing ports.

2. Specific Guidelines

(a) The static pressure ports for venturi scrubbers should usually be in the locations shown in the figure below. The inlet port can be anywhere along the inlet duct to the scrubber but it should not be in the immediate area of the liquor injection point since it will be very difficult to keep clear. The outlet port can be anywhere except in the diverging section of the venturi since in some cases it is conceivable that boundary layer separation may occur. If the outlet port is after the demister, the pressure drop for the overall unit will be several inches of water higher than measured just before the demister.



2. Specific Guidelines (Continued)

(b) Almost all electrostatic precipitators have measurement ports for stack sampling. Due to the size of the ducts, however, single point temperature and O_2/CO_2 measurements may not be representative of the bulk gas stream. With such ducts, it is necessary to traverse the duct to measure conditions at as many points as necessary and then average the results. This is not very time consuming for temperature (if a sufficient thermocouple is available) however, it is difficult for the O_2/CO_2 readings. For this reason, such measurements are rarely made.

The large duct problems associated with electrostatic precipitators are also common to large fabric filter systems.

(c) The clean side static pressure port for fabric filters should not be immediately above the tube sheet since the build-up of solids can make it very difficult to keep the port clean during the measurements.

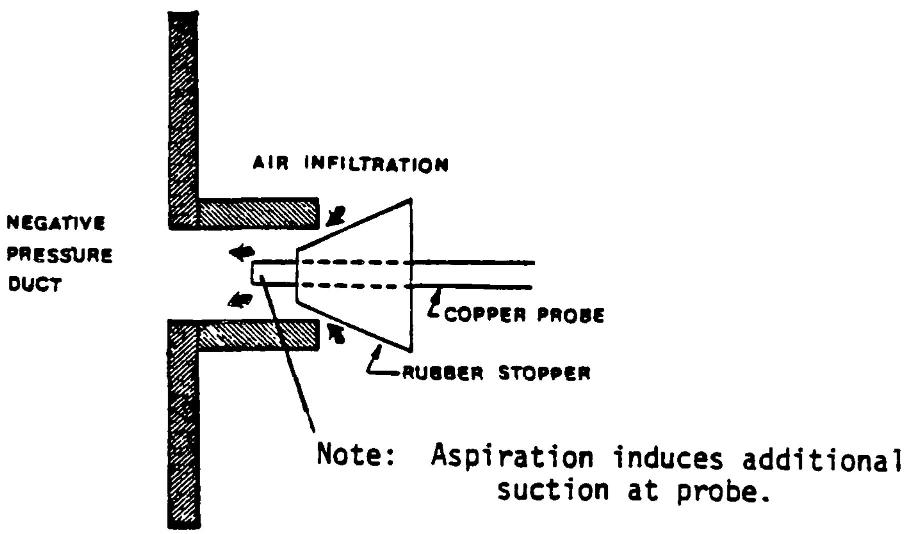
(d) The ports for most fabric filters and mechanical collectors can be anywhere in the ductwork leading to and from the units. The ports should be in areas as far away as possible from flow disturbances and should be approximately 3/4" to 1" in diameter so that a pitot tube can be used.

3. Avoiding the Problems of Air Inleakage through Ports under Negative Pressure

Air inleakage causes the following measurement problems:

Lower than actual Gas Temperatures.
Higher than actual O_2 Levels.
Higher or Lower Static Pressures.

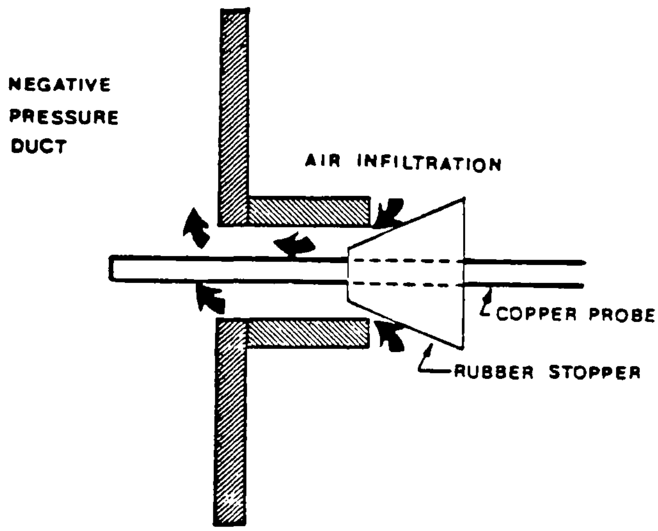
When the static pressure is greater than -10" W.G. the inleakage around the probe can cause an aspiration effect which results in readings significantly more negative than actual conditions. This is illustrated in the figure below.



Avoiding the Problems of Air Inleakage through Ports under Negative Pressure (Continued)

The severity of this problem increases as the static pressure decreases from -10 inches to -120 inches. The condition is often indicated by an audible sound of inleakage (assuming plant noise levels are sufficiently low).

The aspiration effect may be avoided by using the S-type pitot tube for static pressure measurements (disconnect the impact side of the tube) or by using a copper tube (1/2 or 1/4" O.D.) as shown in the figure below. Even if leakage is occurring the tip of the probe is not significantly affected using either approach. (It is often necessary to electrically ground the copper probe or pitot tube.)



Use of the extended copper tube can also be useful for the Fyrite and temperature measurements. In both cases, it is important to bend the tube upstream of the port, so that the effect of air leakage is minimized. The thermocouple wire may be threaded through the copper tube to ensure that the probe stays in the intended location.

If the rigid dial-type thermometers are being used it is important to seal the port very well in order to avoid lower than actual results. This can be done with rubber stoppers or similar materials.

Since there are no stoppers large enough for large 4" ports often encountered at stack sampling locations, it is convenient to use a round sanding disk (sold for small drills) in place of the stopper. Gloves and other fabric materials can also be used, however, it is much more difficult to ensure that the seal is maintained.

3. Avoiding the Problems of Air Inleakage through Ports under Negative Pressure (Continued)

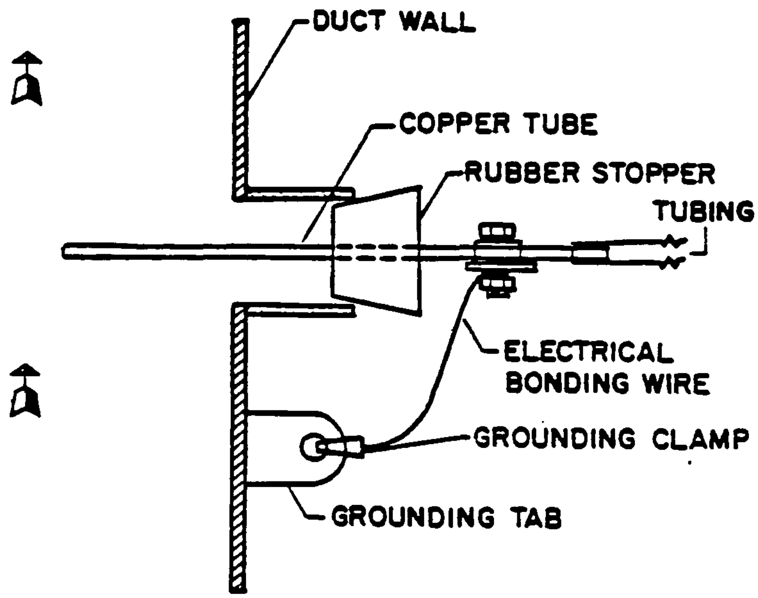
Extreme care must be taken to ensure that the probe and/or the port seal (eg. glove, rubber stopper) is not sucked into a negative pressure duct. This is particularily a problem when the port is fairly large and the duct is at a large negative static pressure. For such ports, the sampling probe should be secured by a disk and a rubber stopper in series as shown in the figure below.

4. Avoiding Problems with Positive Pressure Ports

Positive pressure ports larger than 1" diameter should not be used under any circumstances. While opening such a port it is possible to unintentionally fumigate all personnel in the general vicinity. Even with small positive pressure ports, the port must be opened carefully and sealed quickly.

5. Grounding and Bonding

In some gas streams it is conceivable that a high static electrical charge will build up on the metal probe during the measurement work. A spark to the gounded duct wall could initiate an explosion if the dust concentration and the oxygen concentration were sufficient. Build-up of static can be avoided by attaching an electrical bonding wire from the probe to the duct wall. This should be connected prior to inserting the probe into the duct. The duct itself should be grounded. If there is any question concerning the adequacy of the grounding and bonding apparatus or concerning the explosive potential of the gas stream, the measurement should not be made. Use of a bonding wire is illustrated in the figure below.



Selection of Measurement Site

A. Preferred Measurement Site Location

(1) At least 8 diameters downstream, and
(2) At least 2 diameters upstream

B. Minimum Measurement Site Location

(1) At least 2 diameters downstream, and
(2) At least 1/2 diameters upstream

C. Rectangular Cross Sections - Equivalent Diameter

$$D = \frac{2\ L\ W}{L + W}$$

2. Traverse Points

A. Minimum Number of Traverse Points - Use Figure 1

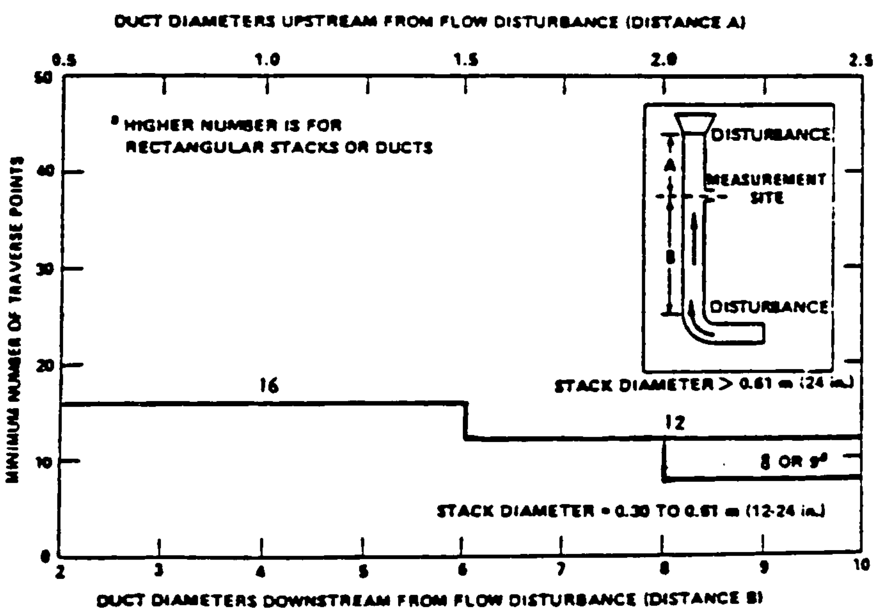


Figure 1. Minimum Number of Traverse Points For Velocity Traverses (From 48 FR 45035, September 30, 1983)

2. Traverse Points (Continued)

B. Location of Traverse Points

(1) Circular Stacks - Traverse points located on two perpendicular diameters of the stack at locations such as shown in Figure 2 and at distances determined from Table 1. For stacks with diameters less than 24 inches, do not locate a traverse point within 0.5 inches of the stack wall.

TRAVERSE POINT	DISTANCE, % of diameter
1	4.4
2	14.7
3	29.5
4	70.5
5	85.3
6	95.6

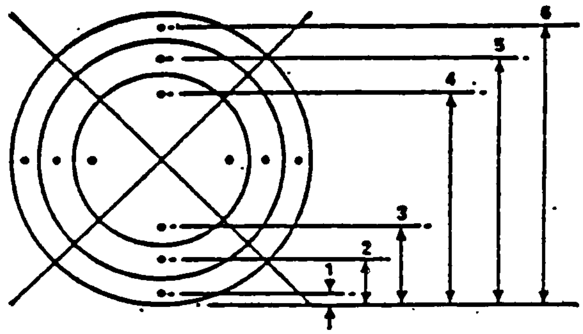


Figure 2. An Example of the Locations of Traverse Points in a Circular Stack. (From FR, Vol. 42, No. 160, Pg. 41758, Aug. 18, 1977)

TABLE 1. PERCENT OF STACK DIAMETER FROM INSIDE WALL TO TRAVERSE POINT FOR CIRCULAR STACKS

Traverse point number on a diameter	Number of traverse points on a diameter											
	2	4	6	8	10	12	14	16	18	20	22	24
1	14.6	6.7	4.4	3.2	2.6	2.1	1.8	1.6	1.4	1.3	1.1	1.1
2	85.4	25.0	14.6	10.5	8.2	6.7	5.7	4.9	4.4	3.9	3.5	3.2
3		75.0	29.6	19.4	14.6	11.8	9.9	8.5	7.5	6.7	6.0	5.5
4		93.3	70.4	32.3	22.6	17.7	14.6	12.5	10.9	9.7	8.7	7.9
5			85.4	67.7	34.2	25.0	20.1	16.9	14.6	12.9	11.6	10.5
6			95.6	80.6	65.8	35.6	26.9	22.0	18.8	16.5	14.6	13.2
7				89.5	77.4	64.4	36.6	28.3	23.6	20.4	18.0	16.1
8				96.8	85.4	75.0	63.4	37.5	29.6	25.0	21.8	19.4
9					91.8	82.3	73.1	62.5	38.2	30.6	26.2	23.0
10					97.4	88.2	79.9	71.7	61.8	38.8	31.5	27.2
11						93.3	85.4	78.0	70.4	61.2	39.3	32.3
12						97.9	90.1	83.1	76.4	69.4	60.7	39.8
13							94.3	87.5	81.2	75.0	68.5	60.2
14							98.2	91.5	85.4	79.6	73.8	67.7
15								95.1	89.1	83.5	78.2	72.8
16								98.4	92.5	87.1	82.0	77.0
17									95.6	90.3	85.4	80.6
18									98.6	93.3	88.4	83.9
19										96.1	91.3	86.8
20										98.7	94.0	89.5
21											96.5	92.1
22											98.9	94.5
23												96.8
24												98.9

Traverse Points (Continued)

(2) Circular Stacks With Diameters Greater than 24 Inches

Do not locate a traverse point within 1.0 inch at the stack wall. Adjust to the larger of at least 1.0 inch or a distance equal to the nozzle inside diameter. If the adjusted points overlap with the next traverse point, treat as two points in the velocity traverse and in the recording of the data.

(3) Rectangular Stacks

(a) Determine the grid configuration from Table 2. Notice that the minimum number of traverse points for rectangular stacks is 9.

TABLE 2. DETERMINATION OF GRID CONFIGURATION

No. of Traverse Points	Grid Configuration
9	3 x 3
12	4 x 3
16	4 x 4
20	5 x 4
25	5 x 5
30	6 x 5
36	6 x 6
42	7 x 6
49	7 x 7

(b) Divide the stack into the grid configuration as determined from Table 2. Locate a traverse point at the centroid of each grid. An example is shown in Figure 3.

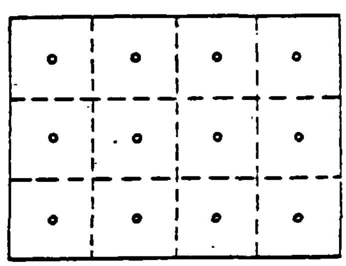


Figure 3. An Example of a Rectangular Stack Divided into a 4 x 3 Grid Configuration for Twelve Traverse Points.

3. Verification of Absence of Cyclonic Flow

The presence or absence of cyclonic flow at the traverse location must be verified if any of the following conditions exist:

- o such devices as cyclones and inertial demisters following venturi scrubbers are present, or
- o tangential inlets or other duct configurations which tend to induce swirling are present.

Procedure

(1) Level and zero the manometer.
(2) Connect a Type S pitot tube to the manometer.
(3) Place the pitot tube at each traverse point so that the face openings of the pitot tube are perpendicular to the stack cross-sectional plane. At this position, the pitot tube is at 0° reference.
(4) If the differential pressure (Δp) is null (zero) at each point, an acceptable flow condition exists.
(5) If the p is not zero at 0° reference, rotate the pitot tube ($\pm$ 90°) until a zero reading is obtained.
(6) Note the angle of the null reading.
(7) Calculate the average of the absolute values of the angles. Include those angles of 0°
(8) If the average is greater than 10°, the flow conditions of the stack are unacceptable.

4. Measurement of Stack Gas Velocity and Volumetric Flow Rate

A. Conduct a pretest leak-check on the apparatus.
B. Level and zero the manometer.
C. Measure the velocity head (Δp) at each of the traverse points and record these measuremennts on the form presented in Figure 4.
D. Measure the stack gas temperature.
E. Conduct a post-test leak check.
F. Calculate the average stack gas velocity and volumetric flow rate using the simplified equation (assuming air at standard pressure):

$$v_s = 2.9 \; C_p \; (\sqrt{\Delta p}\,)_{avg} \; \sqrt{(T_s)_{avg}}$$

where:

v_s = average stack gas velocity (ft/sec),
C_p = pitot tube coefficient (dimensionless, usually varies between 0.83 and 0.87),
Δp = velocity head (manometer reading) of stack gas (in. H_2O), and
T_s = absolute stack temperature (460° + stack gas temp. in °F).

4. Measurement of Stack Gas Velocity and Volumetric Flow Rate (Continued)

$$Q_s = 3600\ v_s A \left(\frac{T_{std}}{T_s}\right)$$

where: Q_s = flow rate (scf/hr),
A = cross-sectional area of stack (ft^2), and
T_{std} = standard absolute temperature (528°R).

Traverse Pt. No.	Vel. Hd., Δp mm (in.) H_2O	Stack Temperature t_s, °C (°F)	Stack Temperature T_s, °K (°R)	P_g mm Hg (in. Hg)	$\sqrt{\Delta p}$
		Average			

Figure 4. Velocity Traverse Data (From FR, Vol. 42, No. 160, Pg. 41763, Aug. 18, 1977).

MEASUREMENT OF OXYGEN AND CARBON DIOXIDE

IN COMBUSTION GAS STREAMS

FYRITE® ANALYZER METHOD

1. Instrument Checks (Daily Before Use)

    1. Check fluid level in center tube -- it should be between 1/8 and 5/8 of an inch after zeroing.

    2. Sampling assembly -- leak check.

    3. Filter packing -- visually check to assure that the packing is clean and not clogged.

    4. Check fluid absorbing power --

        Oxygen - Measure O_2 in ambient air (concentration of 20.9%). Several successive readings should be within 1/2% of each other, at approximately 20.9%.

        Carbon Dioxide - Blow a deep breath at a steady rate for 3 or 4 seconds into the sampling hose with the filter saturator tube removed. Several successive readings should be within 1/2% of each other, at approximately 4% to 5%.

2. Operation

    1. If the flue gases are not saturated with moisture, the filter packing must be moistened.

    2. Place the metal sampling tube at least 2 1/2 inches into the flue gas.

    3. Feed the gas sample into the Fyrite® by squeezing the aspirator bulb 18 times.

    4. Invert the Fyrite® several times to allow contact of the gas and the fluid.

    5. Read the concentration (in percent) directly from the scale located on the center bore.

Combustion systems operate with a definite relationship between the carbon dioxide and oxygen concentrations in the flue gas. The measurements made using the Fyrite® analyzers (or equivalent devices) may be checked using the following table. If the sum of the O_2 and CO_2 measurements are not within the general ranges specified in the table, it is probable that there were some measurement errors.

Fuel	Sum of the O_2 and CO_2 Concentrations
Natural Gas	13% - 19%
#2 Oil	15% - 20%
#6 Oil	17% - 20%
Bituminous Coal, Lignite, and Sub-bituminous Coal	18% - 21%
Anthracite Coal	19% - 21%
Coke	19% - 21%
Refuse and Wood	18% - 22%

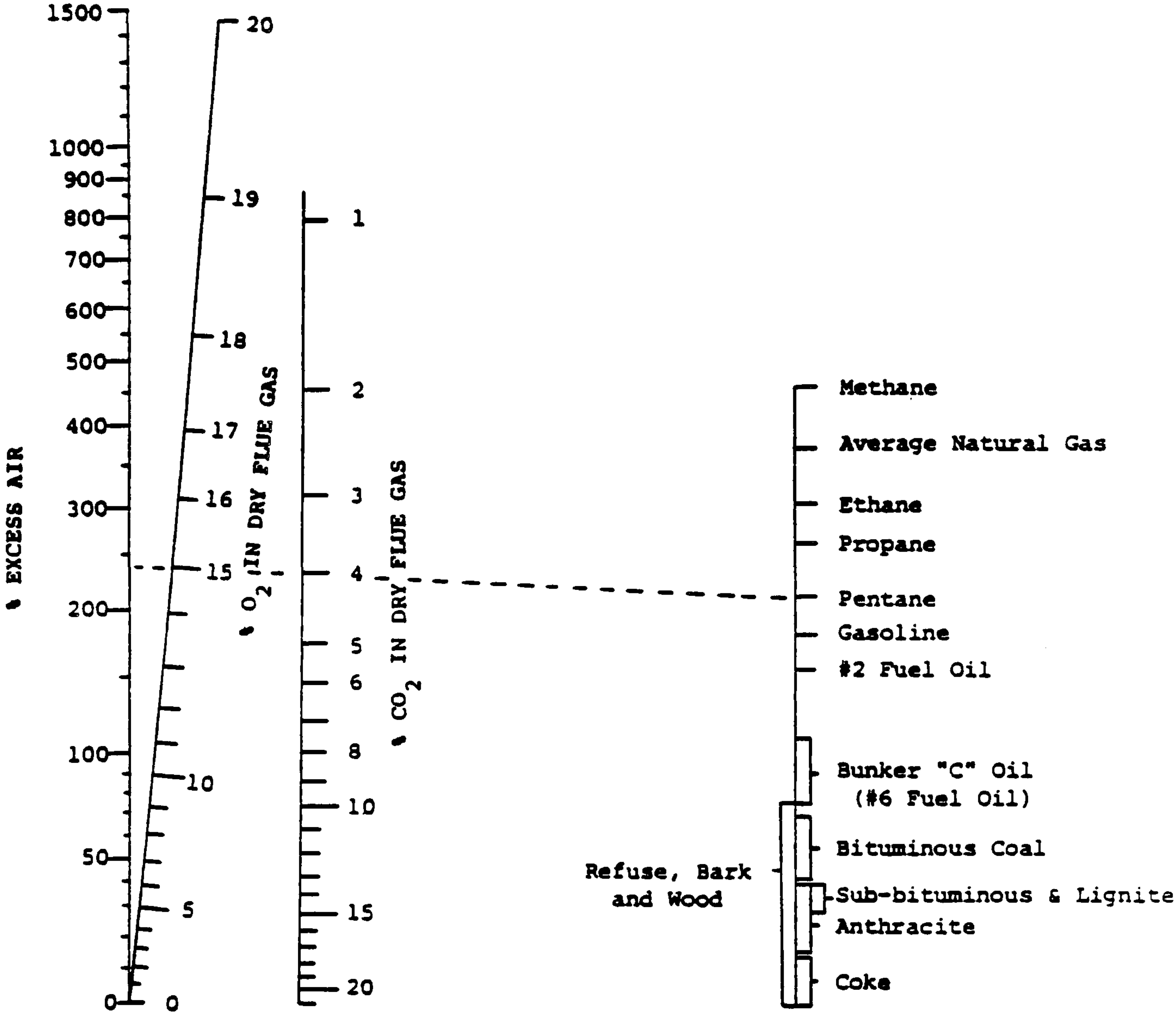
The measurements should be repeated if the sum of the O_2 and CO_2 concentrations do not fall within this range. The presence of high CO concentrations could invalidate the ranges shown above.

USING THE O_2 AND CO_2 MEASUREMENTS

The O_2 and CO_2 data can be used to determine the excess air rate of the combustion system using the nomograph on page 76. A straight line drawn between the O_2 and CO_2 points should be extended to the left axis to read off the the excess air rate. The proper fuel type being burned should be indicated by extending the line to the right axis.

NOMOGRAPH FOR ESTIMATING FLUE GAS COMPOSITION,

EXCESS AIR OR TYPE OF FUEL



SOURCE: Entropy Environmentalists, Inc.
Research Triangle Park
North Carolina

SLANT ANGLE†

The purpose of measuring the slant angle of the observer in relation to the stack is to correct the observed opacity. Observed opacity can be higher than actual opacity because as the angle of observation increases, the pathlength of light through the plume increases and more light is scattered by the particles in the plume. Thus, the observed opacity increases.

To correct the observed opacity, the following formula is used in which the observed opacity is converted to a decimal format (eg. 60% opacity is 0.60) and then subtracted from 1. This difference is then raised to the cosine phi power. The resulting value is then subtracted from 1 to get the corrected opacity.

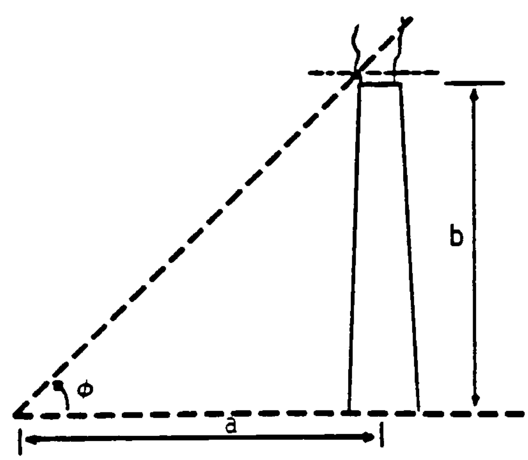
$$O_c = 1 - \left[(1 - O_{obs})^{\cos \phi}\right]$$

where: O_c = corrected opacity (decimal)

O_{obs} = observed opacity (decimal)

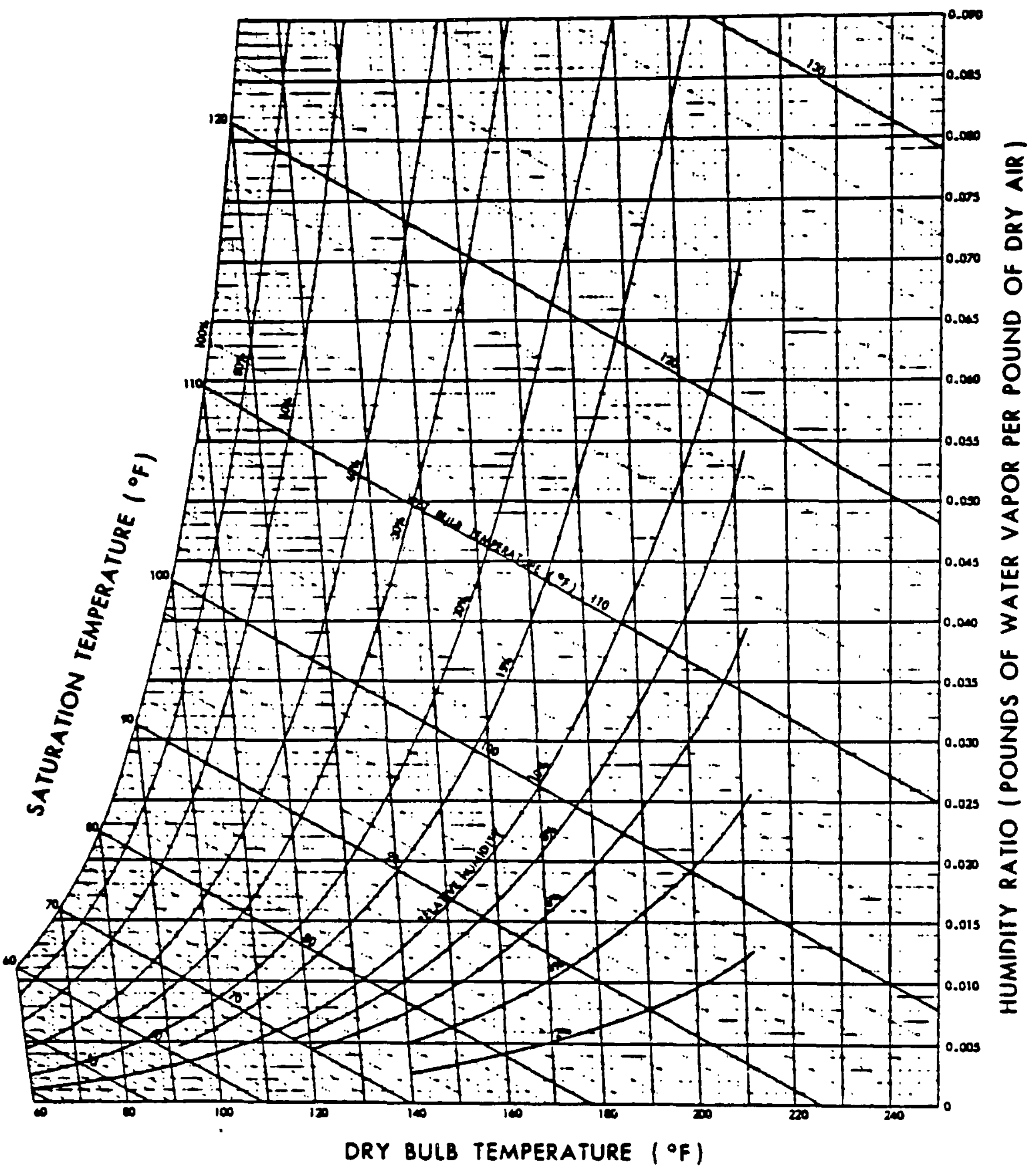
$\cos \phi$ = cosine of the observation angle (dimensionless) measured by abney level, clinemeter, trigonometric relationships (i.e., distance to stack and stack height relative to the observer as sides of a right triangle) or other surveying device

$$\cos \phi = \frac{a}{\sqrt{a^2+b^2}}$$



† Use of the slant angle correction is a matter of agency policy. Inclusion of this section is only to facilitate use of opacity as a diagnostic tool, not necessarily for use in enforcement proceedings.

HIGH TEMPERATURE PSYCHROMETRIC CHART (ENGLISH UNITS)



.nges in Fan Speed

For a given fan and exhaust system, a change in the fan speed will result in the following changes:

Gas flow rate will vary directly proportional to the speed.
Fan static pressure will vary as the square of the speed.
Fan horsepower will vary as the cube of the speed.

Fan speed may increase because of:

1. A change in the fan and motor sheaves.
2. A change in the fan motor.

Fan speed may decrease due to:

1. Slippage of belts (usually 100-200 rpm and accompanied by a distinctive squeal).
2. A change in the fan and motor sheaves.
3. A change in the fan motor.

Changes in System Resistance

For a given fan operating at a constant speed a change in the system characteristic curve due to resistance changes in the ductwork or control device will result in the following changes:

If the resistance increases:

1. The gas flow rate will decrease.
2. The static pressure will increase.
3. The horsepower will decrease (accordingly the fan motor current will decrease).

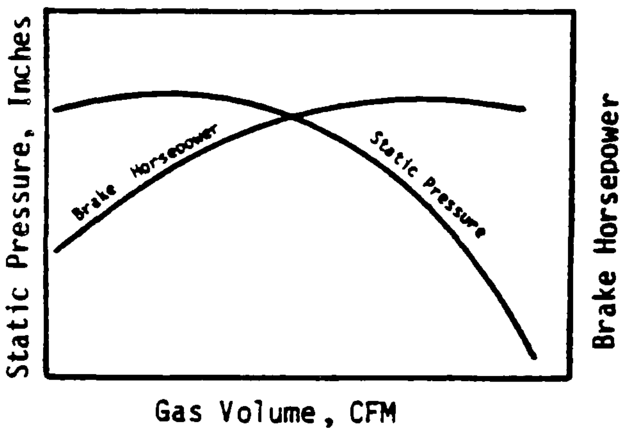
If the resistance decreases:

1. The gas flow rate will increase.
2. The static pressure will decrease.
3. The horsepower will increase.

Changes in Gas Temperature

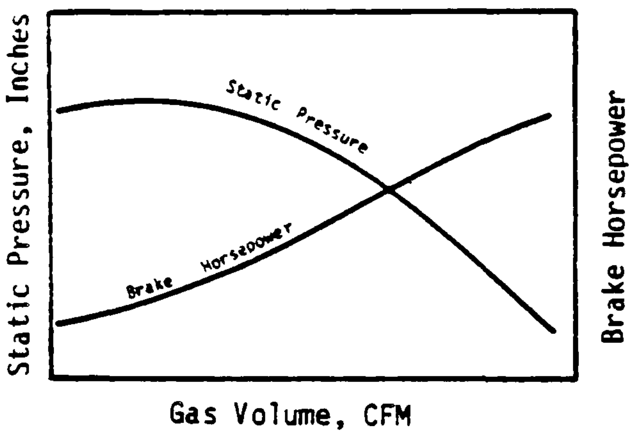
For a given fan and exhaust system and a constant fan speed, a change in the gas temperature will result in the following:

1. The fan speed will remain unchanged.
2. The fan horsepower (and motor current) will vary inversely with temperature and proportional to gas density (see figure in text).
3. Fan static pressure will vary inversely with gas temperature.



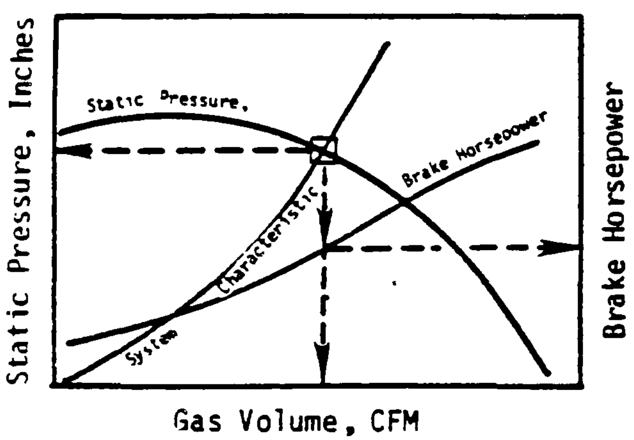
Backward Curved Fan Blades

This type of fan has a high efficiency but is susceptible to buildup of material on the blades. It is usually used in relatively clean gas streams.



Radial Blade Fan Blades

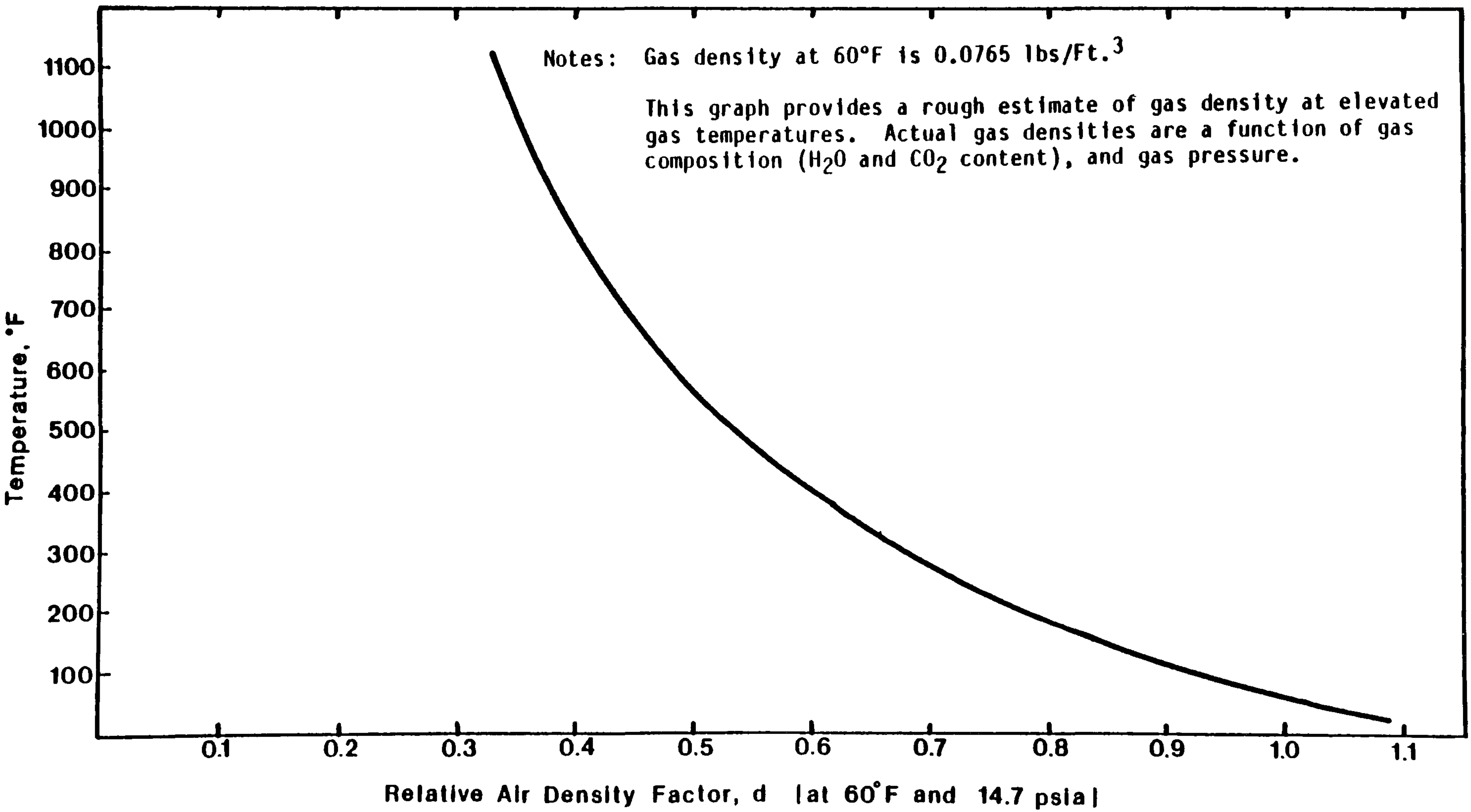
These are less energy efficient than backward curved fans, however, the radial blades can handle heavy dust loadings.



Typical Performance Curve

The actual operating point of a fan on a given system is determined as the intersection of the system characteristic curve and the fan static pressure curve. The system characteristic curve is usually proportional to the square of the gas flow rate.

RELATIVE AIR DENSITY FACTOR



DENSITY OF SOLIDS†

Component	Density (lb/ft^3)
Asphalt	69-94
Barley, bulk	39
Bauxite	159
Cement,	
Portland, loose	94*
Portland, clinker	95*
Clay	63*
Coal,	
anthracite	55-60*
bituminous	43-54*
charcoal	17-36
lignite	69-87
Coke, breeze	30-34*
Lump petroleum	40-50*
Corn, Rye, bulk	45
Dolomite	181
Earth	
dry, loose loam	76*
packed	94
moist, loose loam	73*
packed	100
Feldspar, broken	90-100*
Granite, crushed	98*
Gravel	
dry, loose	96-110*
packed	100-119
wet	119
Gypsum, broken	90-94*
crushed	90*
ground	50-56*
Iron	120-155*
Lead	707
Lime, mortar	103-111
quick (in bulk)	50-60
slaked	81-87
Limestone,	
broken	95*
sized 2x1/2"	92*
ground-200 mesh	65*
Mica	162-200
muscovite	172-187
biotite	168-193
Oats, bulk	26
Phosphate rock,	
broken	75-85*
pebble	90-100*
Pitch	67-69
Riprap	
limestone	81-87
sandstone	87
shale	106
Rock salt	50*
Sand, dry	90-105*
wet	105-125*
Slag,	
bank, crushed	80*
furnace, granulated	60*
Stone, various	135-212
crushed	85-105*
Sulfur,	
ground-100 mesh	75-85*
ground-200 mesh	50-55*
Tar, bituminous	75
Wheat, bulk	48

† *Bulk materials only.*

* As they occur in material handling and processing operations.

DENSITY OF LIQUIDS

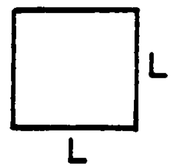
Component	Density (lb/ft^3)
Benzene	55
Gasoline	41-43
Nitric Acid (100%)	94
Petroleum	55
Sulfuric Acid (100%)	114
Water	62

SIEVE NUMBER vs. PARTICLE SIZE

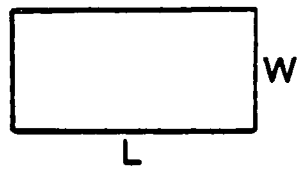
Sieve Number	Particle Size (μm diameter)	Sieve Number	Particle Size (μm diameter)
80	177	200	74
100	149	230	62
120	125	270	53
140	105	325	44
170	88	400	37

Areas

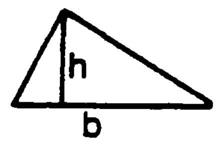
Square $A = L^2$



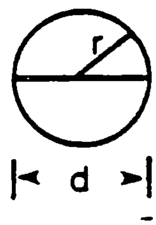
Rectangle $A = L \times W$



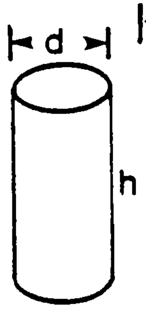
Triangle $A = \frac{b \times h}{2}$



Circle $A = \pi r^2 = \frac{\pi d^2}{4}$

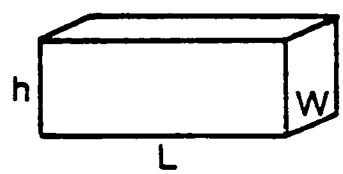


Cylinder $A = \pi dh$

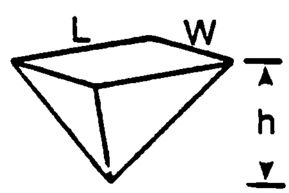


Volumes

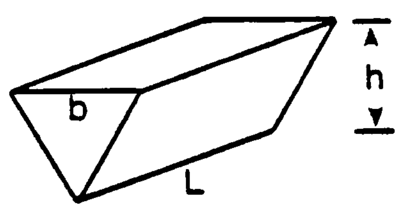
Rectangular Container $V = L \times W \times h$



Pyramid Hopper $V = \frac{L \times W \times h}{3}$



Trough Hopper $V = \frac{b \times h \times L}{2}$



Velocity

Velocity = Gas Flow Rate/Area = $ACFM/Ft^2$

ʼmperature

C = (5/9) (F-32)
C = K-273
F = (9/5) C + 32
F = (9/5) (K - 273) + 32
K = C + 273
K = (5/9)(F - 32) + 273
R = F + 460

Length

1 inch = 2.54 cm
1 foot = 0.3048 m
1 m = 39.37 inches

Area

1 ft^2 = 929.03 cm^2
1 $in.^2$ = 6.452 cm^2
1 km^2 = 0.386 mi^2
1 m^2 = 10.764 ft^2
1 yd^2 = 0.836 m^2

Velocity

1 m/sec = 3.28 ft/sec
1 ft/sec = 0.3048 m/sec

Capacities & Volume

1 barrel (oil) = 42 gallons (oil)
1 cm^3 = 0.061 $in.^3$
1 $in.^3$ = 16.387 cm^3 = 16.387 ml
1 m^3 = 1.308 yd^3
1 yd^3 = 0.765 m^3
1 gallon (U.S.) = 231 $in.^3$ = 3.785 liters
1 liter = 61.0255 $in.^3$ = 0.264179 U.S. gallons

Weights or Masses

1 gram = 15.432 grains = 2.205 x 10^{-3} pounds
1 grain = 6.4799 x 10^{-2} grams = 2.286 x 10^{-3} oz
1 kg = 2.205 pounds = 35.274 oz
1 oz = 437.5 grains = 28.35 grams
1 lb = 7000 grains = 453.592 grams
1 ton (short) = 2000 lbs = 0.907 metric ton
1 ton (metric) = 2204.62 lbs = 1000 kg = 1.1023 short tons

Flow

1 m^3/sec = 35.31 ft^3/sec
1 ft^3/sec = 28.32×10^{-3} m^3/sec = 28.32 liters/sec
1 liter/sec = 1.000×10^{-3} m^3/sec = 35.32×10^3 ft^3/sec

Pressure

1 dyne/cm^2 = 10^{-6} bar
1 mm Hg(std.) = 1.934×10^{-2} lb/in^2
1 lb/in^2 = 51.715 mm Hg
1 atmosphere (std.) = 760 mm Hg (std.) = 14.696 lb/in^2

Energy & Work

1 calorie = 4.186 abs. joules
1 abs. kw-hr = 3.6×10^6 abs. joules
1 ft-lb = 1.356 abs. joules
1 abs. joule = 0.239 calorie

Power

1 abs. watt = 1 abs. joule/sec = 0.239 cal/sec = 0.057 Btu/min
1 cal/sec = 4.186 abs. watts
1 h.p. (electrical) = 746 abs. watts
1 h.p. (mechanical) = 550 ft-lb/sec = 745.7 abs. watts
1 Btu/min = 17.584 abs. watts = 252 cal/min

Emission Rates

1 gm/sec = 0.1323 lbs/min
1 kg/hr = 2.205 lbs/hr
1 lb/hr = 0.454 kg/hr

Prefixes

Multiples	Prefixes	Unit	Symbols
10^{12}	tera	trillion	T
10^9	giga	billion	G
10^6	mega	million	M*
10^3	kilo	thousand	k
10^2	hecto	hundred	h
10	deka	ten	da
10^{-1}	deci	tenth	d
10^{-2}	centi	hundredth	c
10^{-3}	milli	thousandth	m
10^{-6}	micro	millionth	µ
10^{-9}	nano	billionth	n
10^{-12}	pico	trillionth	p

*Occasionally MM is used for million and M for thousand. However, this is not recommended.

FIELD BOOK NO.____________________

Confidential Data

Yes ________ No ________

Plant Data

Name:____

____

Address:______________________________________

____

Phone: _______________________________________

Representative(s):____________________________

____

Plant CDS or Other Identifying Number:________

Type of Plant and Process Description:________

____

EMERGENCY NUMBERS:____________________________

____

Agency Data

Name:____

Inspector Name(s)_____________________________

Phone:____