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Stationary Source Compliance Training Series

Wet Scrubber Inspection Procedures Workshop

Instructor Manual

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Wet Scrubber Inspection Procedures Workshop

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INTRODUCTION

The Stationary Source Compliance Division of the U.S. Environmental Protection Agency has sponsored the development of this manual which is intended to assist regulatory agencies in performing detailed inspections of wet scrubber systems. These inspections are conducted to determine if the air pollution control equipment is operating in compliance with applicable regulations and to determine if the corrective actions proposed by source owners have a reasonable chance to successfully rectify chronic excess emission problems. The technical information will also help equipment operators to monitor the performance of their scrubber systems. The evaluation procedures are intended to identify operating problems at an early stage so that excess emission problems can be avoided and so that any necessary equipment repairs can be made quickly and economically.

The workshop program addresses both particulate and gaseous scrubbers. Common modes of failure of these systems are discussed to illustrate the importance of the various inspection activities. Emphasis is placed on the evaluation of wet scrubber components such as pumps, nozzles, demisters, and piping. There is also considerable information concerning the critical evaluation of on-site gauges and the use of portable instruments when necessary. Inspection safety is also emphasized.

1.0 Use of This Manual

The materials have been prepared so that it is possible to use the manuals either in workshops or as self instructional guides. Both the Lecturer's Manual and the General Manual are used for workshops. The General Manual includes black and white reproductions of all the visual aids used in the workshop program. Detailed lecture notes are included with each of the slides so that all of the attendees can review the technical information at a later date. The presence of the lecture notes also allows the attendees to concentrate on listening to the workshop coordinator rather than attempting to compile a complete set of notes. The general manual also includes a set of review problems and questions at the end of each lecture. These can be answered either individually or in small working groups.

The Lecturer's Manual is identical to the General Manual with the addition of suggestions of various options for presenting the technical material. This is very important since most audiences are comprised of attendees with very diverse backgrounds with respect to wet scrubber systems. It is common to have persons with no experience at all in the same audience with engineers having more than 10 years of practical field experience. The program must be adjusted to the attendees' level of experience. The Lecturer's Manual also includes a detailed discussion of each review problem and question. The additional material in the Lecturer's Manual is arranged so that the workshop coordinator is always on the same page as the attendees who are using the General Manual.

The Lecturer's Manual can be used as a self-instruction manual by persons who want to review material discussed during a previous workshop or by persons who were unable to attend a full workshop. The lecturer's notes will be helpful in determining what material should be studied. The answers to the review problems and questions will be helpful in reviewing the lectures.

2.0 Presentation of Workshops

Workshops are intended to be valuable learning experiences for all of the participants, including the workshop coordinator. To achieve this goal, a considerable amount of preparation work is necessary. This section addresses some of this initial effort required to structure a successful program

2.1 Know Your Audience - This is the most important step in preparing for a workshop program. The range of experience with wet scrubber systems should be determined since it is important to orient the technical information to the backgrounds of the participants. It is easy to bore the highly experienced individuals and to overwhelm those with no prior experience with wet scrubbers. If the range of experience is very large, it may be wise to split the group into more homogeneous groups so that the material of interest to each can be properly presented.

People learn in different ways. Some can effectively learn during formal lectures while others retain more when solving problems or discussing questions in small groups. Others retain the concepts only after they have had an opportunity to try them in the field. To the extent possible, the workshop should include all three major elements: (1) formal lecture, (2) problem sessions, and (3) field demonstrations. Obviously, this manual can only address the first two. Nevertheless, the value of field demonstrations should not be underestimated. They should be conducted soon after the workshop program. The mix of lecture material and problem sessions used in the workshop must be chosen by the workshop coordinator based on the perceived interests of the participants. Within the time frame allowed by the typical workshop agenda, there is insufficient time for both as presented in this manual. This means that the workshop coordinator must carefully review this manual and decide what technical information is relevant and what portion of the time should be devoted to the problem sessions.

It is equally important to know the types of wet scrubbers of concern. The workshop materials are intended for an entirely different purpose than college level engineering courses and the U.S. Environmental Protection Agency Air Pollution Training Institute courses. These formalized educational programs are designed to provide a sound foundation in fundamental principles and calculation techniques. As such they are invaluable pre-requistes to the material presented in this workshop. Here the primary objective is to present very practical information on what the field inspector should do "tomorrow" on the specific scrubber systems within his or her jurisdication. For this reason, it is necessary to emphasize the material concerning the specific scrubbers that are of concern to the participants. Regulatory agency inspectors are usually too busy to enjoy discussing topics which do not appear to have a practical application in their areas.

If the interests and background of the participants are not known prior to the workshop, the coordinator should make a survey at the very beginning of the program. The material should then be adjusted to the extent possible. It is better to preregister all participants so that there is more lead time to tailor the program to the group. Appendix B includes a sample card that can be distributed in advance or used at the beginning of the workshop. This card provides the necessary information on the backgrounds of the attendees and also provides a permanent record of their participation.

2.2 Use an Adequate Meeting Room - Most of the participants attending the program will be accustomed to field work. They are especially intolerate of inadequate meeting rooms. The room should have the following features:

- The chairs should be comfortable.
- The room should be large enough to accomodate the group without taxing the heating and air conditioning system.
- There should be tables for all participants to facilitate note taking and problem solving.
- There should be a way to show the 35 mm slides without darkening the entire meeting room.
- The room should be reasonably quiet.
- There should be an area to display portable inspection equipment and safety equipment.

Overall, the room must be conducive to an intense learning exercise. It is unfortunate that many of the meeting rooms available in agency office buildings are not good for workshops. Hard chairs are common since the rooms were intended only for short meetings, not two or three day programs. It is often impossible to dim the lights without incurring the wrath of other agency personnel in adjacent offices. Also, the rooms are often so small that it is difficult to use the visual aids without the attendees feeling the hot exhaust of the projector. Long programs in inadequate meeting rooms are a form of cruel and unusual punishment. It should be remembered that the cost of a good meeting room is often a small fraction of the transportation costs incurred in bringing field inspectors in to a central location from the various district offices.

2.3 Prepare for the Program - There are a number of preliminary activities which are necessary to ensure that the program runs smoothly. The most important of these is for the workshop coordinator to read the manual thoroughly and decide what portions are relevant. It is also helpful to distribute copies of the general manual to the preregistered attendees so they have an opportunity to review the material before the program. More detailed and interesting questions are asked when the manuals are distributed before program.

The room should be completely set up prior to the arrival of the attendees. The visual aid equipment should be set up and checked out so that there is no question that it is working properly. It is almost always wise to have spare projection bulbs for the visual aid equipment. The slides should be tried on the screen to confirm that the screen is placed properly and that the entire slide is visible. If not, the projector and/or the screen should be repositioned. All of the slides should be loaded and checked on the screen.

One of the most embarrasing and distracting events in a workshop is the occassional backwards and upside down slide. This is entirely avoidable!

The tables should be arranged so that there are enough seats and that everyone has an adequate view of the screen. Handouts and forms should be distributed to each seat to save time at the beginning of the workshop and to ensure that there is no question that there are sufficent copies for everyone.

The locations of rest rooms and fire escapes should be noted so that the attendees can be advised at the beginning of the workshop. It is also helpful to identify a phone which can be used for messages.

2.4 Conducting the Workshop - The workshop coordinator sets the tone for the workshop in the initial remarks. The participation of all the attendees should be encouraged since often they have valuable experience with is relevant to the specific plants in the area. Their comments liven up the program and supplement the technical material in this manual. An informal attitude is generally effective in encouraging active participation.

Under no circumstances should the information simply be read from the manual. This defeats the basic objective of this manual which is to free both the speaker and the attendees from having to cover each detailed point. Any attendee who is truly interested in the topic can read the manual carefully after (or before) the program. This manual simply provides a skeleton over which the speaker and attendees can discuss issues relevent to their area.

Occassional breaks are built into the program. These are necessary to allow everyone to stretch and to allow the speaker's voice to rest briefly. Also, these periods provide some of the most useful informal discussions concerning the lecture material.

At the end of the workshop, a critique form should be handed out to all of the participants (including the coordinator). It should be filled out before everyone leaves since few will ever return it otherwise. The coordinator should carefully review the comments to determine ways to improve future programs and ways to assist the participants in getting the resources necessary to implement the techniques discussed. The latter point is especially important since the workshop is intended to be of DIRECT AND IMMEDIATE BENEFIT TO FIELD INSPECTORS. In many cases, they will not have the time or equipment necessary to perform these inspections. Presumably, they will be receiving these soon or there was no sense in presenting the program in the first place! The critiques help to determine just what is necessary to begin implementing the program. A sample critique form is included in Appendix B.

One common misunderstanding regarding critiques is that they are intended to rate the capability of the speaker or to rate the value of the program. Actually, the value of the program can not be judged until the participants have had an opportunity to try the techniques in the field for six months to a year. The speaker's performance should be just one element of a successful workshop. The very successful workshops are those in which the speaker simply guides the discussion. The attendees should do most of the talking. Remember, this is not a training course! A workshop is a meeting of professionals discussing and refining their technical procedures.

3.0 Typical Agenda

A typical agenda for a two-day program is presented on the next two pages. As discussed above, this should be used as a starting point in the development of a program for the specific audience. A copy of the program agenda to be used should be given to all participants before the start of the program.

WET SCRUBBER SYSTEM INSPECTION WORKSHOP

Sample Agenda

Time	Lecture
8:30 a.m.	Welcome and Introduction
8:45 a.m.	1. Introduction to Wet Scrubber Systems A. System Components B. Flowcharting Techniques C. Review Problems and Questions
10:15	Break
10:30	2. Baseline Inspection Techniques A. Basic Principles B. Comparison of Baseline Data with Inspection Data C. Review Problems and Questions
12:00	Lunch
1:00	3. Visible Emission Observation A. Expanded Method 9 Procedures B. Reentrainment C. Odor Surveys D. Review Problems and Questions
1:45	4. Evaluation of On-Site Instruments and Use of Portable Gauges A. Static Pressure Gauges B. Temperature Monitors
2:30	Break
2:45	4. (Continued) C. Oxygen and Carbon Dioxide Analyzers D. pH Meters and Indicator Paper E. Gas Flow Measurement F. Fan Speed and Motor Currents G. Pump Motor Currents H. Liquid Pressures I. Liquid Flow Rates J. Other Instruments K. Recommended Port Designs
4:30	Adjourn

WET SCRUBBER SYSTEM INSPECTION WORKSHOP

Sample Agenda (Continued)

<u>Day 2</u>

Time	Lecture
8:30	5. Evaluation of Wet Scrubber System Components A. Demisters B. Pumps C. Piping D. Nozzles E. Fans F. Materials of Construction G. Review Problems and Questions
10:30	Break
10:45	6. Liquor Analyses
11:15	7. Particulate Wet Scrubbers A. Particle Size B. Pressure Drop
12:00	Lunch
1:00	7. (Continued) C. Spray Tower Scrubbers D. Packed Tower Scrubbers E. Moving Bed Scrubbers F. Tray Scrubbers G. Mechanically Aided Scrubbers H. Venturi and Other Gas-Atomized Scrubbers I. Review Problems and Questions
2:00	Break
2:15	8. Gas and Odor Scrubbers A. HCl and Chlorine Scrubbers B. Fluoride and SiF4 Scrubbers C. Hypochorite and Permanganate Odor Scrubbers
3:15	9. Inspection Safety A. Walking and Climbing Hazards B. Explosion Hazards C. Burn Hazards D. Eye Hazards E. Heat and Cold Stress F. Inhalation Hazards G. Review Problems and Questions
4:15	Summary and Critique
4:30	Adjourn

INTRODUCTION
TO
WET SCRUBBER SYSTEM
INSPECTION

SLIDE 1-1

**INSPECTION OF
WET SCRUBBER SYSTEMS**

This workshop concerns particulate and gaseous scrubbers. The program begins with a summary of the major differences between wet scrubber systems and other types of control devices. Some of the common components are introduced and all major definitions are presented.

The lecture which follows concerns the Baseline Inspection Technique. The approach for wet scrubber systems is conceptually similar to that for other control devices. However, there are some important differences in emphasis.

There are certain inspection procedures common to all types of scrubber systems. These common operations are grouped together in one major lecture which includes: the use of portable instrumentation, the evaluation of visible emissions, the evaluation of reentrainment, the inspection of pumps, nozzle inspection, and the evaluation of the piping system.

Specific inspection procedures are presented for each major class of particulate and gaseous scrubbers. This material emphasizes the problems which are most common for these types of units.

<u>Lecturer's Notes</u>

This slide and written material is intended to provide a brief overview of the workshop. It is important at this stage of the program to survey the experience of the audience and adjust the level of the technical discussions accordingly. The initial lecture is for persons with only limited experience with scrubber systems. Some of the material concerning portable instrumentation and scrubber evaluations is intended primarily for experienced personnel. The safety considerations are very important for all attendees, and should not be abbreviated under any circumstances.

SLIDE 1-2

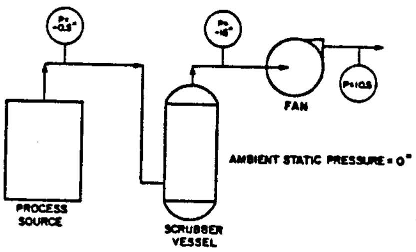
COMPONENTS

Fan
Filter
Clarifier
Demister
Gas Cooler
Scrubber Vessel
Recirculation Tank
Recirculation Pump
Bypass Ducts and Dampers
Alkaline Additive System
Purge and Make-up Systems
Scrubber Instruments

A scrubber is not an isolated piece of equipment. It is a SYSTEM comprised of a large number of individual components. This single point is the most important fact to be presented in this first lecture. It distinguishes scrubbers from other types of air pollution control devices.

Many of the scrubber performance problems originate with deficiencies with the components rather than errors in the design and operation of the scrubber vessel itself. This means that the operation of each system component must be understood and that each inspection will involve a number of inspection points.

SLIDE 1-3



A logical starting point in the evaluation of a wet scrubber SYSTEM is to determine the orientation of the scrubber vessel with respect to the fan which moves the gas stream.

If the fan is downstream from the scrubber vessel, the ductwork leading to the scrubber and the scrubber vessel itself are under negative pressure. This simply means that the gas pressure inside is lower than the atmospheric pressure. The small circles contain typical static pressures at the scrubber outlet and the beginning of the ductwork. The static pressures become more negative as the gas approaches the fan.

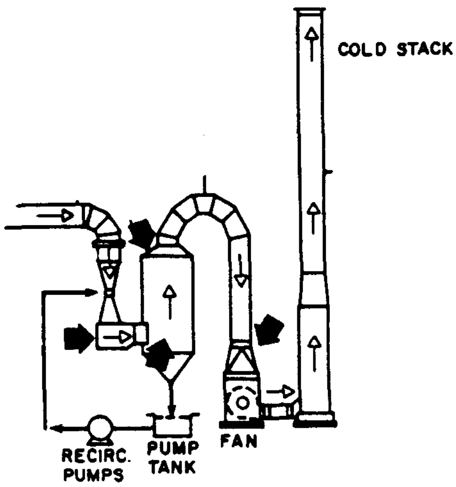
Wet scrubber systems operate at much greater negative pressures than any other type of air pollution control system. It is common for the scrubber outlet static pressure to be in the range of -25 to -60 inches of water. There are a few units operating in the range of -100 to -150 inches of water.

Lecturer's Notes

The term "static pressure" may be unfamiliar to some of the attendees. If so, it should be stated that this is simply the pressure of the gas at rest or measured in a direction normal to the flow direction. It may also be necessary to compare "inches of water" to "pounds per square inch". One pound per square inch (psi) equals approximately 27.7 inches of water.

The concept of "negative pressure" is very difficult for some who see this as a contradiction in terms. It should be stressed that negative pressures are lower than ambient pressure but nevertheless real gas pressures.

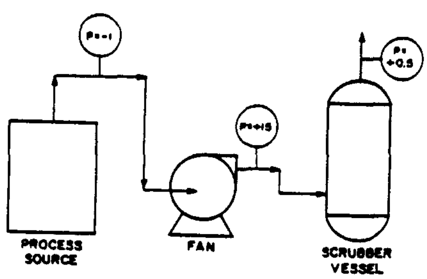
SLIDE 1-4



When the static pressure in the scrubber system is negative, there is a tendency for air to infiltrate the system. This can reduce the amount of gas pulled from the process source and can cause localized gas-liquor distribution problems in the scrubber. Both conditions can lead to significantly increased emissions from the system.

Points of entry are shown on this slide. Since the static pressures are more negative on the discharge side of the scrubber and at the fan inlet, these areas are common sites of infiltration. It is also important to maintain a water seal at the scrubber sump equal to or greater than the static pressure to prevent air infiltration here.

SLIDE 1-5



The fan can be located upstream of the scrubber vessel, thereby placing the entire scrubber and connecting ductwork under positive pressure. Typical static pressure values are shown on this slide. Note that the static pressures become progressively smaller as the gas passes through the scrubber vessel and out the ductwork to the stack.

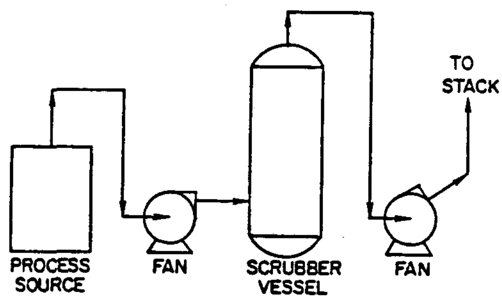
Since the gas pressures inside are higher than ambient pressures, there is a tendency for gas to leak out. These gases can be quite dangerous if there are poorly ventilated areas around the scrubber and ductwork.

The health hazards which can exist around positive pressure scrubber systems should not be underestimated. Wet scrubber systems tend to operate at higher positive pressures than any other type of control system. This combined with corrosion and erosion problems makes gas leakage very possible. Often wet scrubbers are placed indoors to minimize freezing problems, and this containment structure reduces natural ventilation. Field inspectors should have proper safety equipment and should not enter areas with anticipated high pollutant concentrations.

Lecturer's Notes

The gas leakage problem should be stressed here and be reiterated during the safety lecture. It may be useful to point out that some scrubbers handling toxic gases can operate as high as +200 inches of water!

SLIDE 1-6

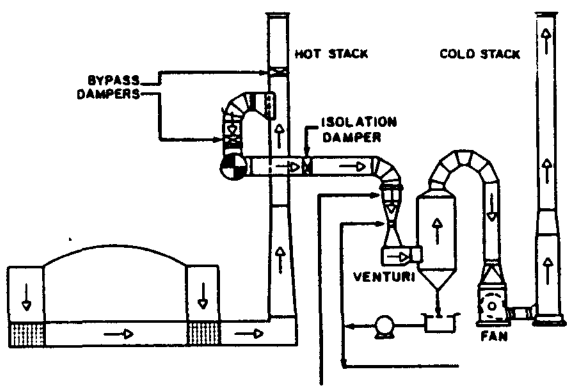


Another gas flow arrangement has fans both before and after the scrubber vessel. This is termed a "push-pull" arrangement.

This type of system usually results from the upgrading of a scrubber beyond the capability of an existing fan. The additional fan provides greater static pressures for the modified system.

As before, the static pressures decrease progressively from the discharge of the one fan to the inlet of the other. This arrangement has no adverse impact on the scrubber performance.

SLIDE 1-7



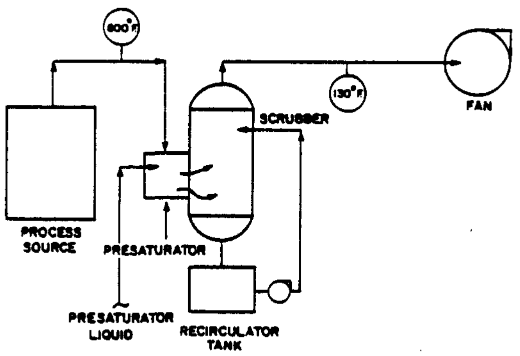
It is common to include a bypass stack ahead of the scrubber vessel. This can be opened in the event of a sudden process upset or the need for scrubber maintenance while the process remains in operation.

The draft created by the stack is usually sufficient to exhaust the process equipment during the interim. Therefore, it is rare to have a fan on the bypass stack.

Corrosion of the bypass damper can lead to some unintentional leakage of untreated gas out the bypass stack. This will not have the characteristic steam plume since the water vapor content at this point of the system is low.

On negative pressure systems as shown here, there can be some infiltration of ambient air down the bypass stack if (1) the negative pressure in the duct is lower than the draft created by the stack, and (2) there is leakage of the bypass damper. Methods of checking for both untreated gas release and air infiltration are included in the inspection procedures discussed later.

SLIDE 1-8

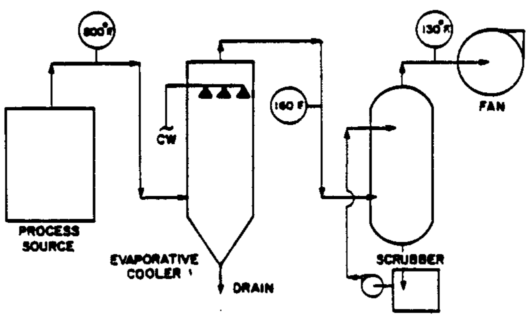


Many sources served by wet scrubbers have very hot gas temperatures. It is not prudent to expose the scrubber vessel itself to these temperatures since this could damage the protective liners on the scrubber walls. The evaporation of droplets exposed to high temperature also makes the droplet less likely to capture a particle. Therefore, scrubber performance is reduced.

Cooling of high temperature gas streams is done almost exclusively by spraying water into the gas stream. Unlike fabric filters, dilution and radiant cooling tubes are not common.

The gas cooling can be done in a specially designed evaporative cooler or in a small presaturator attached to the scrubber vessel. This slide shows a small presaturator ahead of the scrubber. Note that separate liquor lines are shown for the scrubber and the presaturator since the source of liquor is often different.

SLIDE 1-9



An evaporative cooler is shown in this slide. It can be a simple spray chamber with low pressure nozzles or a large cylindrical chamber having a set of high pressure nozzles near the top. Some of the water sprayed into the chamber evaporates, thereby cooling the gas stream. The remainder of the water drains from the bottom. Specially designed evaporative coolers with high pressure nozzles often achieve 70 to 95% water evaporation.

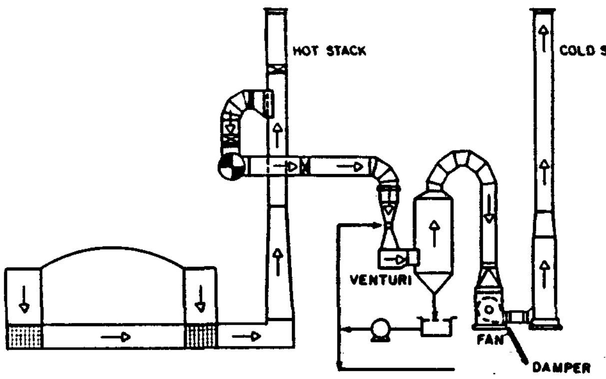
The quality of water used in gas coolers is critical to both the evaporative cooler and to the overall scrubber system. This is an important inspection step.

Once the gas stream temperature has been reduced, material which has been in the vapor state begins to condense to form particulate matter. The particle size range of the resulting material depends on the quantity of material condensed and on the manner of condensation. The water vapor injected into the gas stream may also begin to condense on the surfaces of particles in the gas stream. Both of these phenomenon favor improved collection efficiency.

<u>Lecturer's Notes</u>

One of the major differences between wet scrubber systems and other types of air pollution control systems is that the particulate matter characteristics can change drastically while passing through the system. Such changes have a large effect on pollutant removal efficiencies.

SLIDE 1-10

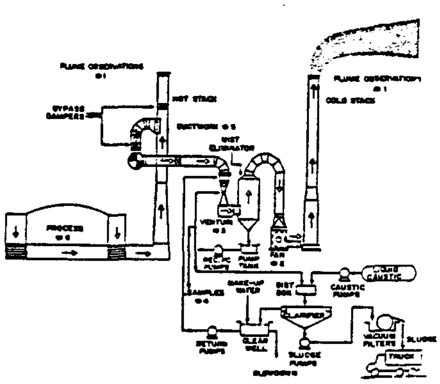


Centrifugal fans are used to move the gas stream through the wet scrubber system. There are two major types in service: (1) radial blade fans, and (2) backward curved fans. The latter are more prone to build-up of solids on the blades and, therefore, require more maintenance.

The inspection procedures will use some of the fan operating data such as the fan motor currents. For this reason, it will be important to have a general understanding of fan curves and system resistance curves. It will become apparent that fan curves have similarites with centrifugal pump curves.

The gas flow rate delivered by the fan is primarily controlled by the dampers before or after the fan. During start-up it is common practice to keep the dampers partially closed to minimize the initial fan motor load.

SLIDE 1-11



The last major component of the gas handling equipment is the stack. Unlike large fabric filter and electrostatic precipitator systems, there are no transmissometers used on wet scrubber stacks. This is because the water droplets which invariably condense in the gas stream scatter light very effectively. Transmissometers can not distinguish between the scattering due to particles and that due to droplets.

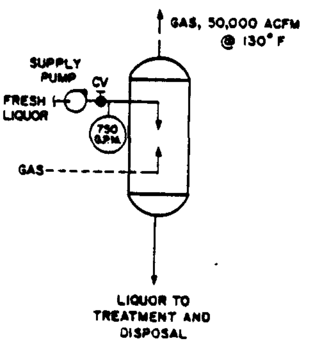
The only visible emissions data which can be used in the inspection technique is that which is obtained by stack observation. No continuously recorded data is available.

The water droplets which preclude the use of transmissometers also can complicate the manual observations. Field inspectors must be trained in the proper procedures for observing wet scrubber plumes. Some of the important points are summarized in a later lecture.

Lecturer's Notes

The frequent lack of adequate visible emissions data forces greater emphasis on measurable scrubber operating parameters. This is one of the major differences between wet scrubber inspections and the inspection of other air pollution control systems.

SLIDE 1-12

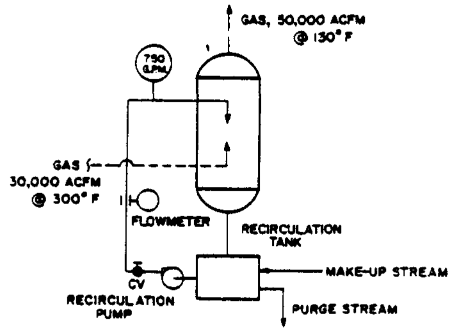


The next set of slides concerns the liquor recirculation system. There are two basic arrangements: (1) the once through system, and (2) the recirculation system. Obviously, the once through system is easier to inspect due to the relative simplicity of the flow pattern.

This slide illustrates the once through flow arrangement. The scrubber liquor is drawn from a process water source or municipal supply. It is drained into a sewer or other treatment unit for final disposal.

The main advantage of this approach is that solids and corrosive materials do not gradually accumulate to harmful levels. This reduces the pump, nozzle and scrubber vessel erosion and corrosion problems. Absorption of some gases is also favored. However, the large majority of these systems have been converted to recirculation systems to reduce water useage and to reduce wastewater treatment costs.

SLIDE 1-13



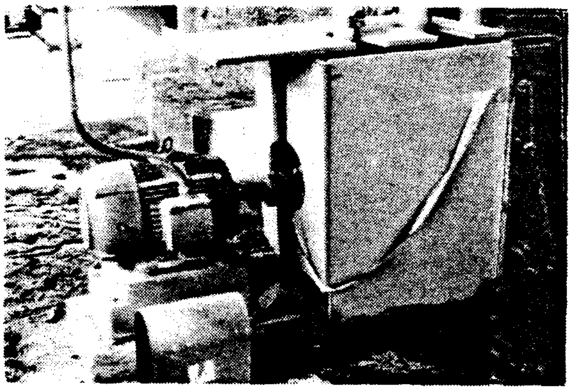
This is a simplified sketch of a recirculation system. The liquor drained from the scrubber sump is recovered in a recirculation tank. A recirculation pump moves the liquor back to the scrubber inlet.

Because of the accumulation of solids and salts within the liquor, it is necessary to purge some of the liquor. This can go either to a sewer or a waste water treatment system.

The water lost through the purge stream and the water lost in the scrubber outlet gas stream must be replaced by a make-up stream. Both the make-up and purge streams are usually much smaller than the recirculation stream.

Due to the higher concentrations of solids and salts, the components of the liquor recirculation systems suffer more erosion, corrosion and pluggage than those in once through systems.

SLIDE 1-14

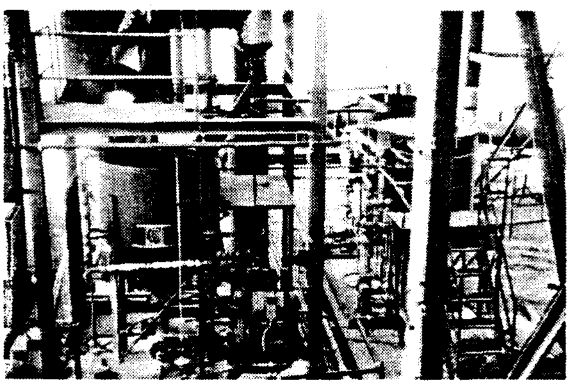


The heart of the recirculation system is the recirculation pump. Centrifugal pumps are used exclusively for this service because they are capable of of supplying high liquor flow rates at moderate to high pressures. The pump must not only provide the necessary liquor pressures at the scrubber inlet; it must also lift the liquor back up to the elevation of the inlet.

The pump must be carefully chosen to provide desired flow rates and pressures for the actual system present.

During the inspection, the pump operating data will provide indirect indications of the liquor flow rate. This is important since the flow rate monitors are rarely present. The operating condition of the pump should be observed briefly to confirm that there are no emerging problems.

SLIDE 1-15

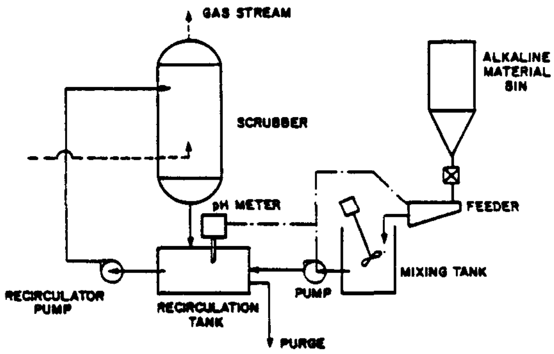


There is more to the wet scrubber piping system than simply connecting point A to point B. The pipe must be sized properly to get the desired system resistance. The materials of construction should be selected so that the pipes will withstand the corrosive, erosive and settling characteristics of the liquor.

The piping arrangement must allow for complete draining of the lines during off-line winter conditions. There must also be provisions for the flushing of solids from the pipes on a routine basis.

The pipes must be supported in a manner that places no loads on the recirculation pump. The valves should be selected so that water hammer is also not transmitted back to the pump. The pump suction line should be sloped to prevent gas pockets and to provide adequate suction head at the pump. In short, the piping should not be an afterthought in the design and installation of a scrubber system.

SLIDE 1-16



Any scrubber composed of carbon steel must operate at pH levels above 5 and preferably above 5.5. Scrubbers being used for odor control often operate between ph levels of 8 to 10 in order to maximize absorption.

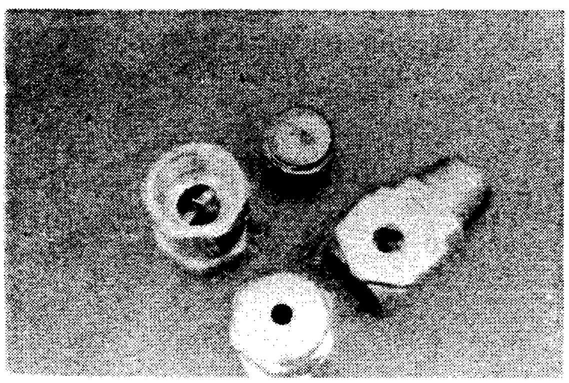
To maintain the pH in the desired range, it is necessary to add a neutralizing agent. Materials in common use include soda ash, lime, and limestone. These can be added either on an intermittant basis by dumping bags into the recirculation tank, or on a continuous basis as shown in the slide.

The continuous addition systems are more complicated. However, they do not suffer the frequent large swings in pH common to those with intermittant addition. The rate of addition is generally controlled by a pH meter located in the recirculation tank or similar location.

Lecturer's Notes

Obviously when evaluating the liquor pH, it is important to know both where the sample was taken and when it was taken. The pH can be a highly variable parameter in wet scrubber systems. The importance of documenting time and location will be a common theme of later discussions of wet scrubber operating parameters.

SLIDE 1-17



The nozzles and liquor distribution headers are critical to all scrubber designs. Pluggage of even a small fraction of the nozzles leads to very poor gas-liquor distribution.

There are a wide variety of commercially available nozzles. The nozzle model must first match the suspended solids levels expected in the scrubber system. Certain types are appropriate only for clean liquors.

The arrangement of nozzles must take into account the spray angle and spray pattern of the specific nozzle.

While the nozzles are the smallest individual component used in a wet scrubber system, they are normally responsible for a large share of the unscheduled maintenance effort. The small clearances through many nozzle designs makes then especially prone to pluggage even at solids levels which do not affect control valves and pipes. The high velocities at the nozzle orifice can result in rapid erosion.

SLIDE 1-18

LIQUOR TREATMENT SYSTEMS

Clarifiers with Vacuum Filters

Settling Ponds

Wastewater treatment facilities range from very simple ponds to elaborate clarifier-vacumn filtration plants. Obviously, only the very large scrubber systems have the latter type of facilities. All of these, however, share the common purpose of reduction in the liquor solids content.

The clarifier (sometimes called a sedimentation tank) is simply a large tank where the suspended solids can settle to the bottom. The accumulated sludge is continuously removed from the bottom. A rotary vacuum filter is used to remove the suspended solids from the calrifer underflow. The clarified effluent is removed from the top of the clarifier.

Often the settling characteristics of the suspended solids can be improved by the addition of flocculation agents. These cause the fine particles to agglomerate together and thus increase the settling rate. Unfortunately, the flocculants may have an adverse impact on the liquor surface tension.

Lecturer's Notes

It is an unfortunate fact that steps taken to optimize the performance of one of the wet scrubber system components can have an harmful affect on another component. In this case, the increased surface tension with certain flocculants can change spray droplet size and decrease particle capture for a given size droplet. Both changes can affect particulate removal. A number of trade-offs must be made by a well informed operator in order to achieve optimum performance of the overall system.

SLIDE 1-19

Ponds are the simplest type of liquor treatment system. They can range from very small, single zone ponds to quite large, multi-zoned settling basins.

The test of pond performance is the ability to deliver relatively clean liquor back to the scrubber system over a long time period. One means to improve performance is the use of several zones each separated by an overflow weir. There should also be an easy way to remove the solids from the first and second zones on a regular basis.

SLIDE 1-20

INSTRUMENTATION

1. **GAS STREAM MONITORS**
   - A. Thermocouples
   - B. Pressure Drop Gauges
   - C. Fan Motor Current

2. **LIQUID STREAM MONITORS**
   - A. pH Meters
   - B. Pump Discharge Pressure
   - C. Pump Motor Current
   - D. Pipe Pressures
   - E. Flow Rate Monitors

This slide lists the types of instrumentation available on wet scrubber systems. Some of these are used to control system operation and some are intended to provide general indications of performance for the operator.

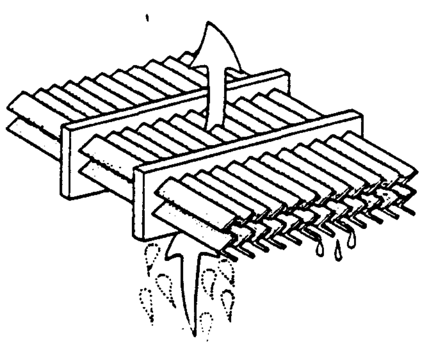
All instruments used on wet scrubber systems are subject to pluggage, erosion and corrosion. Conscientious maintenance is often not sufficient to keep all instruments in proper working order. Therefore, the process control instruments should always be included on an initial list of possible culprits responsible for performance problems. Also, the indicated data for scrubber instruments always deserves scrutiny.

The more advanced forms of the inspection procedures will utilize some portable instruments. They are necessary to overcome the limitations of the permanently mounted instruments and they are also helpful when the necessary gauges are not available. Measurement ports are necessary.

Lecturer's Notes

The attendees need to understand that it is very difficult to keep wet scrubber instrumentation working and they should not be too quick in accusing plant operators of inadequate maintenance of the instruments. While this may sometimes be the case, more often it is due simply to the tendencies for pluggage, erosion and corrosion. In other words, field inspectors need to be sympathetic to occassional instrument malfunctions. Material presented later will address some of the steps which can be taken to minimize failure.

SLIDE 1-21



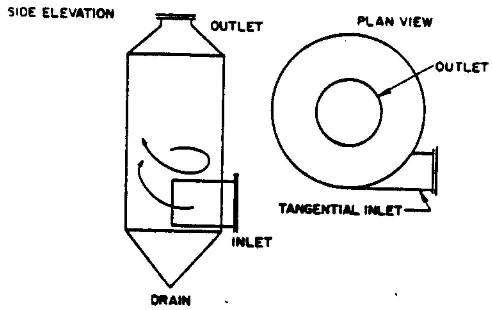
Source: Air Pollution Training Institute

There are several distinct types of demisters in common service. All of these are intended to remove the very large (100 to 800 micron diameter) droplets formed in the scrubber.

The type shown in this slide can be placed in the upper sections of cylindrical scrubbers. The gas stream passes through the demister at superficial velocities in the range of 5 to 20 feet per second. The droplets which impact on the demisters simply drain back into the scrubber.

The chevron demisters force the gas stream to make several quick turns which the large droplets can not negotiate. These come in numerous blade designs and with 2, 3, and 4 passes. Mesh pads (not shown) operate in the same manner as household furnace filters with the fibers serving as impaction targets. Both styles of demisters must be cleaned regularily to prevent the accumulation of solids on the surfaces.

SLIDE 1-22



Other styles of demisters are shown in this slide. Both of these take advantage of a spinning gas stream which results in the impaction of the large droplets on the demister wall. These types of units are commonly included with venturi scrubbers.

On positive pressure units, the stack sampling ports are directly above this demister. Provisions must be made to eliminate the cyclonic flow in the stack so that pitot traverses and stack sampling procedures can be conducted.

Generally the type of demister used is determined by the configuration of the scrubber vessel. The demisters shown in the last two slides serve different applications and are not competitive approaches.

Lecturer's Notes

The removal of 100 to 800 micron droplets may seem simple. However, this is one of the most common sources of trouble in some systems. The consequences of improper demister performance include rainout of particulate laden droplets close to the stack and the accumulation of material on downstream fans.

SLIDE 1-23

TYPE OF SCRUBBER VESSELS

A. SPRAY TOWERS
B. PACKED BEDS
C. MOVING BEDS
D. MECHANICALLY AIDED
E. ORIFICE
F. VENTURI
G. TRAY TOWER

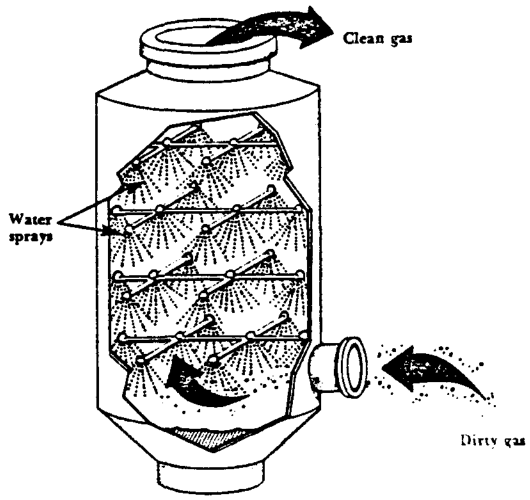
The most common scrubber designs will be addressed in the program. It is important to be able to recognize the advantages and limitations of each during the inspection. Specific inspection procedures have been prepared to focus in on the most common modes of failure of each type.

The list provided is far from complete. There are a number of innovative designs which have been commercially introduced in the last five years. There are also a number of variations of the listed types, each having unique design features. The inspection techniques for these modified and new designs will have to be developed by each inspector based partially on the procedures presented in this program.

Lecturer's Notes

The terminology in the wet scrubber industry is not standardized. These titles could differ from those familiar to some of the attendees. Also, the manner in which scrubbers are grouped can vary. These categories are convenient for this program since the inspection procedures are distinctly different for each of the categories listed.

SLIDE 1-24

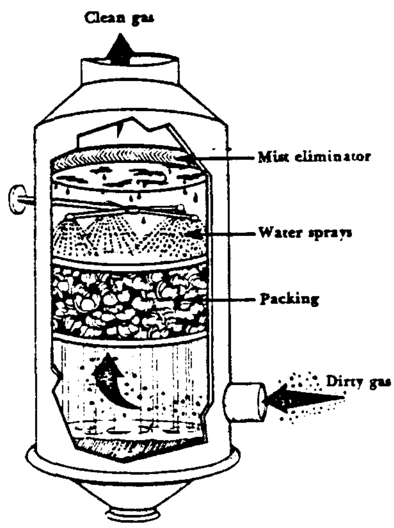


A spray tower scrubber is illustrated in this slide. This is the simplest type of unit and it has only a limited particulate removal capability. It is selected for applications where there is not much particulate matter smaller than 5 microns. It can also be used in some gas absorption systems.

The gas stream enters near the bottom and flows upward at velocities between 2 and 5 feet per second. The liquor enters at the top. Therefore, the flow is in the countercurrent direction relative to the gas stream. Liquor distribution is entirely controlled by the types of nozzles, the nozzle spray angle, the nozzle placements and the liquor pressure.

Most of these systems are relatively simple. However, alkaline addition equipment is sometimes necessary. The instrumentation is usually very limited and this complicates the inspection procedures.

SLIDE 1-25

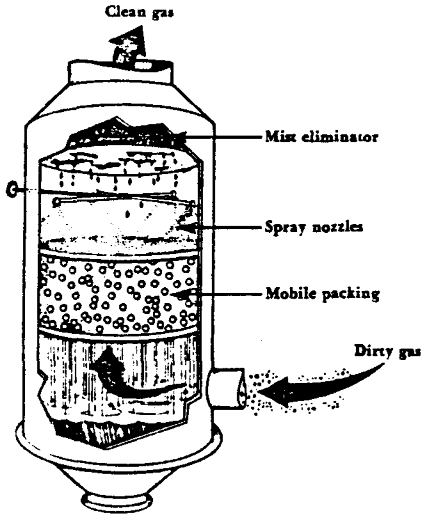


Packed bed scrubbers are primarily intended for gas absorption. The large liquor surface area created as the liquor gradually passes over the packing material favors gas diffusion and absorption. These are not effective for particulate removal since the low gas velocities do not result in much paticulate impaction on water droplets.

The gas stream again enters from the bottom and passes upward through one or more beds. The liquor is sprayed on the top and flows downward. Liquor distribution is important for high efficiency removal of gases.

One of the major problems with these scrubbers is the accumulation of solids at the entry to the bottom bed and within the beds. The dissolved soilds and suspended solids levels in the liquor must be monitored carefully. It is difficult to routinely remove these solids due to the characteristics of the packing materials.

SLIDE 1-26



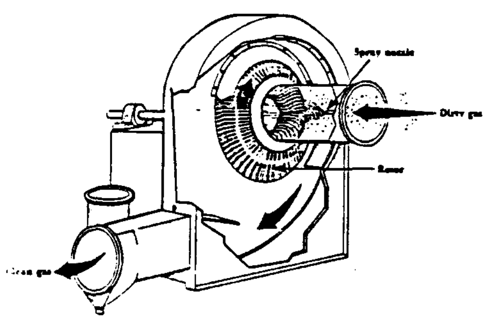
Moving beds have entirely different characteristics than packed beds. They have moderate to high particulate removal capability due to the formation of fine droplets within each bed and the relatively high gas velocities. Both of these factors favor particle impaction. The high liquor surface area created also makes these units acceptable for gas absorption. The turbulent action of the packing provides a self cleaning characteristic. Therefore, pluggage is not an issue. These were originally developed by the primary aluminum industry which needed to remove sticky organic particles and hydrogen fluoride gas.

The most common version of moving bed scrubbers has several "beds" partially full of hollow balls which closely resemble ping pong balls. The packing moves violently due to the combined action of the rising gas stream and the falling liquid. Water droplets formed in the turbulent bed serve as the particle impaction targets and as the gas absorption surface.

Lecturer's Notes

One common trade name for this style of scrubber is the Turbulent Contact Absorber, or TCA for short. It is also called simply a "Ping Pong Ball Scrubber." Marble bed scrubbers are sometimes classified as a moving bed since the packing is free to move. However, the performance characteristics are more like the packed bed than the TCA shown above.

SLIDE 1-27



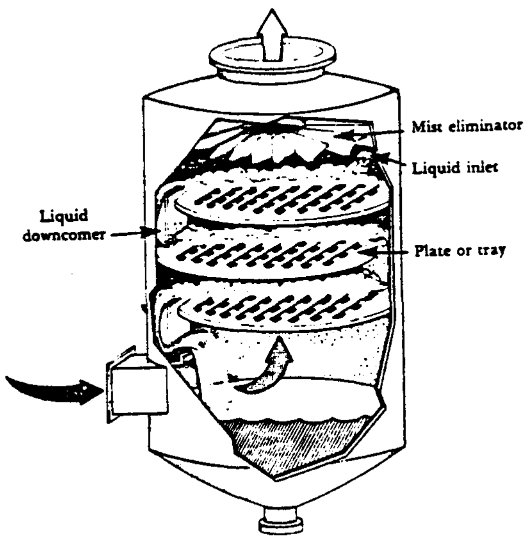
Source: Air Pollution Training Institute

One common type of mechanically aided scrubber is illustrated in this slide. The gas stream enters axially and is spun outward due to the rapid rotation of the scrubber fan blade. Liquor is sprayed in the inlet duct. Impaction of particles occurs on the initially slow moving droplets.

Unlike all other types of scrubbers, this particular design does not have a "pressure drop". The mechanical energy provided by the shaft achieves the scrubbing action and moves the gas stream through the ductwork. There is a static pressure rise across this type of unit.

These scrubbers are used only for relatively small systems having gas flows less than 10,000 ACFM. The scrubber systems are relatively simple. However, it is important to have high quality liquor so that erosion and build-up on the fan blades is minimized. Obviously, no fans are necessary with this type of system.

SLIDE 1-28



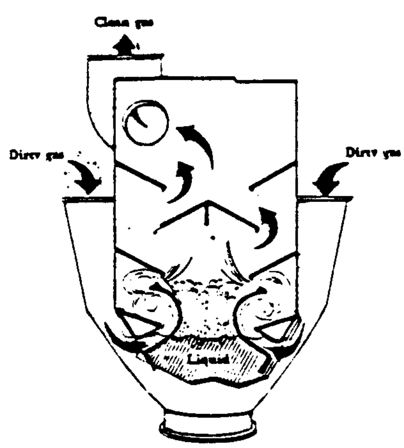
A tray tower scrubber can be used for both particulate and gaseous removal. However, the most common applications are for particulate control. It consists of a series of trays with holes. The gas stream enters from the bottom and passes upward through the holes. Liquor enters from the top and passes across each tray as it goes downward. Downcomers are used for moving the liquor from one tray to another.

A chevron or mesh pad demister is placed above the elevation of the liquor inlet. This collects any droplets entrained from the top tray of the scrubber.

Two of the major tray designs are shown in this slide. The sieve plate has relatively large holes compared with the impingement tray. The latter has high velocities through the holes and a target directly above the holes.

One of the main advantages of this style is that there are several opportunities to collect pollutants. Slight gas-liquor distribution problems on one tray can be tolerated since the material can be caught on subsequent trays. The liquor quality is again important since it is easy for the holes to plug.

SLIDE 1-29

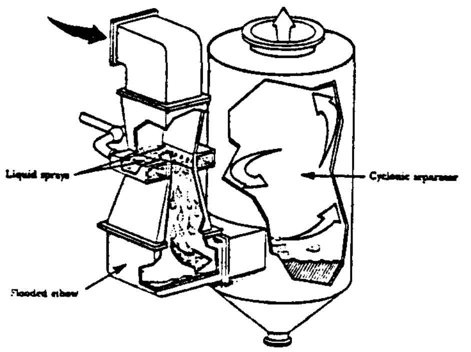


The orifice scrubber is one of a large number of units which is classified as a gas atomized scrubber. This means that the droplets which serve as impaction targets are formed in high velocity gas streams.

In this case, the gas enters the vertical tube and makes a 180° turn just above the surface of the liquor. The action of the gas stream atomizes the liquor which was entrained by the passing gas stream. Baffles included in the scrubber "box" knock down any drops which remain suspended in the gas.

They are usually very small scrubbers. The system can be exceedingly simple since it is not absolutely necessary to have a recirculation pump and piping system. In a sense, everything is self contained in the scrubber vessel. The inspection of these units is often complicated by the almost complete lack of instrumentation.

SLIDE 1-30



A classic style of a venturi scrubber is shown here. The gas stream enters the converging section and is accelerated by approximately a factor of ten above normal duct velocities. The liquor is injected just above the throat. Droplets form due to the shearing action of the high gas velocities.

Impaction of particles occurs on the droplets which are initially moving slower than the gas stream. The high liquor surface area also allows for some gas absorption.

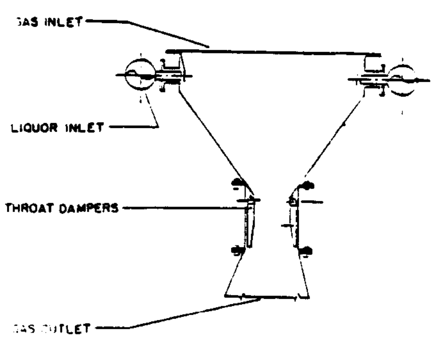
The gas stream is decelerated in the diverging section. In early designs, the diverging section was long and had a small angle in order to reconvert some of the gas stream kinetic energy back to potential energy (pressure recovery). Most of the units in present use have a very short diverging section and angles approaching 25°. There is only limited pressure recovery with these units.

After the venturi section, the gas stream turns 90° and passes into the demister chamber. The venturi scrubbers usually are part of a large and relatively complex scrubber system. Waste water treatment systems, alkaline addition equipment and presaturators are common.

Lecturer's Notes

The feature which makes the venturi so effective is also its Achilles Heel. The very high gas velocities of 20,000 to 40,000 feet per minute at the throat entry provide excellent impaction conditions. However, the gas stream quickly exits the throat and decelerates. Very little particle removal occurs after the gas stream leaves the throat. If the gas-liquor distribution is not proper at the throat entry, the scrubber effectiveness will be compromised.

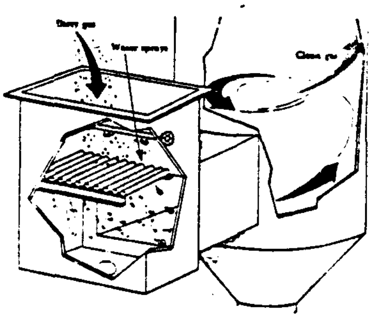
SLIDE 1-31



There are a large number of variations to the standard venturi configuration. This slide shows dampers mounted on both sides of a rectangular throat. These can be partially closed to reduce the throat area. At a constant gas flow rate, the reduced throat area results in higher gas velocities. The improved particulate removal efficiency is obtained at the expense of higher static pressure drops across the throat.

The position and physical condition of the dampers can not generally be confirmed by external checks and there is no way to see inside while the unit is operating. These must be checked when the unit is down, however, since the dampers are subject to extreme abrasion.

SLIDE 1-32



Source: Air Pollution Training Institute

Another common style of venturi scrubber is shown in this slide. Instead of a "venturi" assembly, this scrubber uses a horizontal deck of rods. The restricted area between the rods accelerates the gas stream and provides a zone for droplet atomization. The "throat" has almost negligible length. The numbers or diameters of the rods can be varied as necessary to achieve the desired gas velocities.

The inspection procedure for this style of scrubber is very similar to that for the classical venturi units. The only difference is that there is concern with rod erosion and corrosion in this design.

Unlike classicl venturi scrubbers, these units can be arranged to have several decks in series. This multiple deck arrangement is used most commonly when the scrubber's primary purpose is gas absorption rather than particulate control. In gas absorption units, the gas velocities between the rods is lower than it is in particulate scrubbers.

Lecturer's Notes

These "Rod Deck" scrubbers are mentioned because of the growing use for both particulate and gaseous control applications. Some of the particulate systems can be quite small and serve applications in which historically the "venturi" has not been competitive. Large units are used for utility scale flue gas desulfurization.

SLIDE 1-33

TERMS AND DEFINITIONS

The first portion of this lecture has concerned the typical components of a wet scrubber system and a brief introduction to the most common types of scrubber vessels. Basic functions of each of these must be understood before proceeding with this program.

It is equally important that all of major terms used in the program are defined. Unfortunately, there is some inconsistency in the wet scrubber literature terminology. The next set of slides discusses these terms.

Lecturer's Notes

Up to this point, the material has been introductory in nature and could be skipped when the attendees are experienced with scrubber systems. It is advisable, however, to go over the next few slides so that everyone will understand the meaning of the terms used later in the program manual. It should be noted that the definitions used here are not represented as being the best or most commonly used definitions. They are simply the meanings intended by the author of this manual.

SLIDE 1-34

STATIC PRESSURE DROP

Pressure drop is sometimes used as a measure of the amount of energy consumed in the scrubber. This is supposedly related to the overall effectiveness of the scrubber for particulate removal.

The fact that the correlation seems to make sense sometimes does not alter the fact that pressure drop versus collection efficiency alone is not a measure of energy use. In fact, the energy consumption is related to the TOTAL PRESSURE DROP divided by the AVERAGE GAS DENSITY. The STATIC PRESSURE DROP (which is what is implicitly meant by "pressure drop") is just one component of the TOTAL PRESSURE. The other is the VELOCITY PRESSURE. It is also important to specify the locations between which the pressure drop is measured. In this report the term "pressure drop" will mean the difference in static pressures measured at two specified locations.

Lecturer's Notes

The sloppy use of the term "pressure drop" can be a serious problem. If there is some confusion on the part of the attendees, the definitions of static, velocity, and total pressure should be provided. It may also be helpful to introduce Bernoulli's Equation at this time for the more experienced groups. This will be used later in the program.

SLIDE 1-35

PARTICLE SIZE

A term as simple as particle diameter can be confusing. The meaning of the term depends on the way in which the material was obtained and anaylzed.

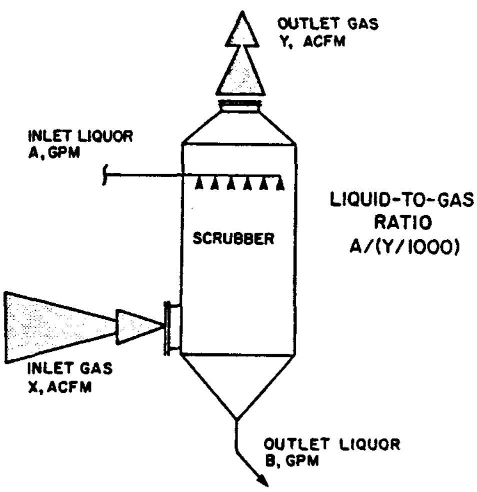
In this manual, the diameter specified is the aerodynamic diameter. This is the diameter of a unit density (same specific gravity as water) sphere having the same aerodynamic properties as an actual particle.

What this means is that the actual particle behaved in a sampling device in a manner which is identical to a known size test aerosol. The factors which affect the motion of a particle in a gas stream also affect the aerodynamic diameter. They include actual diameter, actual density, and particle shape.

Lecturer's Notes

It should be noted that the particle size distribution that would be derived from microscopic analyses may differ from that determined from a cascade impactor. Since almost all size data is obtained by cascade impactors, and since this directly yields an aerodynamic diameter, this term is the easiest to use despite the cumbersome units.

SLIDE 1-36



The liquid-to gas ratio is illustrated here. In this manual, the term means the total gas flow rate in actual cubic feet per minute divided by the liquor flow rate introduced at the scrubber vessel only. It does not include liquor or make up water sprayed in evaporative coolers, or water use to flush demisters.

The outlet gas flow rate is used as the basis for the definition since this is the easiest to measure. Stack sampling ports are usually available for this purpose. Also, the outlet gas flow rate is less subject to change due to temperature fluctuations.

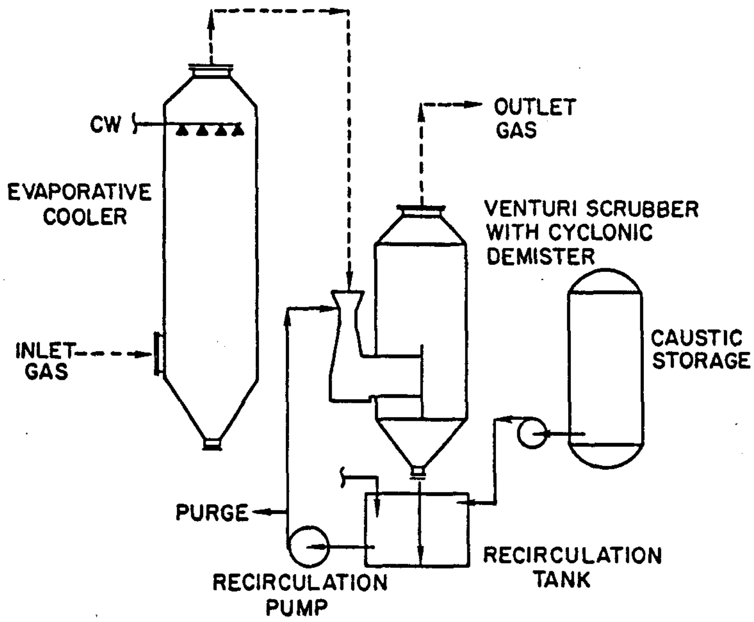
SLIDE 1-37

EROSION/CORROSION

Erosion is the physical removal of a surface caused by impacting particles. Corrosion is the chemical and electrochemical removal of surfaces.

While these are distinctly different phenomenon, there is some interaction between the two. Surfaces which have been eroded are more susceptible to corrosion. Surfaces which have corroded are more susceptible to erosion. The term "erosion/corrosion" is used frequently to refer to the combined action of both. This is a logical approach since it is often impossible to determine which is most significant or which occurred first.

Erosion and corrosion present more problems for wet scrubber systems than for any other type of air pollution control system. One of the reasons is that there are a number of localized areas in the wet scrubber system which have high liquor and gas velocities. The suspended particulate in both streams becomes highly erosive at high velocities. Corrosion is promoted by the moist surfaces.



SLIDE 1-38

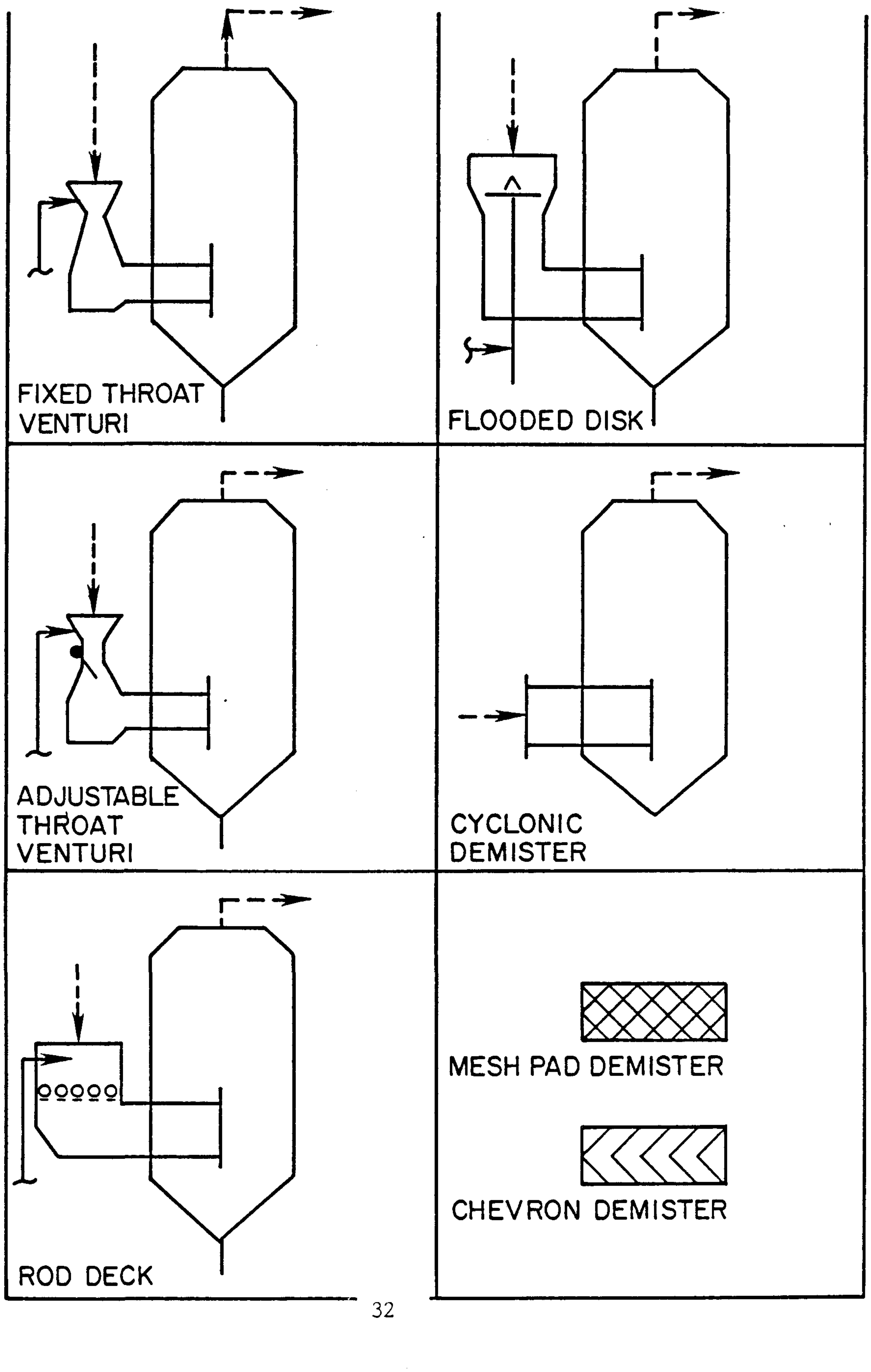
PREPARATION OF FLOWCHARTS FOR WET SCRUBBER SYSTEMS

Flowcharts are absolutely necessary for a detailed and effective inspection of a wet scrubber system.

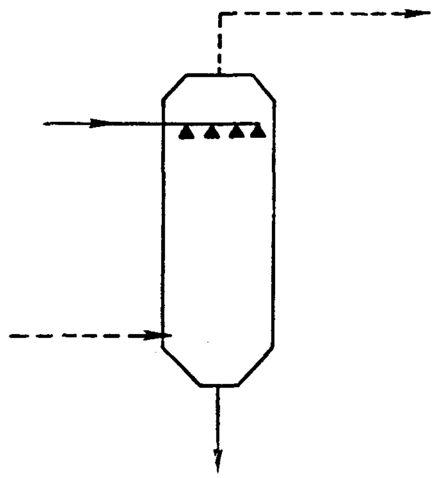
The locations of all measurement ports and instruments should be shown along with the sources of all liquid streams. Bypass vents and stacks should also be marked.

The flowchart should not be cluttered with unnecessary detail. Also, it should be remembered that a flowchart is not judged on the basis of artistic merit, but rather the insight it provides to an inspector trying to evaluate a change in system operating conditions.

Symbols and drawing conventions presented in the next set of slides have been taken from the Chemical Engineering literature and from standards presented by the Instrument Society of America. However, some license has been taken in order to compile a set of symbols specifically for inspectors of air pollution control equipment. Each field inspector is invited to make further changes as they see fit.


FIXED THROAT
VENTURI
FLOODED DISK
ADJUSTABLE
THROAT
VENTURI
CYCLONIC
DEMISTER
ROD DECK
MESH PAD DEMISTER
CHEVRON DEMISTER

SLIDE 1-39

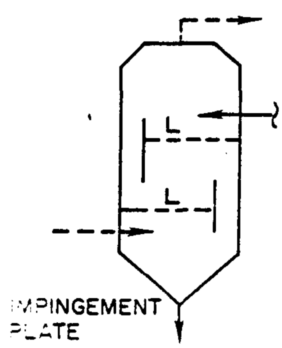


The first step in the procedure is to adopt a convention for liquid and gaseous streams. The line types shown in this slide have been arbitrarily chosen for this purpose.

Note that the pipe sizes can be easily shown on the solid lines. The size data shown is the actual diameter (approximate data is sufficient) rather than the specific pipe size. The dotted lines for the pollutant laden gas streams can also be interrupted to show the approximate size of the ducts. This data helps to identify ducts and pipes while comparing the flowchart to the actual system.

It is usually best not to show steam lines and other material transfer lines not directly related to the scrubber operation. It is difficult enough simply trying to understand some of the complicated and often modified systems. Extraneous material is not helpful.

SLIDE 1-40

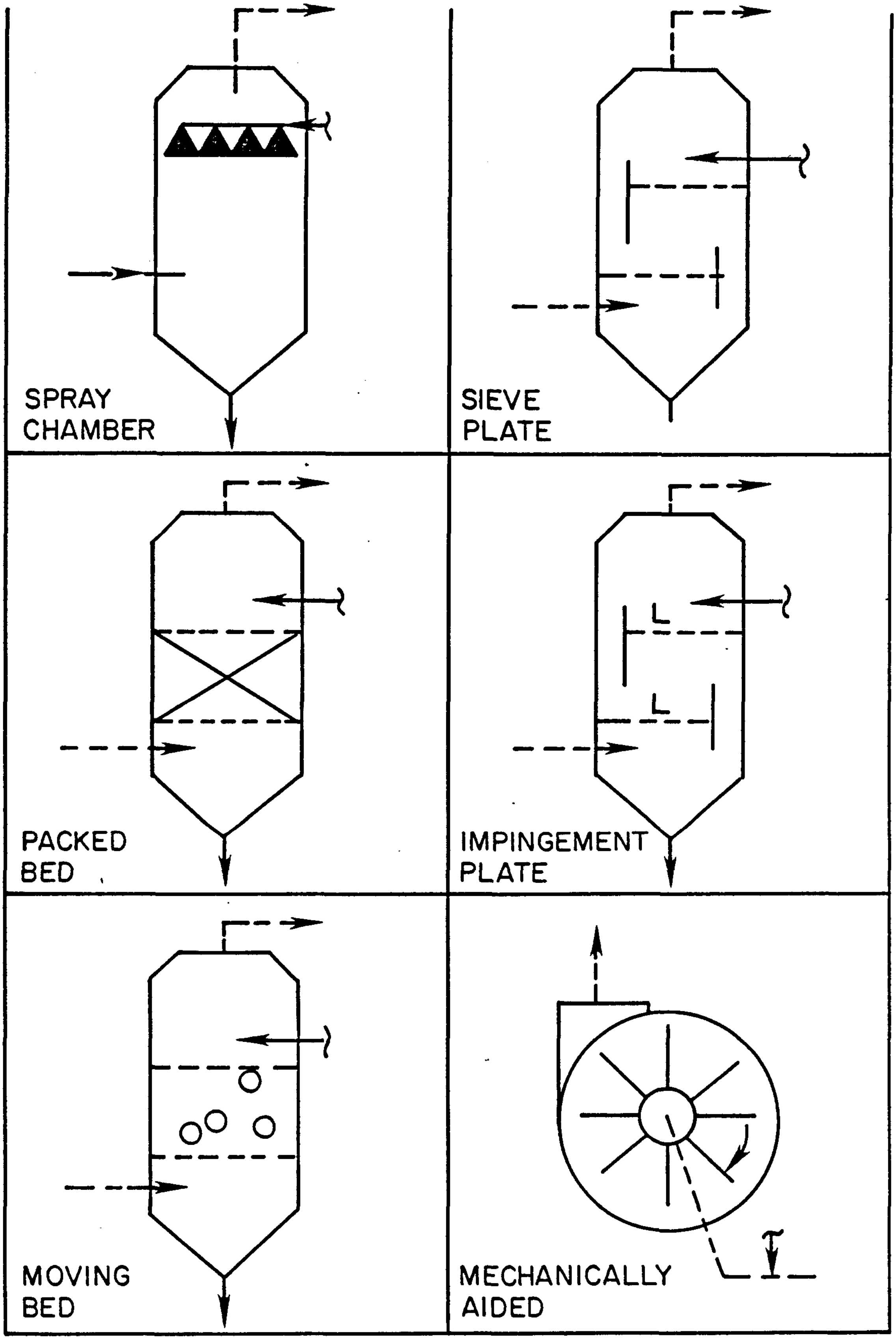


The type of scrubber vessel and demister should be indicated using the figures on the opposite and next pages. Note that these provide just enough information to indicate the type of unit but do not require extensive drawing.

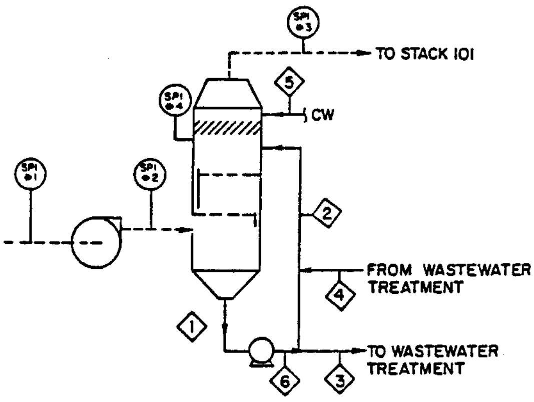
The points at which the various gas and liquid streams enter and exit the unit should be shown. The directions of flow are indicated by arrows.

With this part of the flowchart, it should be possible to get a conceptual idea of how the unit is working.

With the number of innovative systems now entering the wet scrubber market, there will soon be a need to develop additional symbols. Remember that consistency and logic are necessary when it comes to flowcharts.


SPRAY
CHAMBER
SIEVE
PLATE
PACKED
BED
IMPINGEMENT
PLATE
MOVING
BED
MECHANICALLY
AIDED

SLIDE 1-41

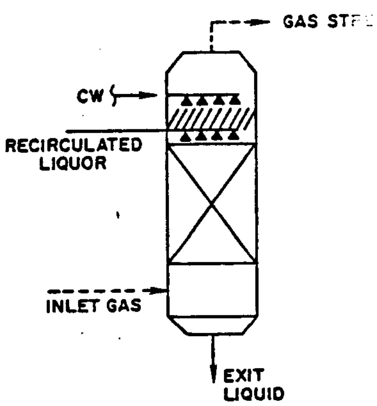


This is an example of a wet scrubber system based on the symbols presented. The scrubber vessel is an impingment type tray scrubber and there is a chevron demister at the top of the unit. The liquor enters from the top and flows down to a sump at the bottom of the unit. While most of the liquor is recirculated, a purge stream (number 3) is drawn off for treatment. Fresh water is used for occassional cleaning of the demister.

The fan is upstream of the scrubber. Therefore the scrubber vessel and ductwork from the source are under positive pressure.

Note that the stack is numbered. It is best to have a consistent numbering scheme for each stack and vent rather than relying on the identification system used at the plant. These are subject to change over time. When making visible emission observations, the number of the stack specified on this flowchart should be recorded along with other identification information.

SLIDE 1-42

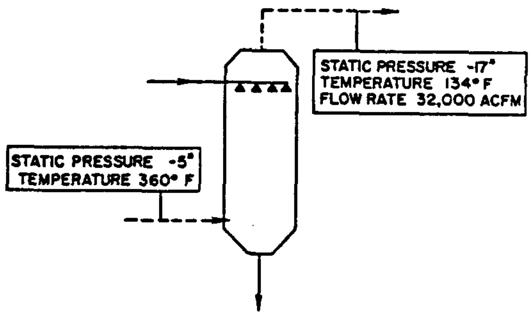


The symbols for process water, city water, compressed air and other system utilities are shown in the list below. The figure to the left shows how these can be used in a flowchart. Use of these symbols helps to unclutter the flowchart.

A - Plant compressed air
IA - Plant instrument quality air
CW - City water
PW - Water from process equipment
BW - Boiler feed water
DW - Distilled water
FG - Fuel gas
FO - Oil
FC - Coal
FW - Wood fuel
HM - Heating medium
HS - High pressure steam
LS - Low pressure steam
SC - Steam condensate
E - Electrically controlled

It should be noted that some of these symbols differ from conventional flowchart practice. The symbol CW, for example, often stands for cooling water rather than for city water.

SLIDE 1-43

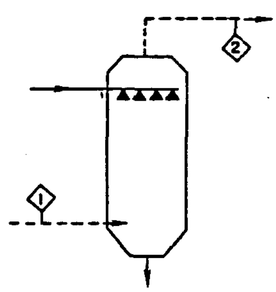


In some cases, it may be helpful to put some of the typical operating data on the flowchart itself. There are two ways this can be done easily.

The figure to the left shows the data contained in blocks. A thin indicator line is used to connect this block to the appropriate stream line.

This is an adequate approach as long as the system is relatively simple and the amount of data listed in small. For large scrubber systems, this can become cumbersome and confusing. The approach shown on the next slide is appropriate for such systems.

SLIDE 1-44

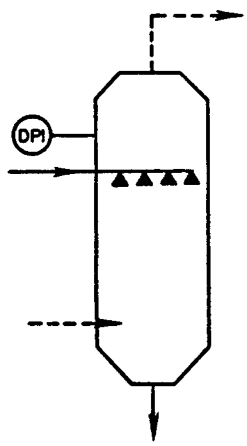


STREAM	STATIC PRESSURE IN. W.C.	TEMPERATURE °F	FLOW RATE ACFM
1	-5	360	NO DATA
2	-17	134	32,000

The liquid and gas streams in this flowchart have been assigned numbers which are enclosed in diamond shaped boxes. These are connected to the appropriate streams by thin indicator lines.

The applicable data for the stream number is shown below the flowchart in a tabular format. Considerably more data can fit into this table than could be put into the individual data boxes shown in the previous slide.

SLIDE 1-45



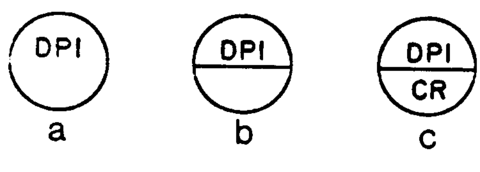
Notation for the process and wet scrubber system instrumentation has been patterned after standard chemical enginering symbols. Several additions and changes were necessary to include features of importance to scrubber systems.

The presence of an instrument or an accessible measurement tap are shown as a circle. A thin indicator line is used to connect this symbol to the appropriate location of the system. The notation inside presents information on the type of instrument.

There are 3 distinct types of codes: those ending in "I" specify that the unit is an indicating gauge only, those ending in "R" are equipped with a recorder, and those ending in "T" are simply accessible measurement ports. The recommended symbols are listed on the opposite page.

The operating range of the instrument can be specified in the indicator circle along with the instrument symbol. For ports, the inside diameter is useful information since it determines the type of equipment which is necessary to seal the port during measurements.

SLIDE 1-46



The use of a line across the diameter of the instrumentation circle indicates that the instrument is panel mounted.

The slide to the left has three different symbols to illustrate how the line can be helpful. The first (1-46a) means that there is a differential pressure indicator on the the system itself. The second (1-46b) means that a differential pressure indicator gauge is on a control panel somewhere. The third (1-49c) is more explicit in that the location of the gauge is stated to be the control room symbol. CR is a useful symbol for this.

INSTRUMENTATION SYMBOLS

1. TI - Temperature indicator
2. TR - Temperature recorder

3. DPI - Gas stream static pressure drop indicator
4. DRP - Gas stream static pressure drop recorder (Both upstream and downstream measurement locations must be indicated for differential pressure instruments)

5. SPI - Gas stream static pressure indicator
6. SPR - Gas stream static pressure recorder
7. GFI - Gas flow rate indicator
8. GFR - Gas flow rate recorder

9. LFI - Liquid flow rate indicator
10. LFR - Liquid flow rate recorder
11. PI - Liquid pressure indicator
12. PR - Liquid pressure recorder
13. LCI - Liquid level control indicator
14. pH - pH meter
15. RHO - Liquid density meter

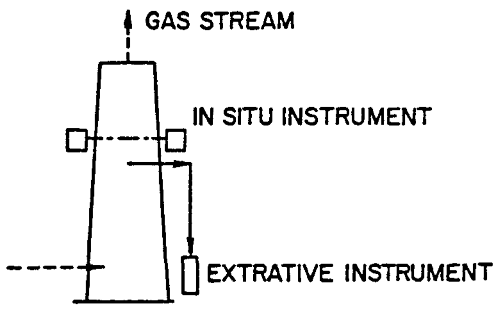
16. PWI - Power on indicator liqht
17. MCI - Motor current indicator
18. MWI - Motor wattage indicator
19. VI - Voltage indicator
20. AI - Current indicator
21. PVI - Primary voltage
22. PCI - Primary current
23. SVI - Secondary voltage
24. SCI - Secondary current
25. SPI - Spark rate

26. O2R - Gas stream oxygen recorder
27. COR - Gas stream carbon monoxide recorder
28. CBR - Gas stream combustibles recorder
29. SO2R - Gas stream sulfur dioxide recorder
30. OPR - Gas stream opacity recorder

31. AT - Accessible measurement tap
32. ST - Stack sampling ports

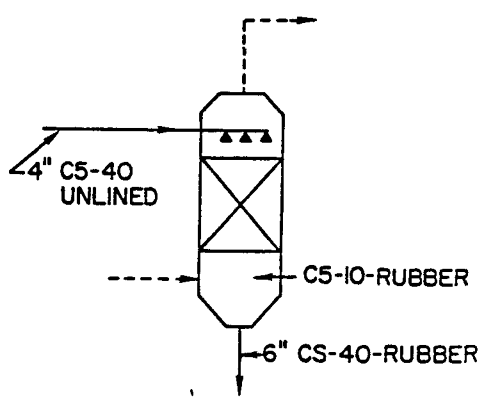
33. API - Compressed air pressure indicator
34. IAPI - Instrument air pressure indicator

SLIDE 1-47



For the few wet scrubber systems having continuous emission monitors, it is useful to specify the general type of instrument. Extractive instruments are shown as a box removed from the gas stream and connected by a short dotted line. The in-situ instruments are shown straddling the gas stream line.

SLIDE 1-48



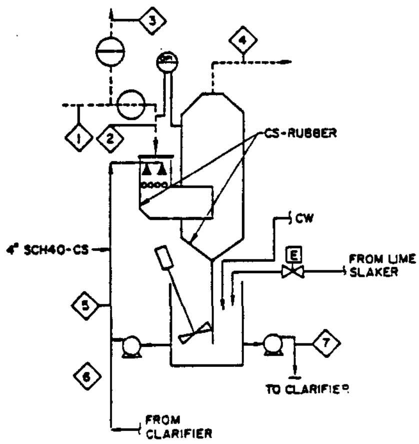
Some of the main causes of wet scrubber system failure are corrosion and erosion. If these problems are likely, the materials of construction can be noted on the flowchart.

A four part coding system is proposed here for identification of the materials of construction. The first part is the pipe or duct size in inches. The second is the basic material. The third is the thickness (or schedule number in the case of pipes) and the fourth is the type of coating or liner. Material codes are presented below and use of the entire code is illustrated in the adjacent figure.

CS - Carbon steel (Specify AISI number if known)
SS - Stainless steel (Specify AISI number if known)
FRP - Fiberglass reinforced plastic
PVC - Polyvinyl chloride (Specify type if known)
NAS - Nickel alloy stainless steel (Specify trade name or AISI number)
W - Wood

There are no abbreviations suggested for the liner. The type should simply be spelled out. The material codes listed above are similar to the standard chemical engineering symbols. However, some changes have been made.

SLIDE 1-49



A complete flowchart for a wet scrubber system is shown in this slide. It incorporates every major feature discussed in this section.

Flowcharts similar to that shown are invaluable when attempting to diagnose operating problems with a system. They also help to determine the most appropriate measurement locations.

Measurement errors and system gauges which are indicating incorrectly can often be identified using the flowchart.

It should be clear that the figure represents a tray type scrubber with a chevron demister. The liquor is recirculated. For simplicity, the entire scrubber system has not been shown.

1-1. The correct answer to this problem is that the static pressure drop can not be calculated from the present set of data which is obviously in error. There is no way the static pressure at point #3 could be higher than the static pressure at point #2.

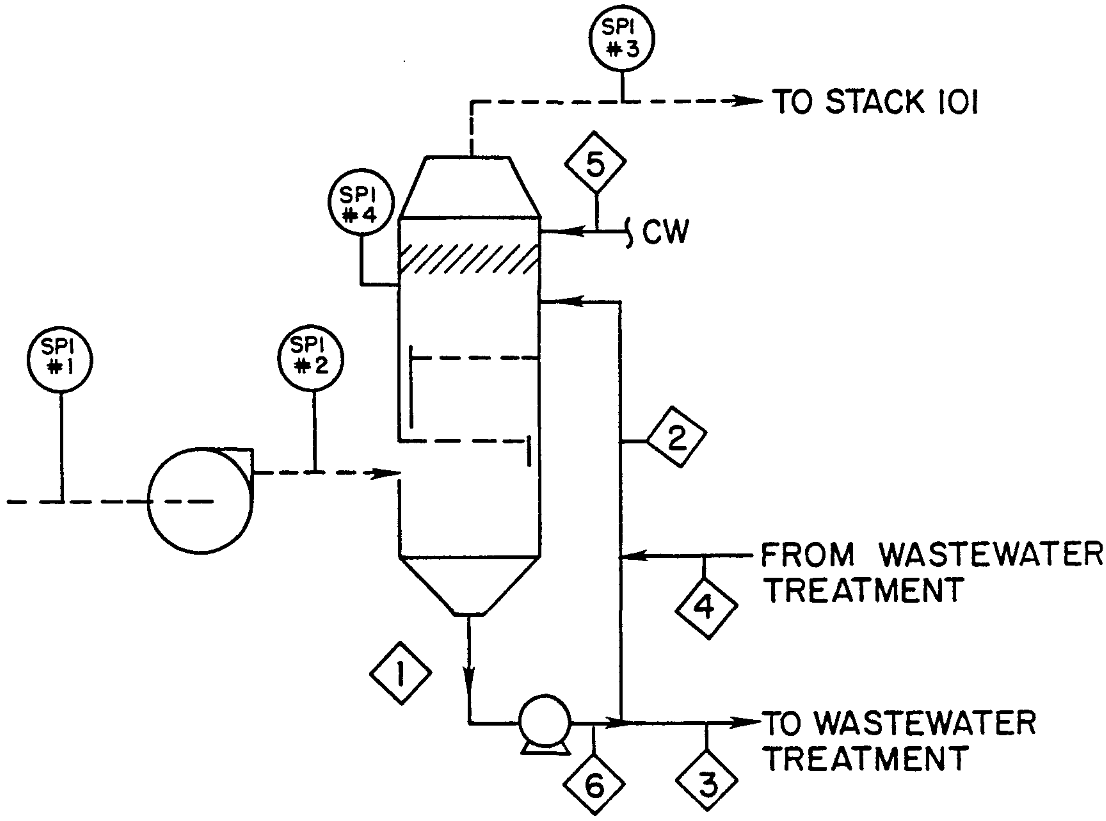
If a number of the attendees answered either 3 inches (point 3 minus point 2) or 12 inches (point 3 minus point 1), that indicates a lack of understanding about the way static pressures vary while gas streams pass through control devices. It increases only when going past a fan.

1-2. Now that we have what appears to be sensible data, the scrubber pressure drop can be calculated as the value at point 3 minus the value at point 2, which is simply 7 inches. PLEASE STRESS THAT THE LOCATIONS OF THE MEASUREMENT SHOULD BE INCLUDED WITH THE DATA. THEREFORE, THE PROPER ANSWER IS: 7 INCHES FROM POINTS 2 TO 3. Note that this now includes the demister's contribution to the overall scrubber pressure drop. It would have been preferable to use data from point 4 had this been available.

1-3. In this particular case there is sufficient information about the liquor flow rates and it possible to calculate the purge stream flow rate from a simple material balance. The answer is 15 gallons per minute. There are times when an approximate material balance can be very useful and the attendees will occassionally be reminded of these in the program. Usually, it is easier to do this with the gas streams than the liquor streams because in the large majority of cases, the flow rates of most streams will not be known. We can measure the flow rates of the gas streams easily. To answer this question correctly, the attendees will also have to be able to recognize which stream is the purge stream.

1-4. The concepts of positive and negative pressure are reviewed in this question. Since the hole in the scrubber wall is downstream of the fan, the chances are very high that there will be gas flow out rather than air infiltration inward. If the gas is highly toxic and ventilation in the area of the hole is poor, this could represent a dangerous situation. One of the first steps in any inspection is the recognition of areas where gas leakage and accumulation is possible.

LECTURE 1. REVIEW QUESTIONS AND PROBLEMS



Sample Flowchart #1

1-1. What is the scrubber pressure drop when the static pressures are as follows: SPI 1 = -6 inches, SPI 2 = + 3 inches, and SPI 3 = + 6 inches.

1-2. What is the scrubber pressure drop and the demister pressure drop when the following static pressures are measured: SPI 1= -3 inches, SPI 2 = +8 inches, and SPI 3 = +1 inches.

1-3. What is the approximate purge stream flow rate if the liquid flow rates are as follows: Stream #1 - unknown, Stream #2 - 210 gpm, Stream #3 - unknown, Stream #4 - 50 gpm, Stream #5 - 0 gpm, Stream #6 - 175 gpm.

1-4. There is a small hole in the scrubber vessel wall, directly below one of the trays. Is air infiltration likely?

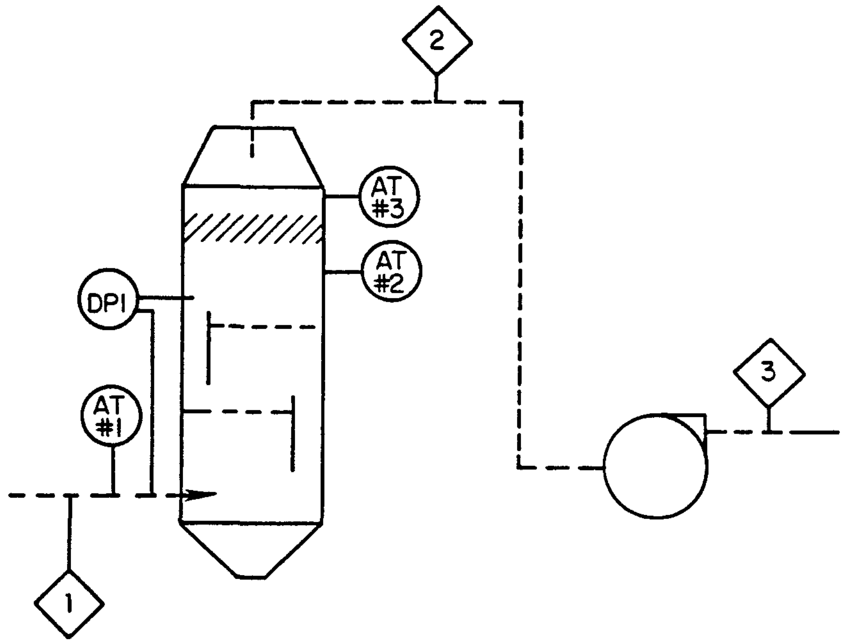
This is again a tray tower scrubber. However, this time the unit is under negative pressure. None of the liquid flow lines have been shown since none of the questions involve this part of the system.

1-5. Assuming that the static pressure measurements at points #1 and #3 have been made carefully, the on-site gauge is definitely wrong. Based on the measurements, the maximum static pressure drop is 8 inches and this includes the demister which normally contributes about 1 inch. The preferred locations for the static pressure drop measurements would be locations AT #1 and AT #2.

1-6. There is no reason to believe that a measurement error has occurred based only on the data provided. It is very possible that some of the oxygen has been absorbed in the scrubber, therefore, reducing the levels in stream. Some air infiltration is always possible, especially at the fan itself, and this could increase the oxygen levels in stream #3. The fact that both streams #1 and #3 are at 8% is a coincidence presented here to confuse the unwary. The point of this question is that oxygen changes before and after a scrubber are not very useful in attempting to diagnose and quantify air infiltration.

1-7. The liquid-to-gas ratio is approximately 11.45 gallons per thousand ACF.

1-8. This is probably not a measurement error. There is some temperature gain across most fans due to the conversion of some mechanical energy to heat. This was not discussed as yet in the program. Through out the workshop program these questions and problems will be used not just for review but also to introduce some useful information which can not be conveniently discussed in the slide-lecture note format. This is the first of these points.



Example Flowchart #2

1-5. The static pressure drop gauge on this system is indicating 12 inches of water. The static pressures measured at points AT #1 is -12 inches and at point AT #3 is -20 inches. Is there any reason to suspect the accuracy of the permanently mounted static pressure drop gauge?

1-6. The measured flue gas oxygen content in stream #1 is 8%, in stream #2 is 5% and in stream #3 is 8%. Does this show that the inspector has made incorrect oxygen measurements?

1-7. What is the liquid-to-gas ratio for this system if the total liquor flow rate is 200 gpm, the gas flow rate of stream #1 is 20,500 ACFM, and the gas flow rate of stream #2 is 17,500 acfm?

1-8. The gas temperature in stream #2 is measured at 109 °F and the temperature in stream #3 is measured at 118 °F. Has a measurement error been made?

LECTURE 1. REVIEW PROBLEMS AND QUESTIONS

This system has a rod deck type gas-atomized scrubber and a cyclonic demister. A calcium hydroxide solution is being added to the recirculation tank to maintain the liquor pH in an acceptable range. Not shown in the figure is a clarifier and vacumn filter system which are necessary to maintain an acceptable solids content in the liquor. A bypass stack with butterfly dampers is included. The damper on the stack is normally closed and the one on the gas stream to the scrubber is normally open. The scrubber and demister are rubber lined carbon steel. Everyone should have been able to describe this system using the flowchart symbols.

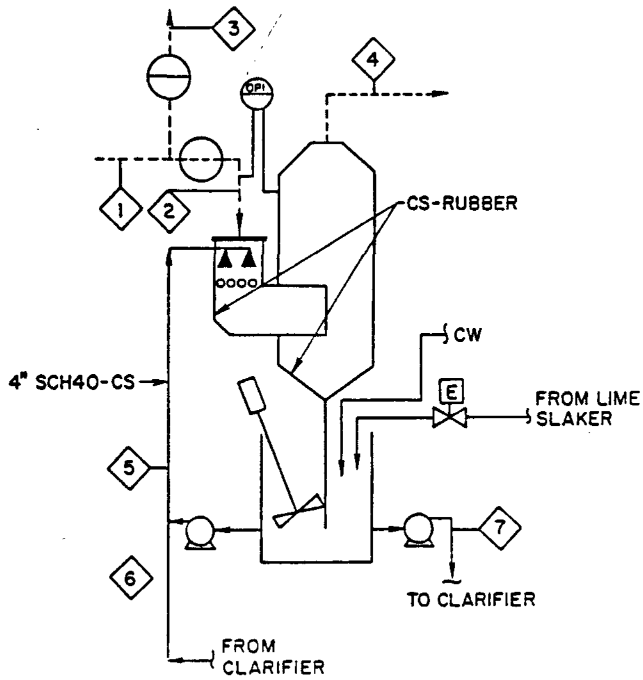
1-11. Yes, there is a slight possibility that untreated gas could be going up the bypass stack. Note that the static pressure in stream #3 is more negative than it is in stream #2 due to the draft created by the stack above point #3. If the damper is not seated properly this will cause some leakage.

1-12. It is clear from the flowchart that the liquor sample has been withdrawn from the area which should have the highest ph since it is downstream from the location of the calcium hydroxide addition. The liquor pH will be lower after the scrubber throat and in the scrubber sump due to the absorption of acidic gases such as SO2 and CO2.

1-13. If things work as they should, the bypass damper should open quickly to vent the hot, untreated gas directly to the atmosphere. If the dampers don't work properly, hot gas will destroy the rubber liner, leading to major damage and perhaps a prolonged outage. This question is intended to illustrate the usefulness of placing materials informtion on the flowchart. If this information were not here, it would be easy to forget that the scrubber is extremely vulnerable to temperature spikes.

1-14. Air infiltration is most likely in areas of the maximum negative static pressure. This means any area downstream of the rod deck in this case. Upstream, the static pressures would be quite low.

LECTURE 1. REVIEW PROBLEMS AND QUESTIONS



Example Flowchart #3

1-9. The static pressures in stream #1 is -1 inch, in stream #2 is -1 inch, and in stream #3 is -2 inches. Is there any possibility for loss of untreated gas up through the bypass duct?

1-10. The pH of the recirculation liquor is measured using a sample obtained at the recirculation pump discharge. If the measured pH is 7 and corrosion is only a problem when the pH is below 5.5, is there any reason to worry about corrosion?

1-11. Due to a sudden failure of the recirculation pump, all liquor flow to the inlet of the scrubber is lost for a period of 20 minutes. What will be the result this problem?

1-12. If air infiltration is suspected due to very poor capture of particulate at the process hoods, where are the logical places to begin searching for the infiltration points?

LECTURE 2

BASELINE INSPECTION PROCEDURES
FOR
WET SCRUBBER SYSTEM EVALUATION

SLIDE 2-1

BASELINE INSPECTION PROCEDURES
FOR
WET SCRUBBER SYSTEM EVALUATION

This lecture concerns the application of the Baseline Inspection Technique to wet scrubber systems. The procedure is designed to help regulatory agency inspectors and source operators to identify performance problems at the earliest possible stage. Determination of the possible causes of observed problems is another important aspect of the Baseline Technique.

The inspection procedure is limited to the full identification and evaluation of problems and does not address specific correction actions. The latter would infringe on the perogatives of the source management. The role of the inspector is limited to determining if the actions proposed by the source have a reasonable possibility of success and would abate the excessive emission conditions in a timely manner. The data and observations made during the baseline inspection enable the regulatory agency to evaluate these proposed actions very effectively. If the plant management actions appear to be unsatisfactory, the baseline inspection data can also be used to support enforcement actions.

The slides which follow present some of the basic principles of the Baseline Inspection Technique. The concept of inspection levels is also defined. The latter is intended to provide flexibility to regulatory agencies in the amount of time invested in each wet scrubber system inspection.

SLIDE 2-2

USE SITE SPECIFIC DATA
TO EVALUATE
WET SCRUBBER SYSTEMS

EACH WET SCRUBBER SYSTEM SHOULD BE APPROACHED INITIALLY AS IF IT PERFORMS IN A DIFFERENT MANNER THAN ALL OTHER SIMILAR WET SCRUBBERS ON SUPPOSEDLY SIMILAR SOURCES. In other words, the performance of one unit should not be compared with the performance of another, unless data gathered over a long time period shows these two to be similar. In the case of wet scrubber systems, there are numerous reasons why significant performance differences occur in two systems which appear similar.

Unlike some control systems, the particle size distributions in the gas streams entering and leaving wet scrubbers are subject to subtle but significant changes. Some of the phenomenon which can affect particle size include heterogenous condensation, agglomerate shattering, and particulate regeneration. Since performance is highly sensitive to particle size, these affect the overall performance. Another major reason for unit to unit differences is the gas-liquor distribution. Subtle changes in this distribution have a major impact on the overall particulate and gaseous control efficiencies. The variation in system components also contribute to the site-to-site differences.

SLIDE 2-3

BASELINE EVALUATION

Normal Value of Parameter for This Unit

Present Value of Parameter for This Unit

COMPARISON

Instead of using literature data or the performance data from other systems as the yardstick of performance, the Baseline Inspection Technique uses data from the specific unit. This data is more easily accessible and is more accurate since there is no question about its representiveness.

During the inspection of wet scrubbers, the present operating conditions are compared with conditions some time in the past when the unit was believed to be working properly. A shift in the a parameter is a symptom of a problem.

Lecturer's Notes

The importance of evaluating scrubbers using unit-specific data can not be overemphasized. One cupola venturi scrubber operating at a 25 inch static pressure drop can have better performance than an adjacent unit operating at 50 inches. Inspectors must avoid the simplistic conclusions which can result from comparing one unit to another. Such comparisons can only be done after it has been demonstrated that the units are in fact similar.

The acquistion of baseline data is discussed in later slides. Questions concerning baseline data should be reserved for later.

SLIDE 2-4

USE AS MUCH DATA AND INFORMATION AS POSSIBLE

Sometimes it is possible to identify a wet scrubber performance problem by examining the shift in one parameter. For example, a 50% drop in liquor flow rate indicates serious trouble for almost all types of scrubbers.

In most cases, however, it necessary to look at as much data as possible in order to figure out the likely fundamental problem. Small shifts in a number of parameters are also useful for the early identification of problems. For these reasons, the inspection procedures used in this workshop deal with sets of symptoms.

SLIDE 2-5

ON-SITE INSTRUMENTS ARE OFTEN UNAVAILABLE OR UNRELIABLE

It is not easy to maintain instruments on wet scrubbers systems. The probes are subject to pluggage, corrosion, and erosion. Even well maintained instruments can be incorrect some of time.

There is a general correlation between the level of performance of the wet scrubber system and the accuracy and availability of the instruments. Those units which seem to be performing very well usually have monitoring instruments which work at least most of the time. The units with chronic compliance problems frequently seem to have instruments out of service or no instruments at all. It is obviously the latter group which is of most interest to regulatory agency inspectors. Therefore, it is good practice to question the accuracy of the gauges.

SLIDE 2-6

RECOMMENDED INSTRUMENTS

Primary Equipment
1. Safety Equipment
2. Static Pressure Gauge
3. Temperature
4. O_2/CO_2 Analyzer
5. Flashlight
6. pH Meter or pH Paper

Secondary Equipment
1. Pitot Tube
2. Tachometer
3. Velometer

The types of portable instrumentation used in the inspection of wet scrubbers are listed in this slide. The list is divided into a primary set which is used very frequently and a secondary set which is rarely used.

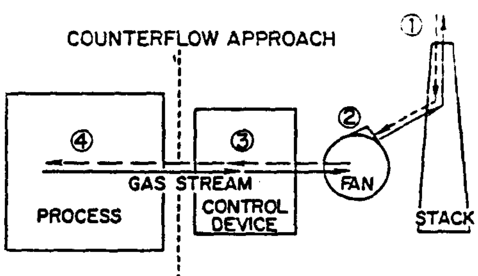
All of this equipment is relatively inexpensive and easy to use. The gauges needed for a given inspection can usually be carried in a tool pouch or small tool case. Instrument calibrations are simple except for thermocouples.

There are several approaches to the use of portable instruments. In plants which have union agreements regarding instrumentation, the gauges should be given to the appropriate plant personnel to conduct the measurements while the inspector observes. In other cases, the plant management may perfer that the agency inspector make the measurements. If the regulatory agency does not presently have the necessary instruments, the inspector can request that plant personnel conduct the measurements using their own gauges (most plants have the items listed above). In any case, the objective is to make sure that accurate and complete data has been gathered during the inspection.

Lecturer's Notes

It should be noted that portable instruments are used only on detailed inspections. On most occassions, the accuracy of on-site gauges will be evaluated visually with no attempt to measure any operating conditions. Anyone using portable instruments must adhere to the general safety procedures covered later in the workshop and any specific policies at the plant being inspected.

SLIDE 2-7



Field inspections should be conducted in a methodical order. The initial data should be reviewed during the inspection so that the remainder of the effort can be focused on any suspected problems. If the initial data suggests that system performance is similar to baseline periods then the inspection is terminated.

The approach recommended in the program is termed the "Counterflow" procedure. The inspection starts with a careful evaluation of stack visible emissions and then proceeds in a countercurrent direction relative to the gas stream.

Emphasis is given to evaluation of scrubber vessel and liquor recirculation system operating parameters. The process equipment is evaluated only when (1) there are indications of an emissions problem, and (2) the data and observations made of the stack and wet scrubber system suggests that the fundamental cause of the condition is a change in process operation. This does not mean that process conditions are not important, but this time consuming part of the inspection should be done only when there is a clear need to do so.

SLIDE 2-8

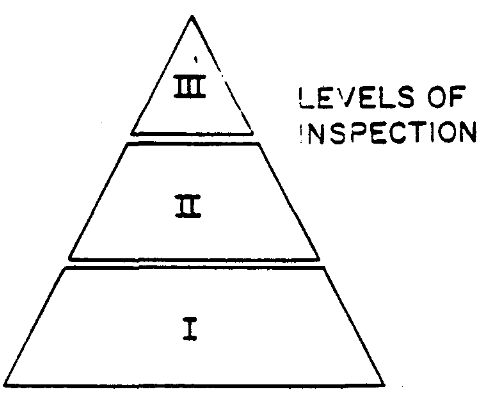
FLEXIBILITY
JUDGEMENT

Two key words necessary in wet scrubber system inspections are flexibility and judgement.

Due to the extreme diversity of system designs, it is difficult to develop an inspection scheme which is appropriate for each one. In some cases, it will be necessary to go beyond the observations and data discussed in the workshop in order to evaluate conditions. In other cases, strict adherence to all the steps mentioned would represent overkill. Each field inspector must understand the inspection procedures and control system operating principles well enough to tailor the inspection to the system. In other words, the inspection procedure must be moderately flexible.

The field inspection, in conjunction with his or her supervisor must make certain judgements regarding the amount of effort warranted for the specific inspection. The material presented for each scrubber type is divided into several distinct levels. The most detailed inspections are done on sources with chronic compliance problems or on those at which a problem is now suspectted. There must also be some judgements regarding any potential health and safety problems. Obviously, a field inspector should not do anything that in his or her judgement would present a safety problem or which could harm the plant equipment.

SLIDE 2-9

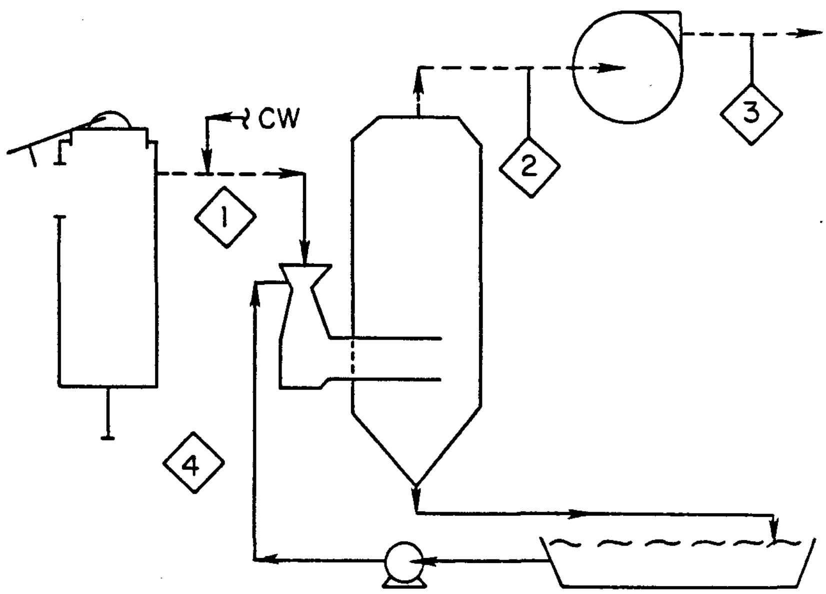


The inspection procedures are divided into distinct levels. Level 1 inspections are done mainly from the plant boundry and consist of an observation of the visible emissions and any fugitive emissions from plant facilities.

Level 2 inspections are walk through inspections of the control system and the process equipment. These are routine inspections which are conducted on sources believed to be in compliance. The emphasis here is on identification of any problems which could lead to excess emissions in the near future.

The most detailed form of the inspection procedure is Level 3. This involves the use of portable instruments so that all possible parameters relevant to the suspected problem(s) are measured and evaluated. The data and observations are shared with plant personnel to see if agreement can be reached concerning the types of problems which exist. The actions proposed by plant personnel to correct or prevent the problem should be evaluated by the field inspector and supervisory agency personnel.

LECTURE 2. EXAMPLE BASELINE ANALYSES



	Inspection Number				
	1	2	3	4	Present
Stream 1 Static Pressure	-5	-5	-4	-4	-3
Stream 2 Static Pressure	-51	-49	-47	-50	-46
Stream 1 Gas Temperature	452	436	445	441	447
Stream 2 Gas Temperature	136	134	134	131	129
Stream 4 Liquor Flow	310	295	303	308	306

Comparison of Present Data with Inspection 1 Data Only

ΔP(present) = 43 inches
ΔP(insp 1) = 46 inches

T2(present) = 129
T2(insp 1) = 136

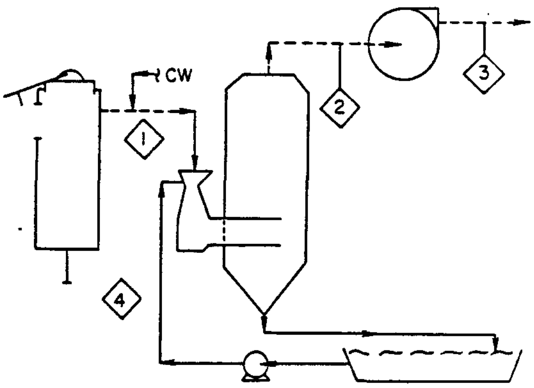
Conclusion: Minor Variation

Comparison of Present Data with All Four Previous Inspections

ΔP(present) = 43 inches
ΔP(mean, 1-4) = 45 inches
ΔP(σ, 1-4) =
T2(present) = 129 °F
T2(mean, 1-4) = 134 °F
T2(σ , 1-4) =

Conclusion: Student's t Test indicates >95% probability that present pressure drop is low and a >98% probability that the gas temperature of stream 2 is low. Air infiltration likely.

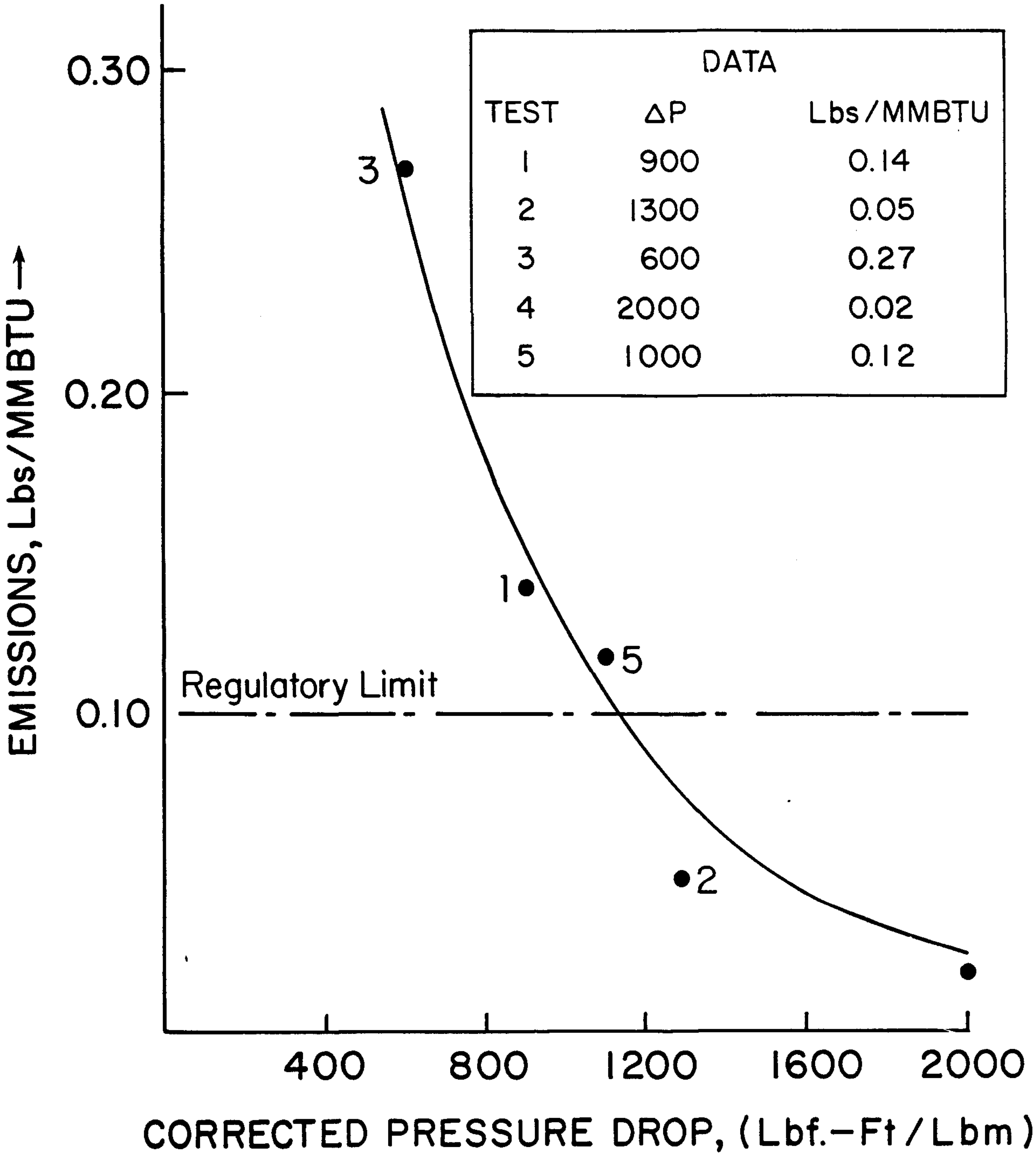
SLIDE 2-10



The baseline data should not be regarded as some mystical, unchanging yardstick with which scrubber performance can always be measured. It should, instead, be a constantly growing data set which is supplemented by the results of each inspection.

For example, The inspection data from plant A is a hypothetical level 3 inspection. Inspections B and C are level 2 inspections during which the plant instruments appeared to be working. A comparison of the present data with the range of data in all three previous inspections clearly shows that there has been a change in the operating conditions. If only the data from inspection A were available, it would have been hard to determine if the differences were due to a change or just to normal variability. When combining data from several inspections it is necessary to confirm that there have been no major process changes.

LECTURE 2. EXAMPLE 2



TEST	ΔP	Lbs/MMBTU
1	900	0.14
2	1300	0.05
3	600	0.27
4	2000	0.02
5	1000	0.12

To calculate corrected pressure drop from data in units of inches of water,

Inches W.G. × (5.2 Lbf/ft^2/inch WG) = M ($Lbf\text{-}ft^2$)

M/(Gas Density, Lbm/ft^3) = C, (Lbf–Ft/Lbm)

SLIDE 2-11

STATISTICAL ANALYSES

In most cases, scrubber performance is evaluated by comparing present condiitions to the general operating range. This was illustrated in the previous slide. In some cases, however, it is useful to apply some basic statistical tests to gain some insight regarding the significance of shifts in the operating parameters. The example on the opposite page provides the data used here.

With only one inspection serving as the baseline, the shifts in static pressure drop and gas temperature are difficult to evaluate. With data from several inspections, the normal variability can be reviewed and the Student's t test can be used to evaluate the significance of the shifts. Both the gas temperature and the pressure drop have apparently changed substantially. In this case, it is very possible that the scrubber vessel is experiencing some air infiltration and this is reducing the quantity of gas pulled from the process source. The remainder of the present inspection concentrates on air infiltration issues. The sites of air infiltration are be checked and pitot traverses are conducted before and after the scrubber vessel.

Lecturer's Notes

The purpose of this example is to show how the baseline data expands over time and how the basic statistic analyses can be applied. This procedure is one step beyond simple comparison of conditions against a range of values as illustrated in the previous example.. The next step goes one step further by using a performance correlation.

SLIDE 2-12

A useful correlation for certain wet scrubber systems can sometimes be prepared when several stack tests have been conducted at different operating conditions.

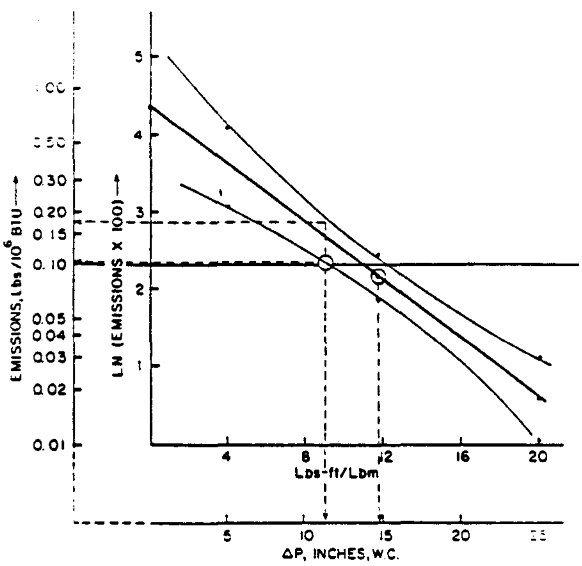
The hypothetical set of data provided on the opposite page has been used to illustrate how the confidence interval on the correlation changes as more data is obtained. The 90% confidence interval using tests 1 and 2 can be compared with the interval using all five tests.

TRANSFORMED TEST DATA

Test	P "x"	Emissions "y"
1	9	2.64
2	13	1.61
3	6	3.30
4	20	0.69
5	11	2.48

As a starting point, it is helpful to transform this data to a form which is easier to use. The data taken from the opposite page has been converted in the form shown in this slide. The natural log of the emissions data has been used since the "eyeball" curve seems to be exponential in nature. Multiplication of the number by 100 avoids the necessity of handling negative logarithms. The pressure data has been converted from the familar inches of water format to the corrected pressure drop form. The general procedures are illustrated at the bottom of the opposite page (the corrected pressure drop term will be introduced later). The corrected pressure drops have then been divided by 100 so it will not be necessary to manipulate large numbers.

SLIDE 2-13



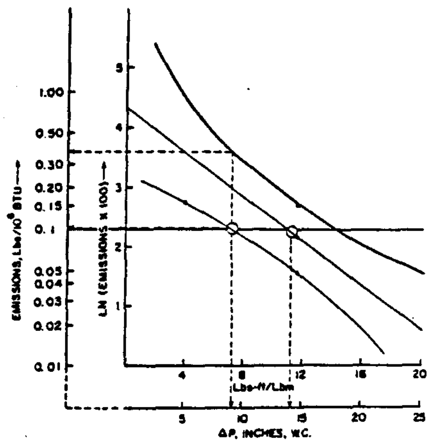
The statistical procedures summarized at the end of this lecture have been applied to the data shown in the above slide. The curve shown in this slide is the result of including all five of the tests.

The solid line in the middle is the linear regression line. The curved lines above and below this are the 90% confidence intervals.

If the measured pressure drop is so low that the lower confidence interval is above the regulatory limit, then there is a 90% probability, based on this one correlation, that the unit is now out of compliance.

The circle on the right indicates the average corrected pressure drop which is necessary to remain below the regulatory limit. If there is a corrected pressure drop of 11 inches of water (see circle to the left), then there is a good possibility that emissions are now greater than the 0.10 pounds per million BTU input.

SLIDE 2-14



This is a graph of the correlation using only tests 1, 3 and 4. The confidence interval now looks much larger. This indicates that less is known about the variability of the emissions-corrected pressure drop data.

In this case, the corrected pressure drop must decrease below 9 inches before there is reasonable confidence that excess emissions are occurring. In the earlier example, a decrease to 11 inches would have indicated this clearly.

These curves are intended to illustrate simply that the more data available, the more sensitive the baseline analyses can be. Each set of data helps to further define the normal variability so that abnormal conditions are easier to spot. It should be noted that the data used in this hypothetical example was specifically chosen so that there would be very little variability. This inherently reduces the width of the two confidence intervals. In some cases, the plotted confidence intervals with just three data points could be so large as to render the entire procedure meaningless. The factor which determines the number of data points necessary for a good correlation is the variability of the system itself and the choice of an operating parameter used in the correlation.

SLIDE 2-15

SUMMARY
PERFORMANCE CORRELATIONS

For some wet scrubber systems, the performance correlations using the baseline data can be very useful in estimating the potential for excess emissions. It should be remembered, however, that these are not sufficiently accurate to serve as a basis for a notice of violation. That can only be done by a reference method test specified in the applicable regulations. These correlations are only intended as an aid to the agency inspector or source operator attempting to determine if a shift in conditions is significant.

One common problem with wet scrubber correlations is that there are a number of conditions which can invalidate a usually accurate relationship. The most common of these are sudden shifts in the inlet gas stream particle size distribution. These changes will be examined in some detail in later sections of the workshop.

Lecturer's Notes

The use of correlations should not be overemphasized. The simple comparisons of present conditions to several previous sets of inspection data are usually more than sufficient. It is conceivable that some of the attendees will spend too much time compiling performance correlations. Sometimes these are worthwhile, sometimes they are not.

SLIDE 2-16

OPERATING LOGS AND RECORDS

One way to compile a baseline data set is to extract data from wet scrubber system operating logs. The main risk with this approach is that data from malfunctioning instrumentation will be used. Nevertheless, this is the only approach possible when the unit has not been stack tested and detailed inspections have never been conducted. Once better data becomes available, the information retrived from old files can be retired.

The data which is most useful includes gas temperatures, static pressure drops, liquor flow rates, liquor pH levels, and nozzle header pressures. Only rarely will data other than that listed above be found.

As much information as possible on the process operating rate and conditions should also be pulled from the files. This information is almost always recorded on other operating logs. Therefore, additional "digging" is in order. Unfortunately, some plants discard operating records after 3 months. This practice may preclude any access to data which predates the apparent problems with the wet scrubber system.

SLIDE 2-17

EXAMPLE DATA EVALUATION

Date	P	Outlet Gas Temp	Nozzle Pressure
5/24/80	22	286	76
7/13/81	24	276	80
6/30/82	21	281	74
9/20/83	25	264	77
Present	18	293	71

There are several ways to evaluate the present data against a set of data retrived from the files. This slide presents data showing how the Student's t test can be applied to several sets of scrubber system operating data.

In this case, all three parameters appear to be significantly different from the data taken from the records. The manner in which the present data deviates from the recorded values indicates a sudden drop in liquor flow rate to the inlet of the scrubber. The diagnosis of problems is discussed in some detail later in the program.

The Student's t test indicates that there is a 90% probability that the pressure drop is lower than normal, there is an 80% probability that the outlet gas temperature is higher, and a 95% probability that the nozzle header pressure has decreased. All of these indicate a reduction in the liquor flow to the scrubber. One possible explanation is a change in the recirculation pump impeller. It is often the simultaneous changes in several parameters that are most useful for pinpointing possible problem areas. The use of several parameters is especially important when using data from operating logs where the accuracy of the data can not be easily confirmed.

SLIDE 2-18

SUMMARY

In summary, the baseline data provides a means to measure present operating conditions. Shifts in the values of key operating parameters can be evaluated simply by inspection or through basic statistical techniques.

There are distinct levels of effort used for different circumstances. Plant boundry inspections consist only of visible emission observation. The regularily scheduled walk through inspecton involves both visible emissions observations and the evaluation of operating conditions indicated by on-site gauges

When a wet scrubber system has a history of excess emission problems or the data gained in the level 1 or 2 inspections suggests potential scrubber performance problems, a detailed inspection is conducted. This involves the use of portable instruments as necessary and a more comprehensive check of system conditions. Regardless of the level of the inspection, the performance is always evaluated by the comparison of present conditions against site-specific baseline data.

LECTURE 2. REVIEW PROBLEMS AND QUESTIONS

2-1. Yes, a more detailed inspection is necessary as soon as possible to determine if the unit is now or soon will be out of compliance. An increase of this magnitude is a very bad sign even though the unit is not out of compliance based on the visible emission observation.

2-2. No, each field inspector, with the assistance of his or her supervisor, decides what is the most effective and safe procedure for conducting an inspection of a given facility. A certain amount of professional judgement is required for all field inspections.

2-3. The answer is simple, the inspector should NOT enter the unit under any circumstances. While most plant personnel are well trained and aware of safety hazards, there are always a few that are not. There could be pockets of toxic gas and inadequate oxygen inside a unit that is out-of-service. It is also possible that the unit is not properly locked off line. Everything a regulatory agency inspector needs to see can be seen very well from an acces hatch. There is NEVER ANY REASON TO ENTER.

2-4. The only correct answer is c, a general assessment of the performance of the wet scrubber. It is very presumptous to think that anyone can go into a plant and in a matter of several hours completely judge the adequacy of their maintenance procedures. Furthermore, no inspection procedure can ever substitute for a reference stack test method, which is the only way to determine compliance with mass emission requirements. To compile and present a list of demanded repairs and modifications is both unwise and wrong. First of all, the agency takes on some of the liability for systems specifically demanded. Furthermore, this approach preempts their ligitimate options for running the plant. The inspection simply results in a list of probable problems so that the inspector can determine if the corrective actions planned by the source have a reasonable chance of minimizing the problem in a timely manner. If there is disagreement between the plant and the agency, legal action is the appropriate next step.

2-5. There is no reason to stack test either unit based on the information presented. Answer c is correct. The fact that two identical scrubbers on two supposedly identical asphalt plants are running at different pressure drops is not significant. What would be significant is a decrease in the pressure drop for the specific unit. It should also be noted that supposedly identical plants can have remarkably different particle size distributions and therefore require different pressure drops. In this case, slight movement of the asphalt injection pipe or a slight change in the mix temperature could create drastic differences in the particle size distributions from the two "identical" plants.

LECTURE 2. REVIEW PROBLEMS AND QUESTIONS

2-1. During a routine plant boundry observation of the visible emissions from a cupola wet scrubber system, the inspector notices that the residual opacity has increased from the normal 5% to a level between 10 and 15%. The regulatory limit is 20%. Is a more detailed inspection of the system necessary at this time?

a. Yes
b. No
c. Maybe

2-2. Is it mandatory to conduct the inspection in a counterflow manner when performing a Baseline Inspection?

a. Yes
b. No
c. Sometimes

2-3. During a level 3 inspection, the plant personnel invite the agency inspector to enter the cyclonic demister to observe a scaling problem which has developed recently. What safety procedures are appropriate in this situation?

2-4. Which of the following is achieved during a Baseline Inspection of a wet scrubber system?

a. An accurate and complete determination of compliance with the regulatory requirements
b. A general evaluation of control system performance
c. An assessment of the adequacy of the plant maintenance procedures
d. Compilation of a list of needed modifications and repairs
e. All of the above

2-5. There are two Model SX-68-7 fixed throat venturi scrubbers serving two identical drum mix asphalt plants. One of these is operating at a pressure drop of 19 inches W.C. and an inlet gas temperature of 264 °F. The other is operating at 14 inches W.C with an inlet gas temperture of 270 °F. Does this data demonstrate the need to stack test either one or both of the scrubbers?

a. The one with the low pressure drop should be tested
b. Both should be tested
c. None of the above

LECTURE 2. REVIEW PROBLEMS AND QUESTIONS

2-6. No, it is not significant at the 90% level. Those who feel it is significant have probably used the wrong degrees of freedom when using the t Tables.

2-7. Comparison of conditions at one unit with data from others should be done only as a last resort and only if it can be demonstrated that the process and control systems are very similar. No statistical test is appropriate at this time.

2-8. The correct answer is that the inspector should recommend that the agency conduct a stack test based on whatever observations and data could be obtained. Concerning the plant's refusal to install ports, they could well have valid legal, technical and/or safety reasons for taking this position. The agency can not demand measurement ports. It is equally inappropriate to wait until a level three inspection can be done. Again, the main purpose of inspections is to minimize air pollution and not to complete some arbitrary sequence of inspections. In other words, it is not necessary to complete a level 3 inspection before requesting a stack test or before discussing the potential problems with source management personnel.

2-9. "Maybe" is the best answer. The point of this question is that inspectors should not let themselves be boxed in by any statistical analyses. Just because the changes are not significant at the 90% level does not mean that they are not real. In fact, excess emissions may have already resulted. The inspection should continue until all of the potentially relevant information regarding possible problems has been obtained. The inspector should base his or her conclusion on all the data and observations made and not just on the few items for which the statistical tests can be applied. Subjective judgements also have a legitimate role in reaching a position regarding the source's compliance status.

2-10 The correct answer is "b", the measurement should be forgotten. In many cases, "all reasonable precautions" may not be enough and the inspector can be overcome. Now plant personnel may be tempted to place themselves at risk to remove the inspector from a location where he or she should not have gone in the first place. The other three answers listed are also poor. Guesses should never be used just because a measurement was not possible. Sometimes no information is better than incorrect information. Calling supervisory personnel for advice may sound good, but how can this individual fully appreciate the exact conditions facing the inspector? It is also possible that during the call, the inspector will not completely describe the situation. Requesting the plant personnel to enter an area that you are not willing to enter is not appropriate. It is the inspector's job to perform the inspection and plant personnel (no matter how willing) should not have to take unreasonable risks to obtain necessary data. Forget the measurement!

LECTURE 2. REVIEW PROBLEMS AND QUESTIONS

2-6. During the previous three inspections the gas outlet temperature from the scrubber demister has been 126 °F, 134 °F, and 132 °F. Now the demister outlet temperature is 137 °F. Using the Student's t Test, is the increase significant at the 90% level?

2-7. Data concerning three venturi scrubbers on grey iron cupolas has been published in a recent publication of the U.S. Environmental Protection Agency. This indicates that these operate at pressure drops of 36, 42, and 43 inches W.C. A similar cupola venturi scrubber being inspected has a pressure drop of 34 inches W.C. What statistical test should be used to determine if there is a potential scrubber operating problem?

2-9. During a level 2 inspection, the data and observations made by the inspector strongly indicate that the unit is out of compliance with the mass emission limits. There are no presently available ports to confirm the on-site instrumentation and the plant management refuses to install these ports so that a more detailed inspection can be conducted in the near future. What course of action should the inspector take?

a. Issue a Notice of Violation to the plant due to the lack of measurement ports.
b. Recommend that the agency request a stack test under the conditions representive of present performance.
c. Wait until a level 3 inspection can be completed, and then determine if enforcement action is necessary.

2-9. The comparison of present scrubber conditions against the available baseline data indicates decreases in the static pressure drop and the liquor flow rate, but an increase in the nozzle header pressure. The statistical evaluations indicate that none of the changes are significant at the 90% level. Does this demonstrate that the unit is working properly?

a. Yes
b. No
c. Maybe

2-10. During a level 3 inspection, it is noticed that there is only limited ventilation around one measurement port of a positive pressure unit. If the measurement is not obtained, it may be impossible to fully evaluate the operating conditions. What should the inspector do?

a. Using all possible precautions, make the measurement.
b. Forget the measurement.
c. Make a reasonable estimate.
d. Call supervisory personnel back at the office for advice.
e. Ask plant personnel to make the measurement.

LECTURE 3

PLANT BOUNDRY LINE INSPECTIONS

SLIDE 3-1

PLANT BOUNDRY LINE INSPECTIONS

1. Visible Emissions Observations
2. Scrubber Reentrainment
3. Odor Surveys

A Level 1 inspection of any wet scrubber system consists simply of an evaluation of the scrubber plume and any bypass stacks plumes. These inspections are normally conducted from the plant boundry.

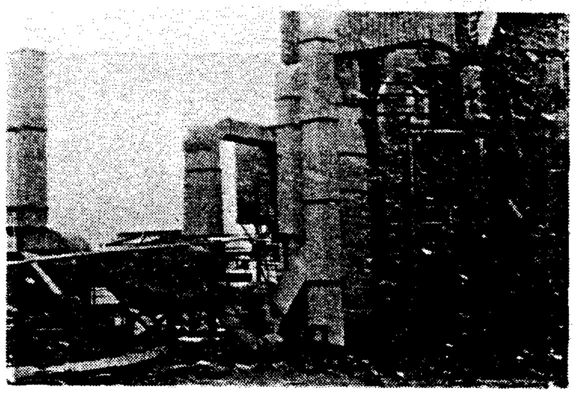
The primary purpose is to determine if the unit is in compliance with visible emission regulations (particulate wet scrubbers) or with odor requirements (gaseous scrubbers). More detailed Level 2 or Level 3 inspections are conducted if symptoms of problems exist.

This lecture briefly reviews important points concerning visible emission and odor observations conducted from plant boundries. This material goes beyond simply determining that there is a problem. A number of observations are discussed which help determine the nature of the problem and which aid in the preparations for the more detailed inspections.

Lecturer's Notes

The plant boundry inspection can be quite beneficial if a modest amount of time is invested by the inspector. It will become obvious that this material is not a rehash of lectures presented in the "smoke schools" or other similar programs.

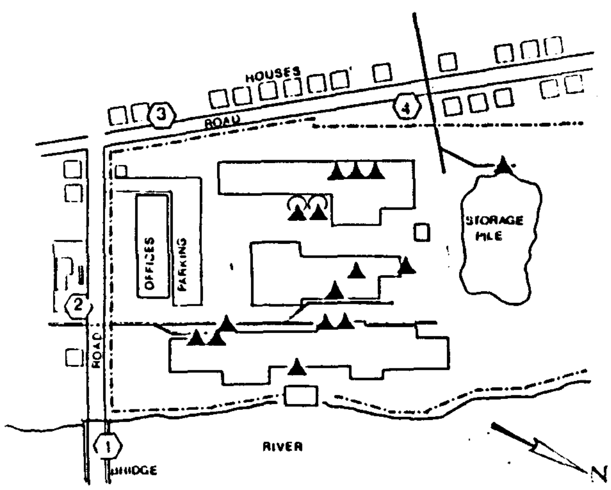
SLIDE 3-2



Before leaving for a Level 1 inspection of a wet scrubber system, the general weather conditions should be noted. Days similar to the one shown in this slide are obviously not conducive to visible emissions observations. It may be possible to conduct a meaningful odor survey. However, even this is doubtful under the conditions shown.

In these circumstances, it may be more appropriate to conduct a Level 2 inspection of the wet scrubber system. On the other hand there is always some paper work to catch up on.

SLIDE 3-3



The initial task during a boundry line inspection is to make a presurvey of available observation sites. The hypothetical plant layout shown in this slide is used as an example of such a presurvey.

The purpose of the initial survey is to determine the optimum location for a visible emission observation for the stack or stacks of interest. This goes beyond just concern over sun angle and the direct of plume travel. The inspector should note any activity which could lead to multiple plumes along the line of sight. This could be caused by several stacks grouped closely together or due to fugitive emissons close to the stack of interest. The reasons for selecting the observation point should be briefly documented in the inspection notes.

During the presurvey, the inspector should make both upwind and downwind odor surveys. This should be done before any visible emission observations, since olefactory fatigue can reduce the sensitivity to odors after prolonged periods of time. The wind direction at times that odors are apparent should be observed and noted. Trees, flags, and plume travel directions usually provide sufficient indicators of wind direction.

SLIDE 3-4

ODOR CHARACTERISTICS

Cool	Putrid
Mint	Fecal
Perfume	Rancid
Sweet	Nutty
Floral	Oily
Etherish	Heavy
Sharp	Greasy
Citral	Rubbery
Fruity	Burnt
Sour	Woody
Spicy	Methanol
Musty	Warm

If odors are detected, the "character" of the odor should be described using some accepted descriptive terms. The list provided in this slide can be used as is or can be modified for common odors near the source. In any case, it is helpful if the regulatory agency inspector, the plant personnel and the residents of community agree on a reasonably concise set of terms. This will facilitate comparison of the records kept by everyone concerned.

The time of day that any odors are noticed should be carefully recorded in the inspection notes. The meteorological conditions are also of interest. This data will be helpful later in tracking down the source(s) of odors and in comparing the inspector's observations with those of the residents and plant employees.

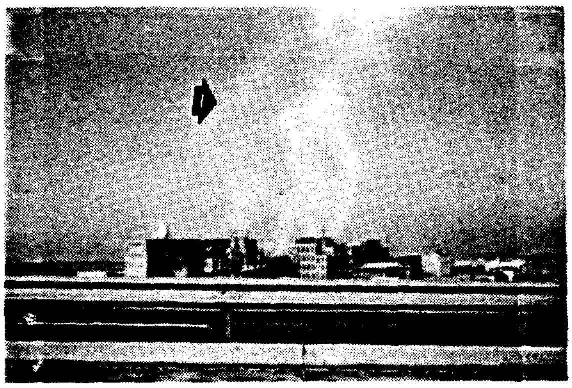
SLIDE 3-5

One of the main questions faced in the visible emissions observations of wet scrubber systems is whether or not the observed plume is composed of real particulate or just condensed water droplets. It is a legitimate question since water droplets scatter light as well as particles.

There are several ways to distinguish the condensed water droplets (sometimes called the "steam" plume) from the true particulate matter in the plume.

This photograph shows the plume from a series of spray scrubbers serving fiberglass forming lines. The point at which the condensed water droplets revaporize is marked with arrow #1. It is not difficult to identify this point of the plume and to see that there is considerable residual aerosol left in the plume after the water droplets cease to exist.

SLIDE 3-6



The residual plume from this scrubber stack is apparent downwind from the point marked as arrow #1. This has a distinct bluish white color (which is not readily apparent in the black and white reproduction). This color is the result of the scattering of blue light by submicron aerosols. Particles in this very small size range scatter blue light efficiently since the particle diameter is close to the wavelength of blue light.

Any time that a bluish white color is noted, it is clear that significant quantities of particulate matter is present.

The color of the plume should be carefully described in the inspection notes. The location in the plume at which it becomes visible and the color itself should be described. The bluish white plumes often indicated inadequate collection of fine particulate (less than 2 microns), condensation of vapors in the scrubber, or regeneration of particles due to droplet evaporation. Brownish-white plumes often indicate poor collection of moderate and large size particulate. Combustion problems in fossil-fuel fired sources can generate a black residual plume.

SLIDE 3-7

OBSERVE STEAM VENTS IN THE VICINITY OF EMISSION SOURCE

In addition, inspectors should observe any steam vents in the general vicinity of the scrubber system or adjacent plants. The time it takes for these to disperse should be noted.

There should be a noticeable difference between the steam plume dissipation and the persistence of the scrubber plume. There should also be a very distinctive color difference.

In a sense, the use of known steam vent plume descriptions provides an "internal standard" regarding the behavior of condensed water droplets under the present meteorological conditions.

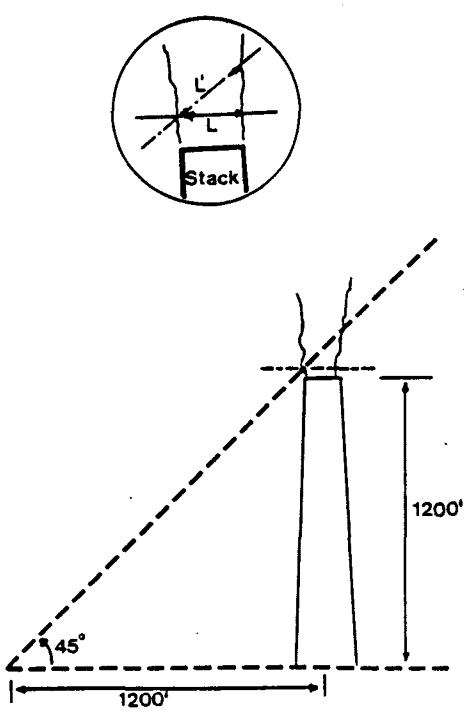
SLIDE 3-8

For compliance determinations, the visible emissions must be observed at the point of maximum opacity either before the water droplets begin to condense (see arrow #1) or at a point after they have re-vaporized (see arrow #2). Since a baseline inspection includes a reference method stack test, such an observation should be made.

However, for diagnostic purposes, the opacity should be observed directly above the stack whenever conditions permit (no water droplets). At the stack there is a constant path length and the opacity readings can be compared with baseline levels.

The path length through the residual plume varies with the weather conditons. Due to this factor it is difficult to compare present conditions against baseline conditions. Also, the residual plume is generally highly diluted and is not a very sensitive indicator of scrubber performance. There could be substantally increased emissions without a noticeable increase in the residual plume.

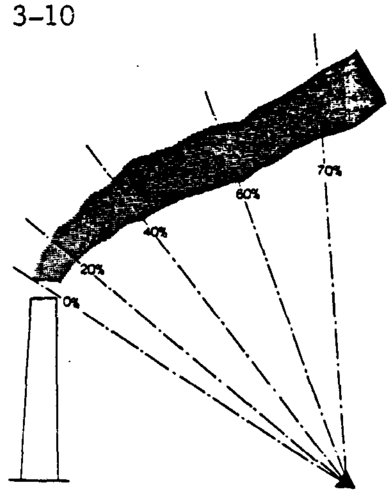
SLIDE 3-9



The elevation angle of the visible emission observation is illustrated in this slide. Stack observations made strictly for diagnostic purposes should be corrected for the difference in the path length between the actual line of sight versus the actual plume diameter.

The equation for correcting the opacity value is shown at the bottom of the slide. The angle of observation can be calculated by knowing the stack height (check file data) and by estimating the distance to the stack. The latter can be accurately estimated from a plot plan of the facility. If the plot plan is not available, a range finder can be used to estimate distance accurately.

SLIDE 3-10

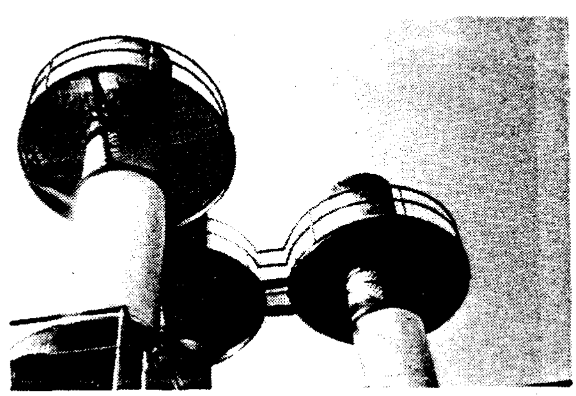


During the visible emission observation, the presence of a condensing plume or reacting plume should be noted. As shown in this slide, the plume has a gradually increasing opacity as it travels downwind.

This characteristic is opposite to what is normally expected. It is caused by the formation of particulate from gases reacting in the plume. In some cases, it could be caused by the condensation of vapor phase material in the plume. However, the latter mechanism would probably be completed in the scrubber vessel and would not be noticed in the plume.

The presence of a plume of increasing opacity is generally caused by material which passes through the scrubber system as a gas or a vapor. This may indicate inadquate collection efficiency for these materials, improper conditioning of the gas stream before scrubber entry, or a change in the process operation which results in the generation of pollutants which can not be properly treated in this scrubber system. In any case, a more detailed inspection is necessary.

SLIDE 3-11

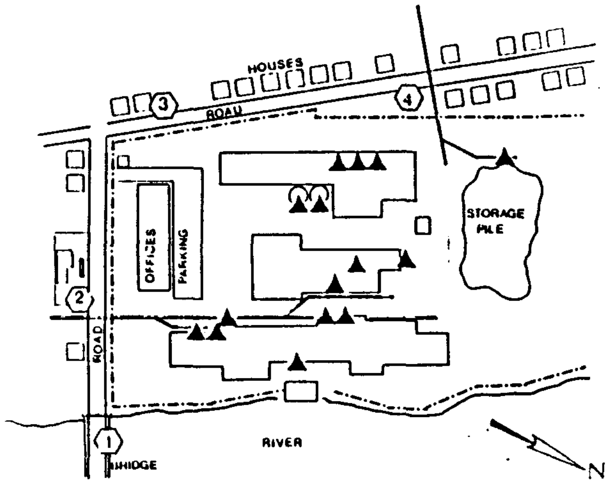


The presence of a layer of mud at the stack discharge is an indication of droplet reentrainment. Another common symptom is a discolored area caused by the drainage of scrubber liquor down the outside of the stack. When these are noticed, there is often rainout of small liquor droplets in the general vicinity of the stack.

If these small droplets are falling outside the plant boundry line, local residents may complain of damage to car finishes, house paints and gardens. During the follow-up level 2 or level 3 inspection, the operation of the scrubber demister should be checked in some detail. Such problems are almost always correctable in a short amount of time.

To determine if the reentrainment conditions still persist, a general survey of the area outside the plant boundry should be made. Obvious spotting of car finishes usually provides a good indication of recent droplet carryover into neighborhood areas. Spotting and discoloration of house finishes are less reliable indicators since this could have occurred some time in the past and the owners have just not had the opportunity to repaint.

SLIDE 3-12



After completing the scrubber stack visible emission observation, a second trip around the facility should be made. During this survey, anything which may have interferred with the stack observation should be noted. Possible situations include fugitive emissions from vehicle movement or from storage piles, and the start-up of another source along the line of site. The absence of any of these conditions confirms that only the scrubber stack was observed.

Steam vent dissipation characteristics should also be described. This helps to demonstrate that the material observed was in fact particulate and not steam.

The second survey around the facility also provides a good time to select the best observation point for checking bypass stack emissions and fugitive emissions from the process equipment served by the scrubber. Standard Method 9 procedures should be used in observing these possible emission sources.

During the second survey, any odors should again be noted. The intensity and characteristics should be described so that the source(s) can eventually be identified.

LECTURE 3. REVIEW PROBLEMS AND QUESTIONS

3-1. There is reason for concern. Two 20% opacity plumes in series would result in an opacity of approximately 36%. The observed value is in excess of this level. Attendees who were incorrect probably assumed that opacities are additive. A review of the basic principles of transmittance quickly indicates that opacity is an exponential function.

3-2. The observations should be repeated for each stack.

3-3. Answer c is the correct answer, assuming that the inspector is qualified to conduct level 2 or level 3 inspections of scrubber systems. The key point is that there is a very significant excess emissions problem at the present time which can not be ignored. The unit is definitely out of compliance with the visible emissions regulations.

3-4 Yes, the 45° angle results in a true 20% opacity plume equivalent 27% opacity.

3-5. Answer b is correct. In this case, it is probable that there is severe air infiltration into the unit or a similar problem which reduces the capture of pollutants at the process area.

LECTURE 3. REVIEW PROBLEMS AND QUESTIONS

3-1. During the second survey of the facility, it is discovered that a second scrubber system has started since the beginning of the visible emission observation. The plume from this second system is in the same line of sight as the observed plume. If the average opacity of the observation just completed was 39%, is there any reason to believe that either of the scrubber systems is out of compliance with a 20% opacity regulation? (Additional Notes: It lasted more than 6 minutes, and the observation point did not include steam from either scrubber).

3-2. In the situation described in problem 3-1, a second source along the line of site starts operating at sometime during the observation. This is not discovered until after the observation is concluded. What should be done?

3-3. During a properly conducted observation of a scrubber stack, the opacity pattern has regularly occurring spikes of 70 to 90% opacity lasting from 30 seconds to 90 seconds. These occur approximately every 4 minutes. The reminder of the time the opacity is in the range of 10 to 15% opacity. The baseline opacity data for this facility indicates an average of 10 to 15% without any spiking. The visible emissions limit is 20%. What should be done?

a. Nothing, there has been no shift in the baseline opacity levels and the unit is in compliance with the 20% regulation.

b. The next regularly scheduled inspection of this facility should be either a Level 2 or Level 3 inspection rather than a Level 1 inspection.

c. A Level 2 or Level 3 inspection should be conducted immediately to determine the cause of the spiking and to determine the corrective actions that the source intends to take.

3-4. During a presurvey of a plant, the best observation point is a small hill overlooking the scrubber stack. The angle down through the plume is 45°. If the observed opacity is 27%, is the unit in compliance with a 20% opacity standard?

3-5. The residual plume from a scrubber system has an average opacity of less than 5%. There are fugitive emissions from the roof monitor above the process equipment served by the scrubber. However, these fugitive emissions are not noticeable at the plant boundry line. What should be done?

a. Nothing

b. A Level 2 or Level 3 inspection should be performed as soon as possible.

c. The observations should be repeated during some period when there are no condensed water droplets anywhere in the plume.

LECTURE 4

EVALUATION OF SYSTEM INSTRUMENTS
AND
USE OF PORTABLE INSTRUMENTATION

SLIDE 4-1

WET SCRUBBER DATA

A. GAS STREAM DATA
- Static Pressures
- Flow Rates
- Temperatures
- Oxygen Concentrations

B. LIQUID STREAM DATA
- Pressures
- Flow Rates
- pH

This lecture concerns data. The parameters which are important in most wet scrubber system inspections are listed in the adjacent slide.

In level 2 inspections it is important to confirm that the permanently mounted on-site instruments are working properly. Some of the common symptoms of gauge malfunction are discussed. While it will not be possible to make a comprehensive evaluation of instrument performance, these procedures will at least help identify gauges suffering from the most common failures.

In level 3 and 4 inspections, both the on-site gauges and some portable instruments may be used. Procedures for using the portable instrumets to evaluate wet scrubber systems are discussed in this lecture. They include basic calibration checks and ways to avoid measurement errors. Safety considerations are an important part of this material.

Measurement ports are necessary for the portable instruments. The proper sizes and locations of measurement ports on common types of wet scrubbers are discussed in this lecture.

SLIDE 4-2

SELECTION AND USE OF MEASUREMENT PORTS

1. Ports should be >½" and <2" diameter.
2. There should be safe access to the port to facilitate rod out prior to the measurement.
3. Never use ports connected to D/P transmitters.
4. Never have measurement ports installed while the system is running.

Before beginning the discussions of each type of instrument, basic common sense facts deserve some attention.

There are a large number of on-site gauges and measurement ports located in strange and obscure locations around wet scrubber systems. HEROIC MEASURES SHOULD NOT BE TAKEN TO REACH THESE IMPROPERLY LOCATED GAUGES OR PORTS. This means that the inspection will not be as thorough as it might otherwise be. However, this is preferable to an accident.

Only the data necessary to confirm compliance or to determine the general types of problems which exist should be obtained. Extensive time should not be devoted to the inspection just so that the inspection is "complete" or so some inspection report form can be filled out. The art of field inspection is determining which measurements are relevant for the particular system at the specific time. Anything beyond these measurements is a waste of the inspector's time and an inconvenience to source personnel who must accompany the inspector.

Lecturer's Notes

There is a tendency of some inspectors to try to become the "consultant" of the source. This is not an appropriate use of time. The job of the inspector is only to determine if there is a problem and if the source has made a reasonable response to correct and minimize this condition in the near future. It is the job of the plant personnel to make whatever supplemental measurements and observations necessary to evaluate the exact nature of the problem and to recommend the design and/or operational changes.

SLIDE 4-3.

MEASUREMENT OF STATIC PRESSURE

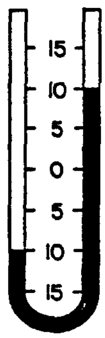
1. Manometers
2. Diaphragm Gauges

There are two main options available for the measurement of static pressure: (1) manometers, (2) diaphragm gauges.

The manometer, which can be filled with either oil or water, does not need to be calibrated. It is a relatively simple instrument and is not very vulnerable to malfunctions. Low range manometers can be mounted on the scrubber vessel permanently and slack tube manometers can be used as a portable instrument.

The diaphragm gauge can also be used as a permanently mounted unit or as a portable instrument. These are made in a number of ranges from 0 to 2 inches W.C. to as high as 0 to 150 inches. At the higher static pressures (>36 inches W.C.) these diaphragm gauges are the only practical approach since the manometers would be too long.

SLIDE 4-4

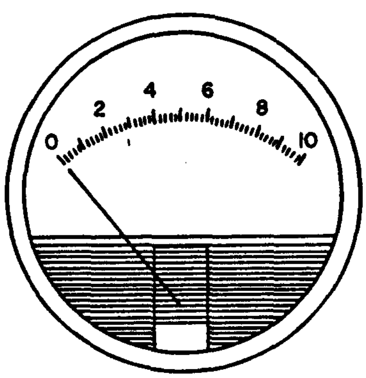


A manometer is simply a U-shaped tube filled with a fluid. When unequal pressures exist at the tops of the two ends, the fluid moves to equalize the pressure difference.

The difference in the heights of fluid in the two sides is a measure of the pressure difference. In the sketch shown here there is a difference of 20 inches. Therefore, the pressure is 20 inches of water.

It should be noted that the specific gravity of the fluid is important. For example, if mercury was placed in the manometer shown to the left, it would show a difference of only 1.5 inches since it has a specific gravity of 13.6. Most scales used on manometers assume a specific gravity of 1 (for water).

SLIDE 4-5

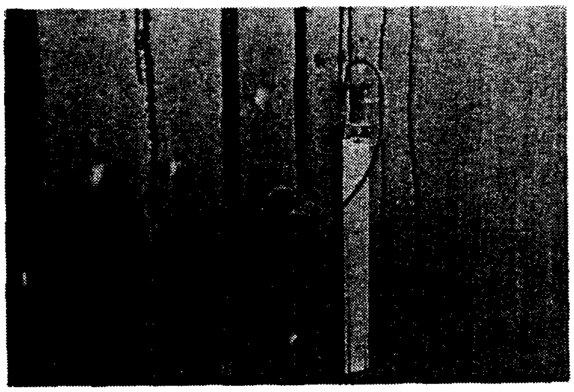


The diaphragm gauge is shown in this photograph. Near the back of the instrument are two chambers separated by a flexible diaphragm. This moves when unequal pressures exist in the two chambers. The degree of movement is proportional to the static pressure difference.

Diaphragm movement is sensed by a helic coil. The move of this coil is transmitted mechanically to the indicator needle on the face plate. The unit does not need electrical power

There is no gas flow through the two chambers. These actually are like dead end streets to the lines coming from the scrubber to the instrument. This feature minimizes the accumulation of material in the chambers and the chemical attack of the diaphragm. As with any resilent synthetic material, the diaphragm does have temperature sensitivities. Due to these limits, the gauge is subject to problems when the diaphragm temperature is lower than 20 °F and higher than 140 °F.

SLIDE 4-6

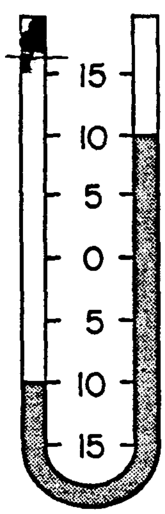


A small water filled manometer is shown on the downstream side of a rod deck gas-atomized scrubber. While this is a relatively cold location, the gas temperature going through this part of the scrubber vessel is still 125 °F. This is a very typical temperature for exhaust streams from wet scrubbers.

Since the manometer is in direct contact with the wall, the manometer fluid is constantly heated. The vaporization will gradually reduce the amount of fluid in the manometer. If the fluid level is so low that a measurement can not be obtained, plant personnel can be asked to refill the manometer during the inspection.

It should be noted that there is nothing to stop fluid vaporization from a manometer regardless of how it is connected. When it is being used to measure static pressure, one side is open to the atmosphere. When it is being used to measure static pressure drop, both sides are open to areas with moving gas streams.

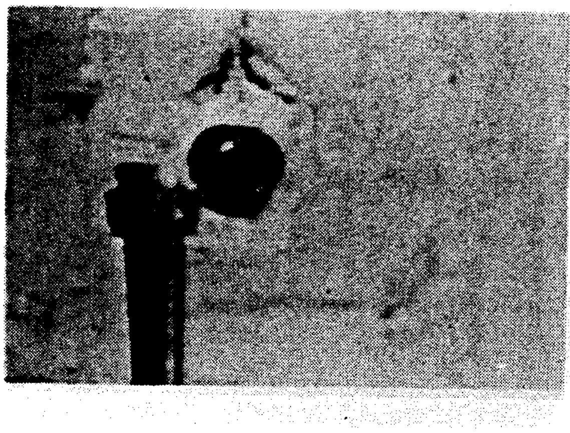
SLIDE 4-7



Pluggage of a portion of the manometer can occur due to the gradual diffusion of particulate matter down one of the lines. The accumulated material blocks the movement of the fluid and can lead to erroneous readings. Occassionally there may be a need to remove the manometer and clean it out.

These deposits are easy to spot. Plant personnel should be able to correct this during the inspection.

SLIDE 4-8

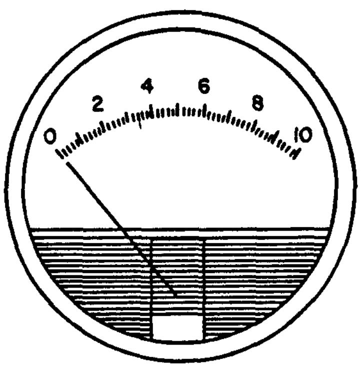


A more common site of pluggage is at the port itself. Solids or sludge can quickly accumulate in the fitting used to connect the manometer (or diaphragm gauge) lines to the port. This is more difficult to identify.

On negative pressure units, the lines can be disconnected at the instrument (by plant personnel) and a very small scrap of paper placed against the line opening. If the line is open the scrap will be held firmly on the line. This works even when the static pressure is as low as -1 inch W.C. On positive pressure lines, it should be possible to feel slight flow out of the disconnected line onto the back of the hand. This is not quite as sensitive as the negative pressure test.

Some people attempt to feel the slight gas flows by placing the line against their face. While this may be more sensitive for low positive pressure conditions, it places the potentially toxic gas stream near the nose.

SLIDE 4-9



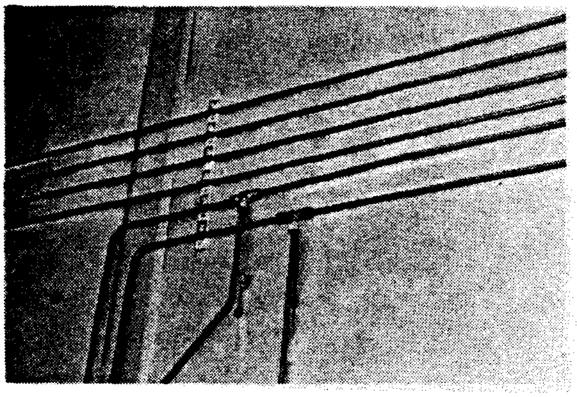
A manometer or diaphragm gauge used for static pressure measurements should indicate zero when the single line is disconnected. This is indicated in the slide to the left.

If a manometer fails to indicate zero there is probably an obstruction in one or both of the lines. Another possible explanation is freezing of the fluid.

An attempt should be made to re-zero diaphragm gauges which do not return to zero when the static pressure line is disconnected. If it can not be zeroed it is definitely bad. Even if it can be zeroed there still remains the chance that it is defective.

A small section of 1/4" O.D. tubing can be connected to the instrument (with the plant representative's approval) and the response of the diaphragm checked by applying slight positive and negative pressures. A squeeze bulb with two check valves is useful for this purpose (one of these is present with the oxygen analyzer to be discussed later). If the gauge responds in the proper directions, it probably is operational.

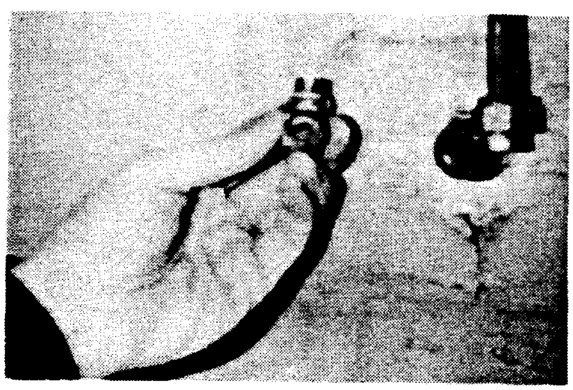
SLIDE 4-10



Pluggage of the port and/or the line leading to the static pressure gauges can be expected whenever a situation as shown here exists. These are 1/4" O.D. copper tubes leading from a number of ports down to static pressure gauges in the control room. It doesn't take much solids to close off a tube this small.

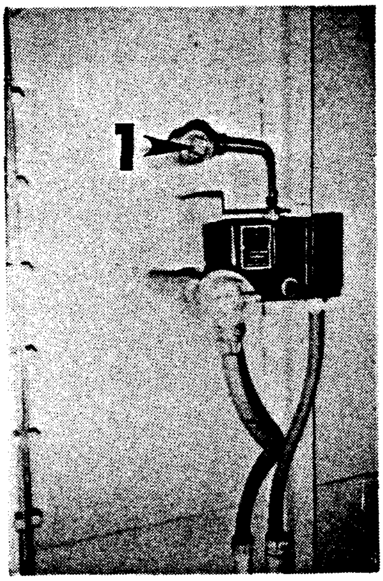
The lines should be as short as possible and as large as possible. It is not unusual to find plants which have ripped out lines like this and put in 1/2" to 2" lines in order to minimize the pluggage problem,

SLIDE 4-11



Another feature which is prone to pluggage is the use of an elbow fitting close to the port. This is an ideal site for solids build-up. As a complicating matter, the small pipe ahead of the elbow fitting is horizontal and fluid may not flow out easily.

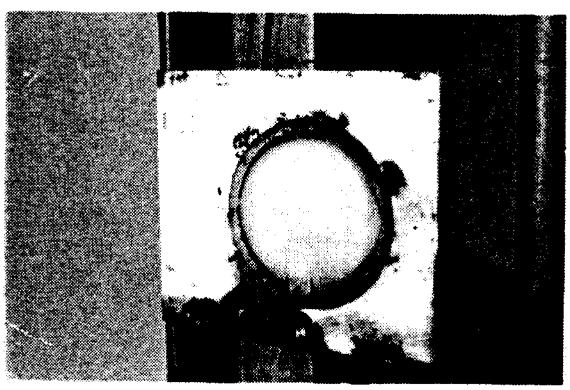
SLIDE 4-12



One way to minimize pluggage problems is to use a differential pressure transmitter close to the port. This converts the static pressure to an electrical value which is then displayed on a control room gauge.

Note that the pipe coming from the scrubber wall is a 1" pipe. This will plug less frequently than 1/4" ports which are commonly used.

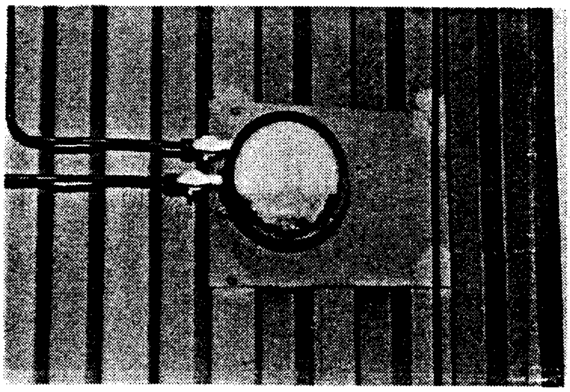
SLIDE 4-13



Diaphragm gauges which are attached directly to the scrubber vessel wall can be adversely affected by the internal gas temperatures. The exit gas temperatures of the scrubber are often quite close to the maximum allowable temperature of the diaphragm between the two chambers. Due to the ease of heat conduct between the wall of the scrubber and the gauge body, the diaphragm could exceed recommended temperatures. It should be remembered that the diaphragm is in the back of the instrument and therefore is quite close to the scrubber wall.

One way to minimize this problem is to mount the gauge on a small stand-off so that there is an inch of more of clearance between the back of the gauge and the scrubber wall. This reduces heat transfer by direct conduction to relatively low rates.

SLIDE 4-14



On-site gauges which are partially or completely full of liquid are probably not working properly. It is easy for this liquid to accumulate even though there is no gas flow through the instrument. Diffusion of moisture (and some corrosive materials) can occur down one or both of the connecting lines. Condensation can occur in the gauge itself or in the connecting tubing. The orientation of many gauges ensures that any condensation in the tubing drains down to the gauge itself.

SLIDE 4-15

PROBLEMS WITH PLASTIC TUBING

1. BRITTLENESS CAUSED BY PROLONGED EXPOSURE TO SUNGLIGHT AND COLD
2. COLLAPSE CAUSED BY HOT ADJACENT SURFACES

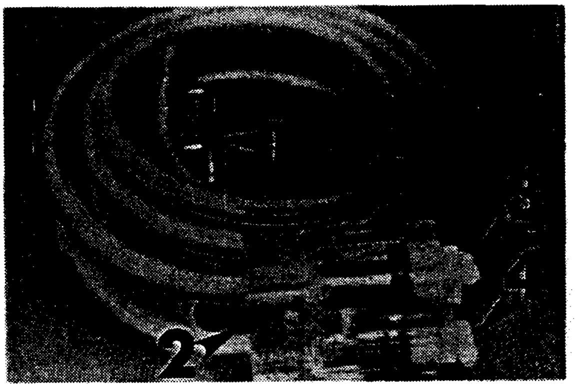
Prior to accepting data from the on-site gauges, the condition of the connecting lines should be briefly checked.

Tubing composed of polypropylene and polyethylene can be common brittle and break. This means that the part of the gauge is actually sensing atmospheric pressure rather than the scrubber system static pressure. The error will not always be apparent from the gauge reading.

Tubing composed of a soft plastic (e.g. Tygon) can be inadvertently crimped. If it drapes over a hot surface part of the tube may have collasped.

If problems with the guage connecting lines are chronic or severe, it may be advisable to replace these with copper tubing. This is less susceptible to crimping and can withstand surface temperatures up to 800 °F. It is the most rigorous material for small diameter gauge connection lines.

SLIDE 4-16

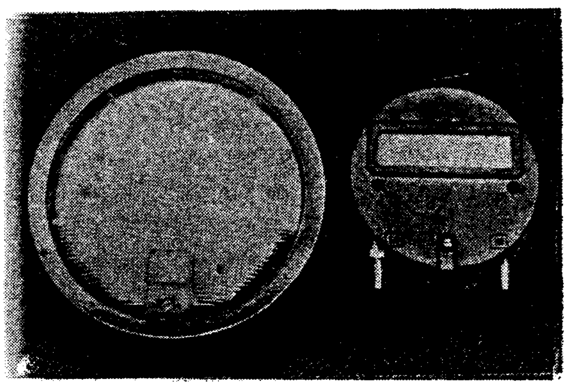


During level 3 inspections of wet scrubber systems, portable instruments should be used when there are questions regarding the performance of the on-site gauges. The portable instruments for measuring static pressure are the same as those used for on-site gauges.

This slide shows a slack tube manometer. It rolls up to facilitate moving from place to place. Magnets at the top and bottom (see arrows #1 and #2) are used to hang the instrument. Screw in caps (see arrows #3 and #4) seal the instrument when not in use.

It is obviously important to remember to close the end caps before rolling up the unit and moving on. The fluid will run all over the careless inspector. The manometer should not be used at locations which exceed the limits of the unit. For example connecting a 36" slack tube to a port where the static pressure is -50 inches will result in the quick loss of some of the fluid into the duct.

SLIDE 4-17



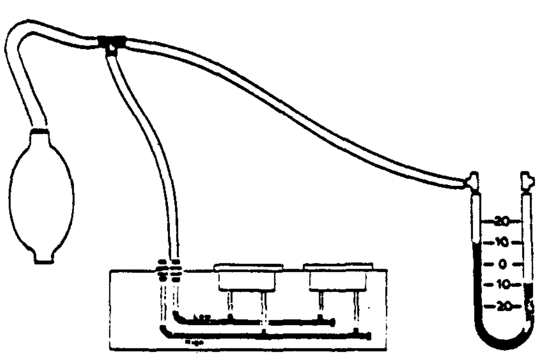
Both the standard size and minature size diaphragm gauges are shown in this photograph. The small sized unit fits in a pocket and is therefore easy to carry around. It has an accuracy of plus or minus 5% while the standard sized unit is plus or minus 3% accuracy.

Both instruments are relatively insensitive to vibration and shock. If the static pressures measured are above or below the range of the instrument, it simply pegs. This does not hurt the unit or throw it out of calibration.

Before use, the instrument is zeroed using the small set screws at the front of each gauge. When used to measure static pressure one of the taps is connected to the wet scrubber system and the other is left open to the atmosphere. When used to measure static pressure drop directly, both taps are connected to ports on the scrubber system.

They are obviously subject to the same temperature limitations as gauges mounted permanently on control systems. When used as portable instruments, however, it is unlikely that they will be exposed to the extreme temperatures for more than several minutes at a time before being put back into a protected area. There is also little time available for diffusion of corrosive gases down into the chambers. In other words, these work better when used as portable instruments than when used into full time service as permanently mounted gauges.

SLIDE 4-18



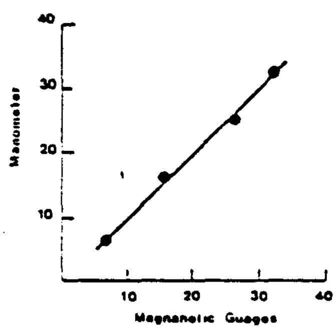
Prior to starting the field work, the diaphragm gauges should be calibrated against a manometer. The apparatus for doing this calibration is simple as illustrated in the adjacent sketch.

Both the diaphragm gauge and a manometer are connected to a tee fitting, which in turn leads to some source of positive and negative pressure. The squeeze bulb with check valves is a convenient source of positive or negative pressure since it is possible to hold the pressure for a few moments.

The squeeze bulb supplied with the oxygen/carbon dioxide analyzer can be used for this service. This has a range of -40 inches W.C. to + 40 inches W.C. which is adequate for most situations. The complete calibration takes about 5 minutes as long as the slack tube manometer can be left set up in some out of the way location.

One of the basic requirements involved in the use of any portable instrument is that the unit should be checked out and calibrated before leaving the office for field work.

SLIDE 4-19

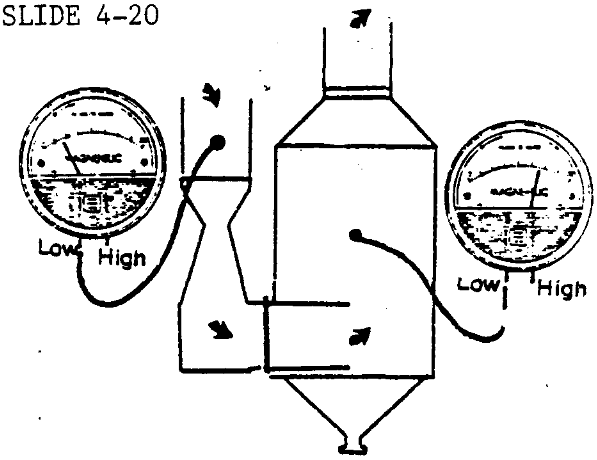


The diaphragm gauge calibration curve should look like the graph shown here. The data should fall close to a 45° line. If the unit fails to remain within the error band or if the plotted data is non-linear, then the gauge should be repaired or replaced.

The calibration data should be maintained in a convenient file at the office and should not be taken to the field. This data can be used later to demonstrate that the measurements taken in the field were accurate.

The same procedure discussed in the last two slides can be used to calibrate a permanently mounted diaphragm gauge at the plant being inspected. The connecting tubes are simply disconnected, and a slack tube manometer used as the primary standard. It is not unusual to find that the various insults suffered by the permanently mounted gauge has thrown it well out of calibration.

SLIDE 4-20

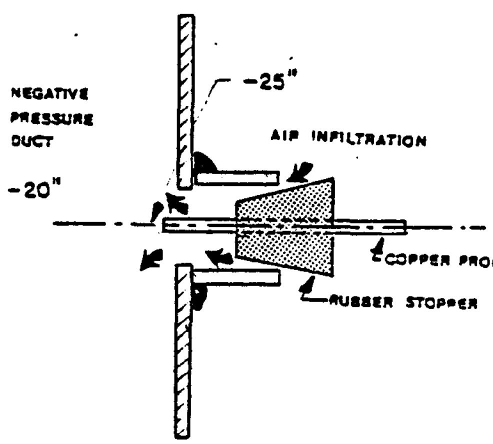


One of the wet scrubber operating parameters of most interest is the static pressure drop. It is usually not advisable to try to measure this directly even though this can be done by connecting the "hi" and "low" ports to different parts of the system as shown in the top portion of this slide.

With this approach, a large quantity of flexible tubing is required and this can become crimped during the measurement. There is also a chance that one of the ports will plug during the measurement.

It is preferable to make the static pressure measurements one at a time. The pressure drop is then calculated by subtracting one value from the other. This approach is easier and less subject to measurement error. Less tubing is also required since a maximum of 3 feet is normally required for static pressure measurements.

SLIDE 4-21



For locations which have high negative static pressures, it is very important to completely seal the port to prevent aspiration effect error. With the condition shown in this slide, the localized static pressure at the tip of the copper probe can be more negative than the true negative static pressure. This is due to the additional suction effect caused by the high velocity ambient air rushing in around the probe. The threshold of this effect is around -10 inches W.C. and it becomes progressively more significant as the pressures decrease (at -50 inches it is worse than at -10 inches W.C.).

For example, it is possible to "measure" a static pressure of -25 inches W.C. when the true static pressure is -20 inches W.C. At higher negative static pressures, it is possible to "measure" a static pressure of -150 inches W.C. when the true static pressure is -100 inches W.C. Sealing the port tightly eliminates the problem immediately. Movement of the probe well into the gas stream and away from the area of the infiltration also totally eliminates the problem.

Lecturer's Notes

In practically every measurement discussed in the workshop, it will be possible to enhance measurement accuracy by moving the probe into the gas stream and away from the duct wall.

This problem is not unique to portable gauges. A permanently mounted gauge with a crack in the weld of the port will suffer the same effect.

SLIDE 4-22

PORT SEALING TECHNIQUES

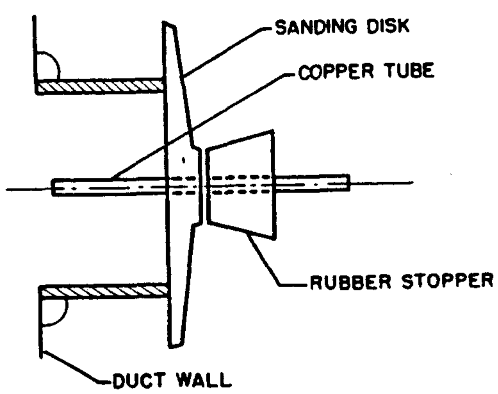
1. Hand
2. Glove or Fabric Piece
3. Rubber Stopper
4. Sanding Disk with Rubber Stopper

Options for sealing of ports are listed in this slide. The hand is never a good choice since a tight seal is almost impossible to achieve. Also, the metal surfaces are usually hot and may be covered with deposits of toxic dusts.

A glove is also not appropriate. At very high static pressures there can be 5 to 10 pound of force across the small open areas of ports. The unwary person will lose the glove to the equipment. Inside, the glove will not be beneficial for the system, regardless of where it comes to rest.

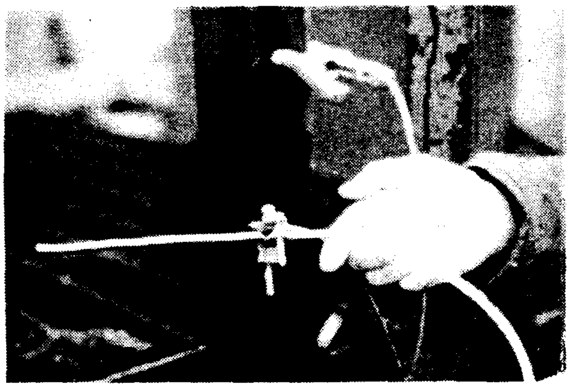
The rubber stopper or the sanding disk with rubber stopper are more useful since it is possible to get a good seal. The rubber stoppers main function is to maintain a tight hold on the probe so it is not lost. These two approaches are useful as long as the port surface temperature is not too high.

SLIDE 4-23



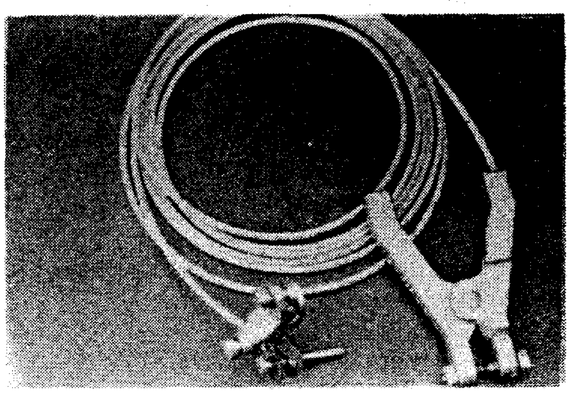
The sanding disk with rubber stopper approach is illustrated here. The sanding disk must be a least 1" larger in diameter than the outer diameter of the port. It is the sanding disk which provides the main seal against air infiltration. The rubber stopper behind the sanding disk is drilled slightly small so that the 1/4" copper tube is firmly held. This apparatus is extremely cheap to assemble and is easy to use.

SLIDE 4-24



Another problem that can occur during static pressure measurement does not affect the accuracy but instead involves a potential safety hazard. As illustrated in this slide, any probe in a rapidly moving gas stream will have particles frequently colliding with the probe surface. The rubbing action will cause static electrical charges to accumulate on the probe surface. It is conceivable in certain situations that the charges could reach a high enough voltage to cause an arc from the probe to the grounded duct wall. This would initiate a primary explosion in the duct with the possibility for more violent secondary explosions as the duct ruptures. The factors which favor this condition include: (1) an electrically isolated probe, (2) low relative humidity in the duct, and (3) high particulate mass concentration.

SLIDE 4-25



One way to avoid any static charge build-up on the probe is to use a grounding/bonding cable similar to that shown in this slide. On one end is a standard household type clamp which can be firmly attached to the metallic probe. The other end is a jaw type clamp which attaches to any grounded item outside of the port. Since the cable does not have any insulation, it is easy to confirm that there are no breaks.

The grounding/bonding cable should be visually inspected prior to use and all connections should be made before the probe is inserted into the gas stream.

The grounding/bonding cable allows the continual dissipation of the electrical charges. The duct wall and the probe remain at the same voltage potential. Therefore an arc can not occur.

If there is any question at all concerning the need for a grounding/bonding cabe, it should be used. Obviously the clamp should not be attached to any electrical line or conduit in the vicinity of the port.

One of the reasons this subject is emphasized in this workshop is that wet scrubbers are often used to remove pollutants from gas streams which are potentially explosive. All other particulate control systems have components which could detonate the gases components, thus leaving wet scrubbers as the only alternative. It is particularily important at the inlet of scrubbers to avoid any possibility of static arcs. Downstream there usually (but not always) is enough moisture to dissipate the static without the cable.

SLIDE 4-26

SUMMARY
STATIC PRESSURE MEASUREMENTS

Static pressure data is an important part of all level 2 and level 3 wet scrubber system inspections.

In the level 2 inspections, the on-site guages should be checked to the extent possible before the data is recorded in the inspection notes. With the plant management's permission, the lines to gauge should be disconnected to check the meter response and to determine if the lines are plugged.

Obvious problems should also be noted, such as freezing of manometer fluid, use of improper fluid for manometer scale, excessive temperatures on diaphragm gauges, and water in diaphragm gauges.

The portable gauges used in level 3 inspections should be checked and calibrated before use. Air infiltration around the port should be prevented during the measurement by a seal which can not be sucked into the duct. The probes should be grounded to prevent static accumulation.

SLIDE 4-27

TECHNIQUES
FOR THE
MEASUREMENT OF TEMPERATURE

1. Mercury Thermometer
2. Dial-Type Thermometer
3. Thermister
4. Thermocouple (Battery Powered)

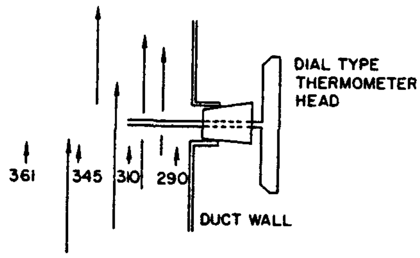
The four types of instruments that can be used to measure gas stream and liquid stream temperatures are listed in this slide. Of these, the mercury thermometer is definitely not desirable since it is easily broken.

The thermister is often readily available from the control agency lab. This however, is limited to a maximum temperature of approximately 150 °F. It is useful primarily for the measurement of liquid temperatures and possibly the measurement of pipe skin temperatures.

The dial type thermometer is attractive to control agencies since it is relatively inexpensive. The limited reach of this instrument can lead to measurement errors.

The most versatile instrument is the thermocouple. It operates over the widest temperature range of any temperature monitor and the probes are easier to use. The main disadvantage is the relatively high cost. Like all battery powered instruments, the thermocouple should not be taken into potentially hazardous locations.

SLIDE 4-28



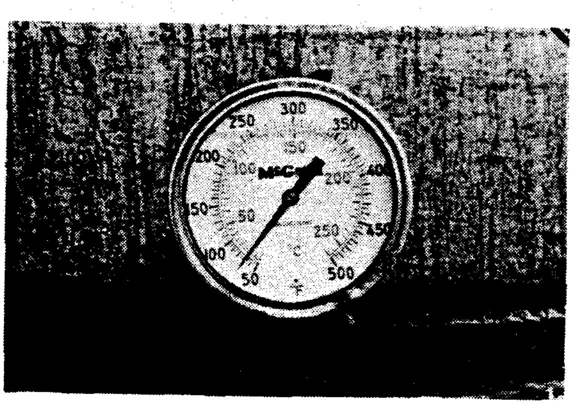
One disadvantage of the dial-type thermometers is the very limited reach possible with the 9 to 12 inch stems. As shown in the adjacent sketch, the temperatures of the gas streams close to the wall may be lower than those out in the main part of the duct.

In some common ports, the pipe nipple extends out from the duct wall 4 to 8 inches. With these ports, the sensor part of the instrument may only barely be in the gas stream at all.

It is not wise to attempt to use the dial-type thermometers in any duct in which there is a strong gas temperature gradiant. This situation should be suspected whenever the port is close to flow disturbances such as elbows, and access hatches.

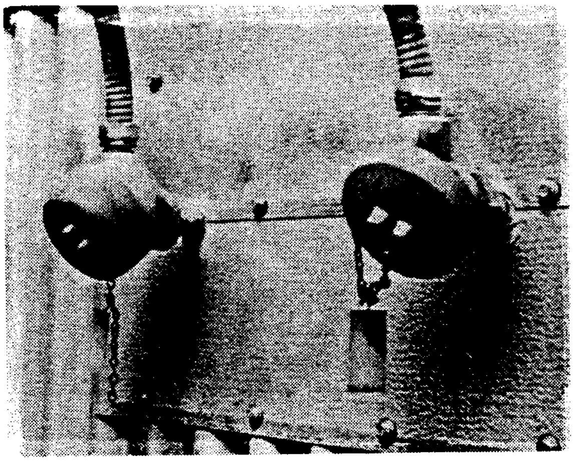
This same problem can affect the accuracy of thermocouple mounted in permanent thermowells. If they do not extend far enough into the gas stream, they may also indicate lower than actual gas temperatures. There is no way to tell from the outside of the thermowell just how far it does extend inward. However, the plant instrumentation group should be able to supply this information and explain the rationale for the specific thermowell length and location.

SLIDE 4-29



If condensed water (or any other fluid) is visible in the dial-type thermometer the gauge is no longer working. It is supposed to be a totally enclosed gauge, so the presence of liquids demonstrates that part of the stem has corroded or eroded away.

SLIDE 4-30



This is a photograph showing the connection heads for two thermocouples. Just by locating these heads it is possible to determine the locations of any thermocouples along the gas stream path.

There is very little that happens to these instruments that does not completely shut them down. If the unit is providing a read-out at all, it is probably working adequately. Of, course it is always prudent to check if the indicated temperature is logical.

All thermocouple data must be obtained in the control room for the process or wet scrubber system. One of the most common errors in recording this data is misassigned location I.D.s on the strip chart recorder or plant data acquistion system. The best way to screen out these inadvertent errors is to check the changes in temperature as the gas stream passes through the wet scrubber system. Usually it gets colder until it reaches a gas reheater (if used in the system). This is one of the reasons that it is helpful to have a flowchart handy so the locations of the thermocouples can be clearly marked.

SLIDE 4-31

THERMOCOUPLES

1. Calibrate probe and meter against a NBS traceable thermocouple.
2. Check ice point and boiling point values prior to each day.

When conducting level 3 inspections, there is often the need to supplement the available temperature data supplied by on-site monitors. The instruments commonly used for this purpose include the dial-type thermometer and the thermocouple.

Before starting any field work each day, both should be checked in boiling water and in finely crushed ice. This two point check is not a full calibration but it does increase confidence in the performance of either instrument.

On a regular basis, the units should be calibrated at a certified lab. In the case of the thermocouple, it should be compared against an NBS traceable probe and instrument. The cost for these semi-annual or annual calibrations is nominal.

SLIDE 4-32

TEMPERATURE MEASUREMENT ERRORS

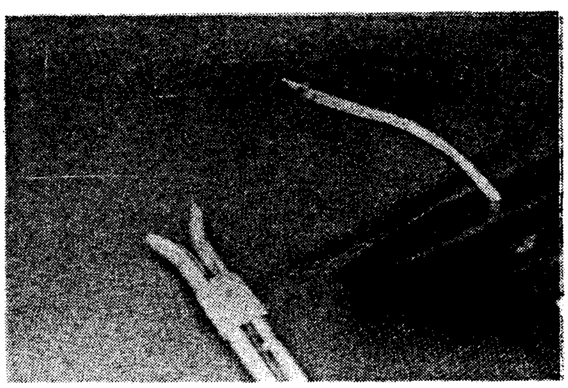
1. Unrepresentative Measurement Location
2. Cooling of the Probe Due to Air Infiltration Through the Port
3. Impaction of Water Droplets

This list summarizes the three most common errors in the measurement of gas stream temperatures with portable monitors.

To avoid the problems of unrepresentative measurement locations, the port location should be carefully chosen. Again ports downstream of large access hatches, or in bends in the duct work are not the optimal locations. Also, it is important to measure the gas streams in the main flow of the duct and not just at the wall.

The problem with air infiltration should be solved with the same basic approach discussed with respect to the aspiration error in static pressure measurements. The port should be completely sealed using a rubber stopper or a sanding disk and rubber stopper.

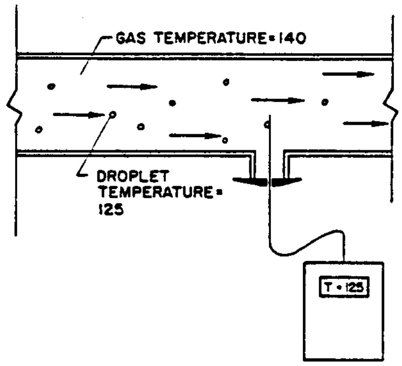
SLIDE 4-33



Two ways to position the thermocouple probe at the desired location well inside a duct are shown in the photograph to the left. The one on the left of the slide is the tip of a S-Type pitot tube. A flexible thermocouple probe without a protective sheath has been attached to the pitot tube. The thermocouple bead is approximately 1" behind the end of the pitot.

The equipment to the right of the slide is a standard 1/4" O.D. copper tube through the sanding disk seal. The flexible thermocouple probe has been threaded through the copper tube and terminates at the end of the copper tube.

SLIDE 4-34

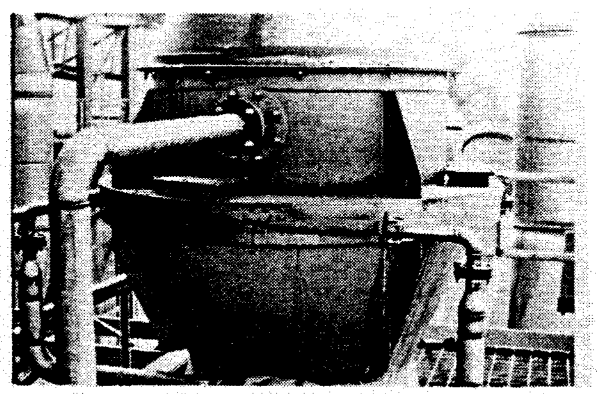


Erratic temperature measurements can occur immediately downstream from wet scrubbers and evaporative coolers. Liquor droplets in the gas stream impact on the temperature probe and briefly reduce the temperature from the dry bulb to the wet bulb levels. The observed temperature is characterized by sudden drops in the values followed by slow climbs back to steady state values. This, of course, is only a problem when the gas stream is not fully saturated and there is a difference between the wet bulb and dry bulb temperatures.

In some cases, it is possible to shield the thermocouple probe so that there is no impaction on the probe itself. Also, a sample can be extracted through a trap to remove the droplets prior to the monitor. The latter is done at the risk of cooling the gas stream as it passes through the trap and sample delivery lines. The preferred approach is to find another location where the dry bulb temperature can be measured accurately.

When evaluating gas-liquor maldistribution, it is sometimes useful to use ports where some liquor droplet entrainment remains. Gas streams from wet scrubbers should usually be saturated and the presence of this measurement problem is a sign of poor distribution. Wet bulb measurements can also be made by wetting a sleeve around the thermocouple probe.

SLIDE 4-35



The liquor temperatures can be measured by obtaining a small sample and then using a dial-type thermometer, a thermister, or a thermocouple. The probe should be washed and dried after each measurement to remove corrosive materials.

Frequently, it is necessary to estimate the liquor temperatures at locations where it is inconvenient to obtain a sample. One example is the various headers leading to nozzles on the inlet of a venturi scrubber. For these situations, the pipe skin temperature can be measured using either a thermocouple or a thermister.

The pipe skin temperature is always slightly lower than the actual liquor temperatures. However, it is proportional to the liquor temperatures. One of the advantages of the baseline approach is that a shift in the pipe skin temperatures becomes a meaningful parameter. It is not absolutely necessary to know the actual values.

SLIDE 4-36

SUMMARY
GAS TEMPERATURE MEASUREMENT

When making temperature measurements one of the main requirements is to ensure that a representative location is chosen. This applies to both on-site instruments and to portable units.

With the portable instruments it is possible to locate the probe well inside the duct or even to perform a complete traverse. This is useful when a strong temperature gradiant exists across the duct.

Before using any portable instruments, a two point (zero and 100 °C) calibration should be made. The units should be sent out for calibration every six to twelve months.

For liquid stream lines, the temperature of a small sample is measured. In locations where it is impractical to get a sample, the pipe skin temperature should be measured.

SLIDE 4-37

OXYGEN MEASUREMENT INSTRUMENTS

1. ORSAT Analyzer
2. Gas Absorbers
3. Electroconductivity

The oxygen concentration of the inlet gas stream is useful for evaluating the combustion conditions at the boiler and for evaluating air infiltration upstream of the wet scrubber system.

The instruments generally used for this purpose are listed in the adjacent slide. All permanently mounted units are electroconductivity sensors. These extract a small gas sample continuously. They are normally installed directly behind the boiler and next to any continuous monitors for sulfur dioxide.

The ORSAT is a manual, wet chemical method which simultaneously yields data concerning oxygen, carbon dioxide and carbon monoxide. The ORSAT apparatus is relatively inexpensive. However, the measurement is time consuming. The gas absorption instruments utilize the same techniques as the ORSAT. The main difference is that each unit will only measure one compound. Also, there is no gas absorption unit for carbon monoxide. The gas absorption units are easy to carry around during an inspection.

SLIDE 4-38

PROBLEMS WITH ELECTROCONDUCTIVITY ANALYZERS

1. Unrepresentative Measurement Location
2. Air Infiltration into Sample Line
3. Defective Electroconductivity Cell
4. Pump Failure

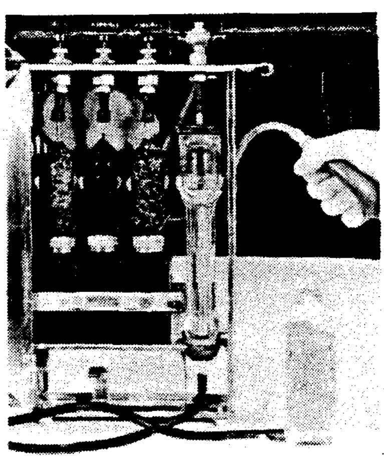
The most frequent problems with the electroconductivity instruments are listed in this slide.

Unrepresentative locations can be avoided by pulling the sample from well inside the gas stream. It should not be extracted close to the duct wall.

All of the other problems can be identified by the attempted calibration. All permanently mounted units should have a calibration cylinder having a known oxygen concentration close to the concentration expected in the duct.

The calibration gas should be connected to the sample line through a three-way valve which shuts off the duct line when the cal gas line is open. The cal gas should enter the line very close to the duct wall so that leaks along the sample line to the instrument can be found. Air infiltration along the line leads to higher than expected oxygen concentrations while electroconductivity cell problems usually gives low readings.

SLIDE 4-39



The ORSAT analyzer is shown here. It consists of three liquid reserviors and a sample reservior. A gas sample is drawn into the instruments and sequentially mixed with all three liquids, each of which removes one of the gas sample components. The oxygen, carbon dioxide and carbon monoxide concentrations are determined by the height of a column of liquid displaced by the gas sample. This decreases as each component is removed. The unit has an accuracy of plus or minus 1/2% for each gas compound.

The gas sample is drawn from the measurement port using a pump and a Mylar or Tedlar sample bag. A portion of this sample is then pumped into the ORSAT instrument. Care is necessary to avoid dilution of the sample during pumping from the duct, during storage in the bag, and during pumping to the instrument. This will obviously lead to high oxygen levels and lower than actual carbon dioxide and carbon monoxide values. Another potential error results from the use of exhausted absorption chemicals.

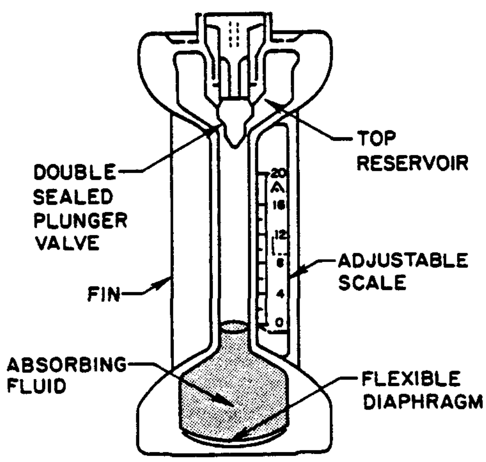
SLIDE 4-40

A common type of gas absorption unit is shown in this photograph. The absorbing solution is similar to that used in the ORSAT with the exception that there are separate units for oxygen and carbon dioxide.

The types of solutions used in the carbon dioxide unit is potassium hydroxide and in the oxygen unit is a combination of zinc chloride, cuprous chloride and hyrdochloric acid. Both solutions are highly corrosive and should be handled with care. If used improperly, it is possible to get these materials on the hands.

As with the ORSATs, it is necessary to change the fluids on a regular basis. The oxygen solutions last for 50 to 100 measurements while the carbon dioxide solutions last for 200 to 400 measurements. The actual fluid life depends partially on the concentrations of gases measured.

SLIDE 4-41



This slide presents a cutaway sketch of the Fyrite analyzer. The gas sample is pumped into the top reservior using a squeeze bulb (not shown). The double seated plunger valve is manually closed when sampling is done. The entire unit is then inverted several times (between two and four times) to completely mix the gas sample and the fluid. The absorption of the specific gas compound reduces the overall gas pressure inside the unit, thereby causing the flexible diaphragm at the bottom to rise. This lifts the column of fluid up the small center tube. The rise in the height of the fluid is proportional to the amount of gas absorbed.

The absorption of any gas is a temperature dependent process. If the fluid is too hot, the indicated reading can be low and if the fluid is chilled (during winter inspections) the indicated readings can be high.

Pumping gas through the reservior too long before closing the top valve can give lower than actual readings. This is due to slow diffusion of the gas down to the fluid surface resulting in depletion of part absorbable component in the gas sample.

SLIDE 4-42

GAS ANALYSIS ERRORS

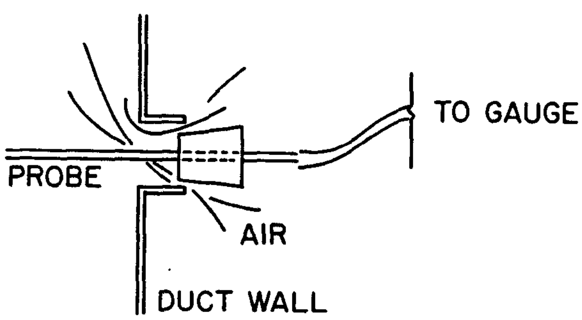
1. Unrepresentative Location
2. Air Infiltration Through Measurement Port
3. Air Infiltration Into Sampling Line
4. Exhausted Chemicals

The four most common errors in the use of gas absorption instruments and ORSAT instruments are listed in this slide.

In selecting a location to make the measurement, it is wise to avoid the areas adjacent to potential air infiltration sources. These include access hatches, expansion joints, duct flanges, and dust drop out hoppers.

If stratification of the gases in the flowing gas are anticipated, it will be necessary to make the measurements at a number of locations across the duct. The pitot tube provides a convenient means to "traverse" the gas stream for this purpose.

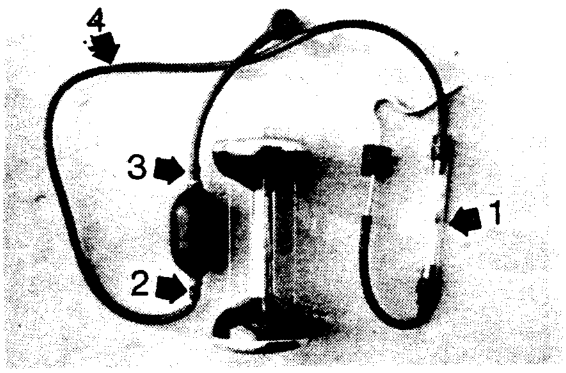
SLIDE 4-43



When using a 1/4" O.D. copper tube as the sampling line, it should extend a foot or two into the gas stream. It should also be bent in an upstream direction so that any air infiltrating through the port is not pulled into the instrument sample line.

As with all metallic probes in rapidly moving gas streams, a grounding/bonding rod should be attached to the tube before it is used.

SLIDE 4-44



A typical sampling line for the gas absorber is shown here. Item #1 is a humidification tube which is needed only during the calibration. The friction seals on either side of the tube can leak and it is helpful to use a line without one of these for the field measurements.

The items marked as #2 and #3 are the inlet and outlet check valves. Air infiltration can occur on the inlet check valve if it does not seat properly in the squeeze bulb or if the check valve has cracked. Both problems are common. Before using the sampling line, its integrity should be checked.

This is done by crimping the flexible tubing near the metallic probe and squeezing the bulb. It should not reinflate while this line is crimped. If it does, one of the check valves is not adequate. The fitting on the end of the sampling line (marked with arrow #4) should then be blocked with a thumb. It should be impossible to pump the squeeze bulb if the check valves are in good shape. If the sampling line does not pass these two tests, then it should be replaced before attempting any measurements.

SLIDE 4-45

CHECKING O_2 AND CO_2 MEASUREMENTS

FUEL	SUM OF O_2 AND CO_2 CONCENTRATIONS, %
Natural Gas	13-19
#2 Oil	15-20
#6 Oil	17-20
Bituminous Coal	18-21
Lignite	18-21
Anthracite Coal	19-21
Refuse	18-22
Wood	18-22

To check the accuracy of either the gas absorber instruments or the ORSAT the sum of the oxygen and carbon dioxide measurements should be checked against the ranges shown in this slide.

If the sum of the two measurements does not fall within this range, then there has been a measurement mistake or the chemicals are exhausted. In either case the data is not good and should not be used. These ranges take normal instrument error into account.

Lecturer's Notes

A demonstration of the gas absorbers (or ORSAT) is often useful to further explain how to check the accuracy of the measurements. A small mylar bag should be filled with your exhausted breath to be used as "typical flue gas" Measurements of the oxygen concentration should be approximately 15 to 16% and the carbon dioxide concentration should be approximately 4 to 5%. The sum falls into the range for bituminous coal and for wood.

SLIDE 4-46

GAS ABSORPTION INSTRUMENT CALIBRATION TECHNIQUES

1. Gas Cylinders containing known concentrations of oxygen and carbon dioxide
2. Ambient Air for O_2 instrument; Exhaled Breath for CO_2 instrument

The two options for calibrating any oxygen analyzer are listed in this slide. Obviously the gas cylinders containing known concentrations of oxygen and carbon dioxide are the preferred approach. This is the way the electroconductivity instruments should be calibrated. Records concerning the frequency and method of calibration should be on file at the plant.

Agency inspectors using the ORSATs and the gas absorption units should also use gas cylinders if they are affordable. Alternatively, these can be calibrated using ambient air and exhaled breath.

SLIDE 4-47

SUMMARY

OXYGEN AND CARBON DIOXIDE CONCENTRATION MEASUREMENTS

During level 2 inspections it is useful to mark the locations of any oxygen analyzers on the system flowchart and check if the reported values make sense. The calibration procedures for the electroconductivity instruments should be checked briefly. The condition of the sample delivery line should be checked for possible leaks. If there are any questions about the data, the plant personnel should be asked to repeat the calibration (single point is adequate) during the inspection.

If plant personnel are using the ORSAT or the gas absorbers, the inspector should confirm that the sum of the values makes sense and that the probe or bag is not leaking.

The gas sample should always be taken at a location well within the duct to avoid ambient air infiltration. In some cases, multiple measurements across the duct may be necessary if the gas stream is stratified.

As with any probe used in the rapidly moving gas stream, it is important to use the grounding/bonding cable to prevent static accumulation. Both the ORSAT and the gas absorption instruments use highly corrosive liquids and care in handling is necessary. If some is spilled it is important to wash it off the skin prompty and keep the liquid away from the eyes.

SLIDE 4-48

TECHNIQUES FOR THE MEASUREMENT OF SCRUBBER LIQUOR pH

1. Indicator Paper
2. pH Meter (Battery Powered)

pH instruments are used in wet scrubber systems to control the addition rate of alkaline materials. They enhance the absorption of some gases, ensure that oxidizing chemicals are in the active chemical form, and reduce the chances of corrosion.

The only way to check the on-site pH meter accuracy is to obtain a liquor sample FROM THE SAME LOCATION AS THE METER PROBE and repeat the measurement with another meter. On level 2 inspections this is not possible since a meter is not brought to the plant. It would be possible to take a sample back to the agency lab. However, there is always a question about the stability of the pH as the sample ages.

On level 3 inspections, it is possible to use either indicator paper or a battery powered pH meter. The measurement should be made soon after the sample has been obtained.

SLIDE 4-49

LIMITATIONS OF pH PAPER

1. Highly Colored Solutions
2. Oxidizing Solutions
3. High Suspended Solids Levels

The inherent limitations of pH indicator paper are listed here. These are most common when inspecting odor control scrubbers using hypochlorite solutions or permanganate solutions.

As long as the listed conditions are not present, the pH paper has an accuracy in the range of plus or minus one full pH unit. This may not seem to be very accurate, but highly accurate pH data is not needed in all inspections.

In many situations, it is only necessary to know that the pH is not much below 6 or much above 11. The pH paper provides sufficient accuracy to support this conclusion. Therefore, it is acceptable for a large portion of the particulate wet scrubbers.

SLIDE 4-50

CALIBRATION TECHNIQUE FOR pH MEASUREMENT

Use Fresh Buffer Solutions to Calibrate Battery Powered pH Meter or to Check Indicator Paper.

Prior to any pH measurement, the meter should be checked against buffer solutions of approximately 4, 7 and 10 pH units. Reasonably fresh buffers should be used since they have a tendency to age.

Although it is not usually done, it is also a good practice to check the indicator paper against a least one of the buffers within the measurement range of the paper. If the paper has aged, it will not indicate properly.

Lecturer's Notes

If there are any questions concerning how to use a pH meter, it should be demonstrated using the coffee, soft drink and limestone slurry solutions. The latter is used to illustrate how the pH can change over time as alkaline material slowly dissolves. Most of the attendees are experienced with these instruments. Therefore, these demonstrations can often be skipped

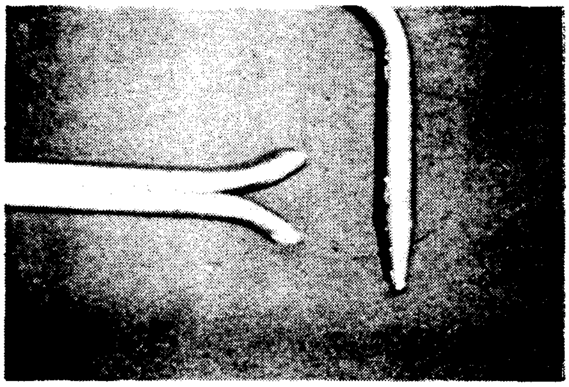
SLIDE 4-51

PITOT TRAVERSES TO MEASURE GAS FLOW RATE

The pitot traverse is conducted when there is a need to determine the gas flow rate. These is done (1) to evaluate the amount of gas pulled from process hoods and equipment, (2) to evaluate increases in static pressure drop across scrubbers, and (3) to quantify air infiltration into scrubbers.

This is a time consuming measurement that is not done routinely by plant personnel or agency inspectors. For these reasons, this is not part of a normal level 2 inspection. It is necessary in only a fraction of the level 3 inspections.

SLIDE 4-52



There are two types of pitot tubes: the standard pitot and the S-type pitot. The standard pitot is two concentric tubes shaped like an "L". The center tube is open to the gas flow and measures the total pressure of the gas stream (velocity pressure plus the static pressure). The outer tube has a number of small holes around the circumference. When the standard pitot tube is in the proper orientation, these small holes are pointed normal to the gas flow direction. They measure only the static pressure. When both pitot tubes are connected across the differential pressure gauge, the velocity pressure is read directly.

The S-type pitot tube is shown on the left center of the photograph. It consists of two parallel tubes bent in opposite directions. The one facing the gas stream measures the total pressure and the one pointed away from the gas stream measures the static pressure. The velocity pressure is measured as the difference between these two pressures.

The S-type pitot tube is preferred for equipment inspection since it is less prone to pluggage when used in areas with high particulate mass levels or with entrained water droplets. The main disadvantage of the S-type is that it must be calibrated.

Lecturer's Notes

Both types of pitot tubes should be on display during breaks during the lecture. It is also helpful to have an inclined manometer or a low range diaphragm gauge available to illustrate how the velocity pressure is measured. It is not wise to pass the large 6 foot long pitot tubes around the room during the lecture for obvious reasons.

SLIDE 4-53

VELOCITY PRESSURE GAUGES

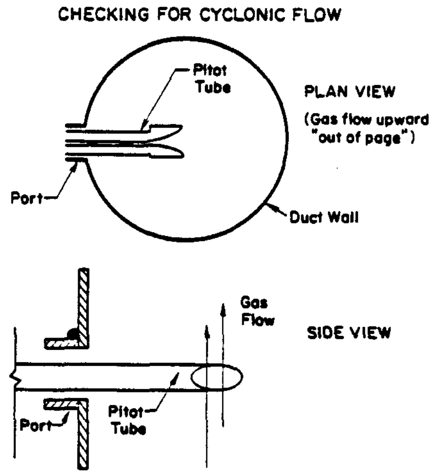
O-10" Inclined Manometer

O-2" Differential Pressure Gauge

The two instruments available for the measurement of velocity pressure are listed in this slide The type used in stack tests is the inclined manometer (either 0 to 5 inch or 0 to 10 inch units are available). It provides high accuracy in the 0 to 1 inch velocity pressure range which is the most commonly encountered range. It is somewhat bulky to carry around and difficult to level.

As an alternative to the inclined manometer, the low range diaphragm gauge can be used. This one has a "D" ring taped to the top so it can be hung from a magnet. It is slightly less accurate but easier to use.

SLIDE 4-54



A check for cyclonic flow should be made before beginning the pitot traverse or any of the preliminary work in determining the number of traverse points required. Cyclonic flow is very common down stream of wet scrubber demisters and certain fans.

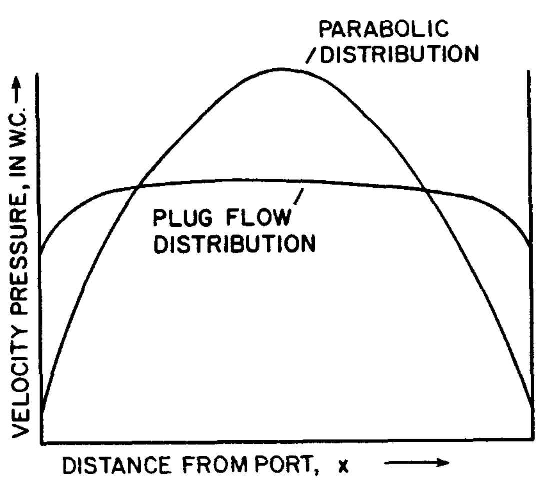
As shown in the adjacent slide, the pitot tube is inserted with the nozzles oriented perpendicular to the direction of gas flow. Since both nozzles should be sensing the static pressure, the differential pressure indicated on the gauge should be zero.

The pitot tube should be rotated 10 to 20° in both directions in an attempt to "null" the readings. If measurable velocity pressures persist even with this slight twist, then the flow has too much cyclonic character to conduct a pitot travers.

Lecturer's Notes

It is important that this check be done first. There is no sense making all the traverse point calculations and marking the probe if the location is not acceptable due to cyclonic flow. Inspectors should not ignore this test even though cyclonic flow appears unlikely. The angular momentum of cyclonic flow can persist for long distances. Therefore, the origin of the gas spin may not be so obvious.

SLIDE 4-55

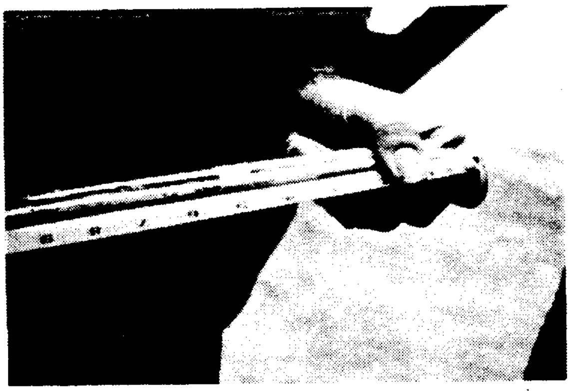


Conducting a pitot traver in accordance with EPA Reference Method 2 can be very time consuming. In some cases, the inspector may be able to make a single point velocity pressure measurement rather than a full traverse. This is appropriate when only an approximate estimate of flow rate is sufficient.

A quick check of the velocity pressures across the duct should be made to determine if a single point traverse is possible. If the distributions are similar to either of those shown on this slide, a single point measurement is possible.

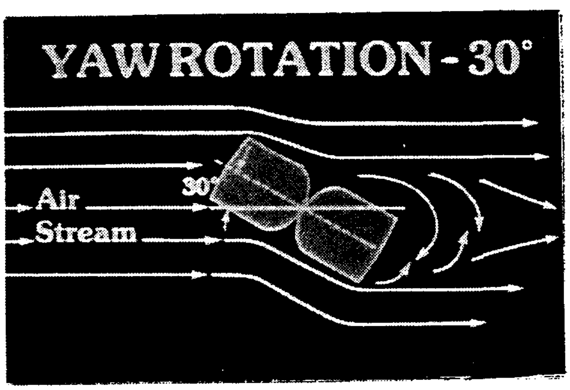
In the case of the parabolic distribution, the velocity pressure should be measured at the peak of the curve. The average velocity is related to the peak velocity multiplied by 0.81. In the case of the plug flow distribution, the average velocity is equal to the measured value near the center.

SLIDE 4-56



If a complete traverse is necessary, the procedures stated in EPA Method 2 should be followed. The distances to the upstream and downstream flow disturbances are measured and the number of traverse points are determined from the Method 2 figure. The next step is to measure the diameter of the stack or duct. The diameter can be measured by placing the pitot tube across the duct. However, this risks damage to the sensor tips of the pitot. It is also possible to jam solids into the pitot tube if the opposite wall has thick deposits. A better approach for measuring the diameter is to measure the circumference and divide by 3.14 (assuming it is cylindrical).

SLIDE 4-57



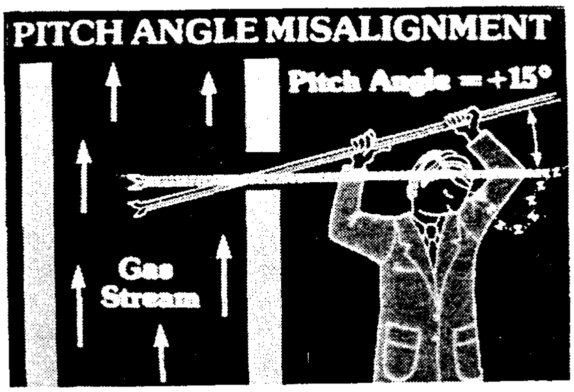
Source: Air Pollution Training Institute

One of the most common errors made during a pitot traverse is the rotation of the tube away from the direction of the flow. When this occurs in the manner shown in this slide, it is termed the "Yaw" error.

With slight rotation, there tends to be higher than actual velocity pressures measured. Additional rotation results in readings far below the actual values.

This type of error is generally due to lack of concentration on the part of the inspector. It is important to keep the two parallel tubes which comprise a S-type pitot tube constantly lined up in the direction of gas flow.

SLIDE 4-58



Source: Air Pollution Training Institute

The second form of alignment error is the "Pitch" angle. As the pitot tube moves at an angle to the gas flow direction, the value of the observed velocity pressure drops rapidly.

This error is particularily difficult to prevent on large ducts when the pitot tube may be extended as much as 6 feet into the gas stream. The inspector is then holding only a small portion of the pitot and has very little leverage. Compounding the problem is the tendency for the pitot tube to "sail" in high velocity gas streams.

Every attempt should be made to minimize this error by watching the angle of the pitot tube relative to the duct or stack. The measurements should be repeated several times if there is any question concerning the quality of the data.

As with any probe in a moving gas stream, a grounding/bonding cable should be attached to the pitot tube prior to conducting the measurement. It is also important to seal the port to prevent air infitration related errors on points close to the port and to prevent exposure to toxic particulate and gases coming out of the duct.

Lecturer's Notes

Several of the port designs shown later in this lecture have been specifically designed to minimize yaw and pitch error while conducting pitot traverses. These designs also seal the port so there is less chance of exposure to toxic gases and particulate during the measurement.

SLIDE 4-59

SUMMARY
GAS FLOW MEASUREMENTS

In summary, an S-type pitot tube is normally used for gas flow measurements since it is less prone to pluggage than the standard pitot tube. Before conducting the full traverse, it is necessary to check for cyclonic flow. A pitot traverse should not be done in any location where cyclonic flow is significant. The velocity pressure distribution should also be checked before beginning the calculations for the traverse. If it is parabolic or very uniform, a single point traverse may be possible.

Whenever conducting a pitot traverse the grounding/bonding cable should be attached. The port should be sealed to prevent exposure to toxic pollutants and to prevent measurement errors.

SLIDE 4-60

FACTORS AFFECTING GAS FLOW

Rotational Speed

System Resistance

Dampers

The gas flow rate through a wet scrubber system is partially controlled by the fan rotational speed and the fan damper settings. The fan operation should be checked whenever gas flow changes have been shown by pitot traverses or are suspected based on the scrubber operating conditions.

One of the best indicators of fan operating conditions is the fan motor current. AN INCREASE IN THE CURRENT MEANS AN INCREASE IN THE TOTAL MASS OF GAS MOVED BY THE FAN. By adjusting for changes in gas density, it is possible to QUALITATIVELY evaluate changes in the gas flow rate.

There is no practical means to check the accuracy of on-site fan current meters using inspector supplied portable instruments. Inspectors should request that the plant representative arrange for the current to be measured using an inductance ammeter if there is any question concerning the indicated value. This can also be done if the fan motor current is not monitored. Under no circumstances should the inspector attempt to make this measurement! Only a qualified electrician should open electrical cabinets and make current measurements.

SLIDE 4-61

MEASUREMENT OF FAN SPEED

1. Manual Tachometer
2. Phototachometer
3. Strobetachometer
4. Sheeve Ratio Calculation

The gas flow through an air pollution control system is proportional to the fan rotational speed. In a sense, the fan works like a shovel and the faster it moves, the more gas is moved.

On direct drive fans, the speed can be changed only by changing the motor. The speed can be read directly from the nameplate of the motor. On belt driven fans, the most common type on wet scrubber systems, it is easy to modify the fan speed simply be changing the sheaves.

There are rarely monitors for the fan speed. Whenever the fan speed data is needed, it is measured by plant personnel using one of the instruments listed above. The same instruments can be used by agency inspectors. The manual tachometer is inexpensive and easy to use. There must be good access to the end of the fan shaft, but this is often blocked by belt guards. Phototachometers and strobotachometers do not require direct access to the rotating equipment. However, these are more expensive and difficult to use. In the case of the phototachometer, a piece of reflective tape must be placed on the fan shaft (when the unit is down) to serve as a light reflector.

SLIDE 4-62

One way to estimate the fan speed is to measure the fan sheaves. The fan speed is the ratio of the fan sheaves times the fan motor rotational speed. The latter can read directly from the nameplate of the motor.

This photograph illustrates the measurement of the sheave on the fan. In this case, it is easy to see the sheave and to make a reasonable measurement of the diamter. Some fans come with a sheet metal belt cover rather than the expanded metal cover shown here. With the sheet metal covers, it is impossible to estimate the sheave diameter and this approach is not possible. 'THE BELT COVER SHOULD NEVER BE REMOVED. ALSO, THE FAN SHOULD NOT BE OPERATING WHEN THE SHEAVE DIAMETER IS BEING MEASURED.

Fan RPM = (MRPM)[MD/FD]

Where:
MRPM = Motor Speed
MD = Motor Sheave Diameter
FD = Fan Sheave Diameter

It could be argued that this is not an accurate enough measurement. However, it clearly indicates when an intentional change in fan speed has been made. This fact is more important than the actual fan rotational speed value at the present time.

SLIDE 4-63

OBSERVATION OF FAN OPERATING CONDITIONS

1. Severe Vibration
2. Belt Squeal

The presence of fan vibration and/or belt squeal should be noted.Severe fan vibration can occur due to build-up of material on the fan wheel or due to erosion of the fan wheel. Bearing wear is another common cause of this conditions. IF THERE IS SEVERE VIBRATION, THE INSPECTOR SHOULD LEAVE THE AREA IMMEDIATELY! THE FAN CAN DISINTEGRATE SUDDENLY! It can occur during start-up and during sudden changes in routine operation.

Belt squeal is due to the slippage of the drive belts in the fan and/or motor sheaves. This results in a modest fan rotational speed reduction, often in the range of 100 to 200 rpm. It is hard not to notice the highly irritating belt squeal.

SLIDE 4-64

FAN EVALUATION LIMITS

1. Damper Settings
2. Gas Flow Rates

There are two things that can not be determined by evaluating fan operating parameters or by checking fan conditions. These practical limits to fan evaluation are listed in this slide.

It is usually impossible for an agency inspector to check the damper position from the position of damper activators outside the duct. A change in the gas flow rate can be made by changing the damper position without any change in the rotational speed. The only indication of this is a change in the motor current and the latter is affected by a number of conditions, not just damper position.

It is also extremely difficult to estimate the gas flow rate through the fan based on fan operating parameters such as static pressure rise, motor current, rotational speed and gas temperature. The fan performance curves are expressed in terms of the brake horsepower which is related to the motor current. Unfortunately the brake horsepower is also affected by the motor load factor for common three phase motors as indicated in the equation below.

$$B.H.P. = \sqrt{3} \times V \times A \times L$$

Where: B.H.P. = Brake Horsepower, Watts
A = Motor Current, Amps A.C.
V = Motor Voltage, Volts A.C.
L = Motor Load Factor, dimensionless

The load factor is the difference in the phase angles of the voltages and currents in the alternating current line. This is not a constant value at a given site over time. For example, this will vary significantly as the over load of the motor is varied. Also, other electrical equipment at the plant can influence the load factor for the motor serving the wet scrubber fan. The only way to measure this value is to place wattmeters on two of the three lines of the three phase motor. This degree of effort goes beyond that reasonable for field inspectors especially considering that the pitot traverse is both easier and more accurate.

SLIDE 4-65

SUMMARY
FAN EVALUATION

During level 2 inspections the fan motor current should be noted from the on-site meters. If there is any question about the data, the inspector should request that plant personnel remeasure the motor currents using an inductance meter. In some cases, the fan speed can be estimated by using the sheave ratio method. The nameplate rpm ratings of the fan motors should be noted in every case. During level 3 inspections, the fan speed should be measured when gas flow changes are suspected.

SLIDE 4-66

PUMP OPERATING PARAMETERS

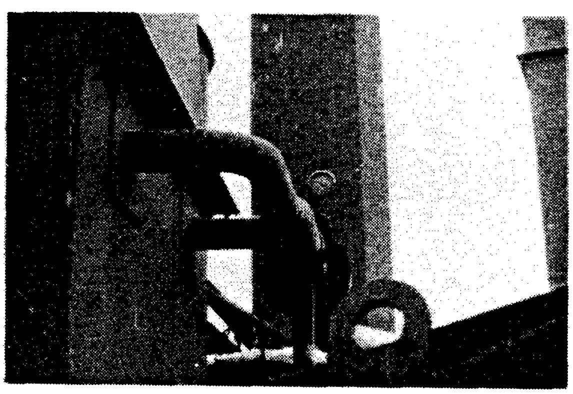
1. MOTOR CURRENT
2. DISCHARGE PRESSURE

The data concerning pump performance is similar to that for analyzing fan operation. The pump motor current is proportional to the quantity of liquid delivered. If this is not measured continuosly, it can be measured during the inspection by plant personnel using an inductance ammeter. Like the fan gas flow rates, it is not possible to quantify the liquid flow rate using the motor currents.

The second operating parameter of interest is the pump discharge pressure. This is normally monitored by a gauge mounted immediately downstream of the main control valve on the discharge line.

It should be obvious that there are no "portable" gauges which can be used to measure the pressure in a pipe. If there is no gauge or not a fitting which would accept a gauge, it is impossible to determine the pressure. When there is some question concerning an existing gauge, it is sometimes possible to temporarily substitute a new unit for the present gauge. There must be a valve isolating the gauge if this is done while the pump is operating. It is conceivable that a regulatory agency inspector could bring a gauge for this purpose. However, a pipe fitter would be needed to connect the gauge to the specific valve fittings.

SLIDE 4-67



The most common type of liquid pressure gauge is a bourdon tube. This has a metallic element which bends slighlty when exposed to pressure. The movement of the bourdon tube in response to the pressure is transmitted mechanically to the indicator needle.

Pressure gauges of this type are vulnerable to pluggage within the tube itself and in the gauge inlet. The indicated value on the gauge is no longer valid when it is plugged. As with all pressure gauges, there is no flow through the gauge to purge it of accumulated solids. To minimize the problem, the gauges should be mounted above the pipe to facilitate drainage.

Excessive vibration can also lead to the early demise of bourdon gauge. Constant vibration, especially on the pump discharge, leads to the eventual failure of the mechanical linkage between the bourdon tube and the indicator needle. Vibration can be minimized by mounting the pressure gauge on a short coil of pipe or tubing which dampens the vibration intensity.

SLIDE 4-68

TYPES OF LIQUID FLOW MONITORS

1. Rotameters
2. Orifice Plates
3. Paddle Wheel Gauges
4. Vane Type Gauges
5. Magnetic Flow Meters
6. Doppler Gauges

There are a number of instruments in use for measuring the liquid flow rates. All but one of these must be permanently installed on the pipe.

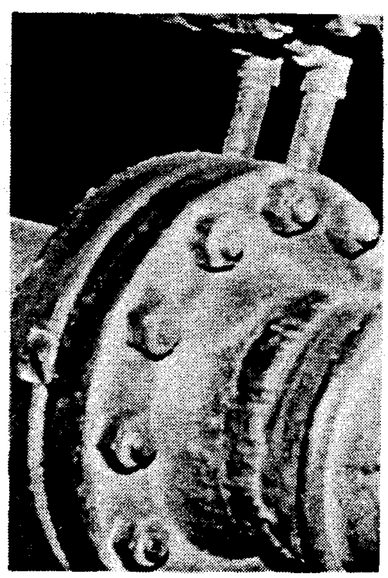
While the doppler instrument could be used as a portable inspection tool, its use has been limited due to its high cost. This means that there is no portable instrument available to check the accuracy of the on-site permanent instruments. This fact increases the importance of checking the meter operation to the extent possible.

All of the liquid flow meters can suffer performance problems when exposed to high suspended solids liquor streams and to corrosive liquids. The degree of vulnerability varies roughly with the cost and sophistication of the instrument.

Lecturer's Notes

The large majority of wet scrubber systems do not have flow meters. This is especially common on the medium to small systems. Due to the lack of portable instruments, there is no way to estimate liquid flow rate in such systems. This is particularily unfortunate since a number of scrubber problems include a reduction in liquid flow and the availability of this data would aid in the early detection of the problems. Some inspectors have attemped to overcome this deficiency of data by attempting to measure the flow from the scrubber sump using a bucket and stopwatch. This is not advisable since many of the scrubber effluent liquors have irritant characteristics and a few have pathogenic organisms.

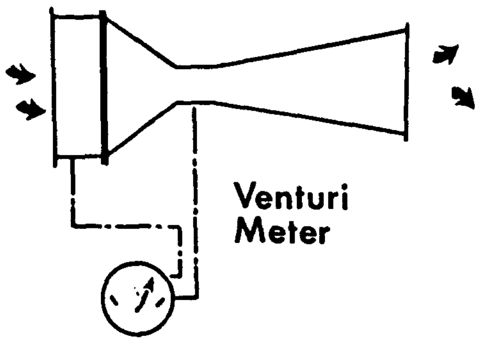
SLIDE 4-69



This is a photograph of an orifice meter on a sewage sludge incinerator scrubber. The orifice plate is in the middle of the flange. Taps before and after the flange are connected to a mercury filled manometer to measure the differential pressure across the plate. This pressure is proportional to the liquid flow rate through the orifice.

Gradual erosion and corrosion of the sharp edge orifice plate will cause the gauge to read less than the actual flow rate. Unfortunately, there is no easy way to confirm that the orifice plate has been damaged until the pipe can be isolated or the system shut down. These must be inspected frequently due to the susceptibility to wear.

SLIDE 4-70

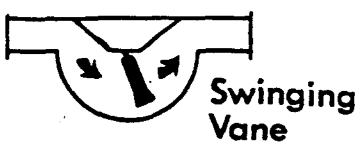


A venturi meter works in a similar manner to the orifice plate. Here, the liquid is accelerated as it enters the converging section and it decelerates as it leaves through the diverging section. Pressure lines before and after the venturi throat are connected to a mercury filled manometer. The liquor flow is proportional to the differential pressure. Unlike the orifice plate, this instrument does not have a component in the direct path of the abrasive liquid stream.

The main disadvantage of the venturi meter is the space requirement. It is also much more expensive than the orifice plate.

One of the few problems which can affect the accuracy of this type of flow monitor is pluggage of one or both of the manometer leads. It may be possible to see these deposits.

SLIDE 4-71



A sketch of a swinging vane liquid flow meter is shown in this slide. This instrument is mounted in line with the piping. The deflection of the vane is proportional to the liquid velocity. This deflection can be seen through the transparent portion of the unit.

Like most other styles of flow meters, these are vulnerable to error when used in high suspended solids streams. The accumulation of solids on the vane changes the weight and therefore affects the amount of vane movement at a given liquid velocity. The solids can accumulate to the point that the vane is unmoveable.

SLIDE 4-72

Magnetic Flowmeter

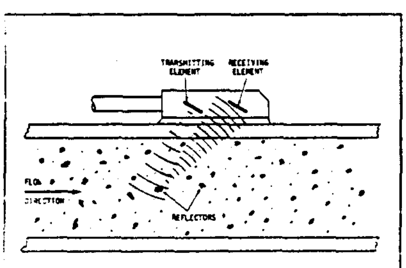
A magnetic flowmeter is less susceptible to measurements problems in liquid streams with high solids levels. It is considerably more expensive than other flow monitors discussed so far.

A magnetic field is established at right angles to the flow through the instrument. Since water is an electrical conducter, a current is induced as the water cuts the magnetic field lines. The inducted current is measured by electrodes on both sides of the instrument. This current is proportional to the liquid velocity. The flow rate is calculated as the cross sectional area of the pipe times the average velocity.

Since the sensor portion of the instrument is not in the direct path of the liquid, there is only minimal abrasion. The only components which are vulnerable are the two electrodes and the lining of the flow tube. The latter is normally lined with an abrasion resistant material such as polyurethane.

The instrument can be calibrated using actual liquid streams in a calibration rig. A simplier and more common technique is an electronic calibration of the instrument circuits. The latter is normally adquate for use with wet scrubber systems.

SLIDE 4-73



Source MAPCO Controls Co.

The doppler liquid flow monitors use ultrasonic noise to sense the velocity of solids and bubbles entrained in the liquid stream. These can be installed as permanent instruments or used as small portable gauges. The permanent instruments generally have a sensor that is exposed to the liquid stream while the portable units simply clamp to the outside of the pipes.

The transmitting element sends an ultrasonic sound wave diagonally into the liquid stream. The rapidly moving particles or bubbles reflect this wave back at a frequency slightly higher than the transmission signal. The difference in frequencies is proportional to the velocity of the liquid stream.

To use this portable instrument, it is necessary to carefully clamp the sensor to the pipe wall. An acoustic pad supports the sensor and special petroleum is used on the pipe wall. This is necessary to optimize the transmission of the sound waves in and out of the pipes. The "wetted" sensor used for permanent installations is more sensitive since there is no pipe wall to attenuate the signal and to cause "ringing" of the sound.

SLIDE 4-74

DOPPLER METER LIMITATIONS

1. Bubbles or Particulate Necessary
2. Velocities Must Be Greater Than One Foot Per Second
3. Pluggage of Element Port Possible

The major limitation of this approach is the need for an adequate concentration of bubbles and/or particles in the liquid stream. This technique will not work for clean liquids.

As with any sensor exposed to the liquid stream there is always the potential for pluggage over the sensor. This could act to reduce the sensitivity of the instrument. Corrosion of the ultrasonic elements is also possible in some cases.

This can not be used at all below liquid velocities of 1 foot per second and has limited sensitivity below 3 and 1/2 feet per second. Neither of these limits presents serious problems, however, since most liquid streams are in the range of 5 to 12 feet per second.

SLIDE 4-75

OTHER POTENTIALLY USEFUL INSTRUMENTS

1. Bubble Level
2. Fiberscope
3. Sling Psychrometer
4. Nephleometer
5. Reentrainment Probe
6. Explosion Proof Flashlight
7. Range Finder

Other instruments potentially useful for wet scrubber system inspection are listed here.

A small level is used to determine if the piping is sloped properly. The suction line should be sloped as least 1° to prevent the accumulation of air pockets. The recirculation lines should be sloped to faciliate draining and to faciliate solids flushing.

Fiberscopes have the potential to allow close-up inspection of nozzles mounted inside hard-to-reach scrubber internal areas. Commercially available models include a battery powered light source and a 6 foot long rigid probe which rotates. The probes are normally 1/4" diameter. Therefore, these would fit through common static pressure measurement ports.

The sling psychrometer is often useful for measuring the ambient relative humidity during visible emission observations. The wet bulb and dry bulb temperatures are measured simultaneously with this instrument and the relative humidity is determined by plotting the data on a psychometric chart.

Nephleometers have been suggested for use as portable opacity monitors for wet scrubber systems. These are not vulnerable to water droplet interference problems which to date have precluded use of transmissometers. They operate as extractive instruments. Therefore, only a small port is needed.

SLIDE 4-76

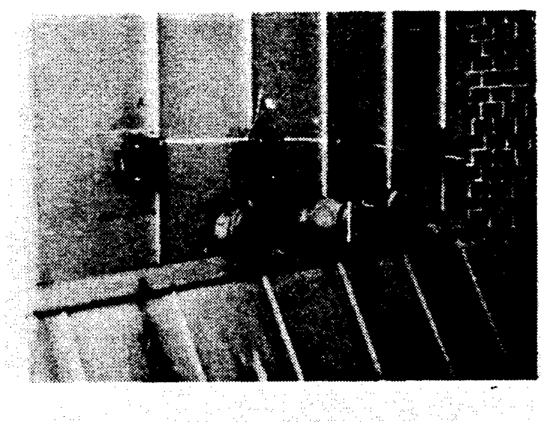
SELECTION OF MEASUREMENT PORTS

The next set of slides concerns measurement ports. It is important to select the appropriately sized and located ports in order to avoid the measurement problems discussed so far in this lecture.

Unfortunatly, a large number of existing wet scrubber systems have no ports at all or have ports in inaccessible locations. HEROIC EFFORTS SHOULD NOT BE MADE TO REACH IMPROPERLY LOCATED PORTS

Hopefully, in the next several years, regulatory agencies will encourage source operators to install the proper ports so that both the operators and the inspectors can adequately evaluate performance of wet scrubber systems. Some port designs are recommended in this section. Locations for measurement ports are discussed in the lecture concerning each specific type of scrubber vessel.

SLIDE 4-77

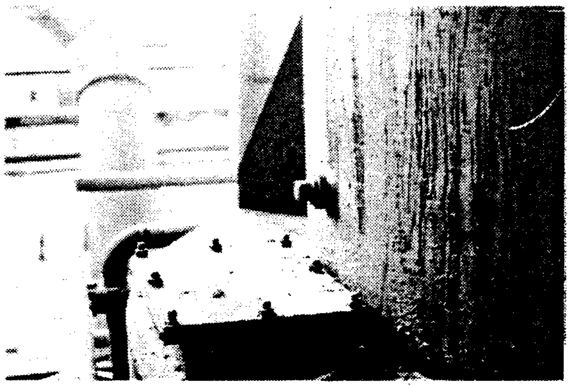


The only ports available on some units are the stack sampling ports downstream of the scrubber. These are usually four inches in diameter.

If the gas stream is slightly positive, the pollutant laden gas will flow out rapidly and accumulate in the breathing zone of the person making the measurement. If the port is under negative pressure, ambient air will rush through the port and cause errors. These ports are difficult to work with.

An additional problem with large ports is the removal of the pipe caps or plugs used to seal the ports when not in use. This can take several hours.

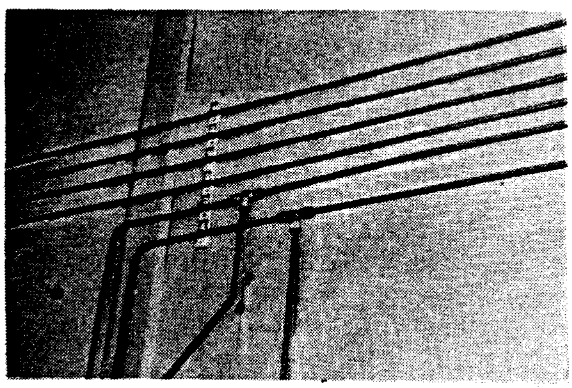
SLIDE 4-78



This photograph illustrates the ideal size for a measurement port on a wet scrubber vessel. It should be in the range of 1/4" diameter to 1" diameter. This minimizes the potential for fumigation in positive pressure systems and reduces the ambient air infiltration problems in negative pressure units. The small plug is also much easier to remove than large ports.

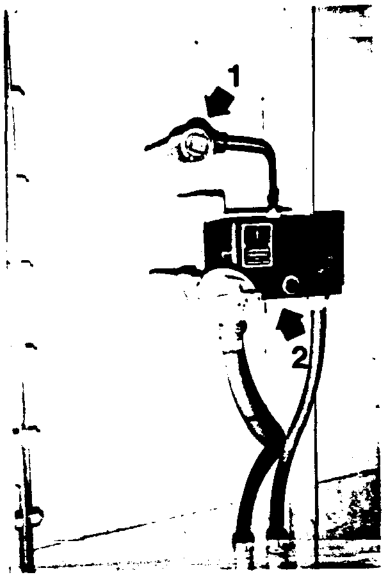
On gas handling ducts, a larger port is necessary to permit the use of an S-type pitot tube. It should be at least 1 and 1/2" in diameter but smaller than 2" diameter.

SLIDE 4-79



There must be convenient and safe access to the port itself. Running small diameter tubing down from an inaccessible ports is not sufficient. It is difficult to clean out a plugged port with this arrangement. It is impossible to measure the gas temperature even if a pump were used to pull a gas sample. The temperature would drop close to ambient levels while passing down the tubing. Even the measurement of gas stream oxygen and carbon dioxide concentrations is difficult under these circumstances.

SLIDE 4-80



This is a photograph of a clean out port (marked as arrow #1) with a differential pressure transducer (marked as arrow #2). The purpose of this port is to permit removal of accumulated solids from the port while the D/P transducer is off-line. OPENING THIS PORT WHILE THE INSTRUMENT IS OPERATING WILL RESULT IN AN ERRONEOUS SIGNAL BEING SENT TO THE PLANT PROCESS CONTROL SYSTEM. THE PROCESS WILL BE TRIPPED OFF-LINE. Do not open these clean out ports!

A small inspection port installed at least several feet from the instrument port could be opened without causing this problem.

Lecturer's Notes

This is a good time in the lecture to make the point that specific ports are needed to faciliate wet scrubber inspection. Ports installed for stack sampling or for routine system monitors are rarely the correct size or at the correct location. Specific ports should be installed to faciliate the use of portable inspection instruments!

SLIDE 4-81

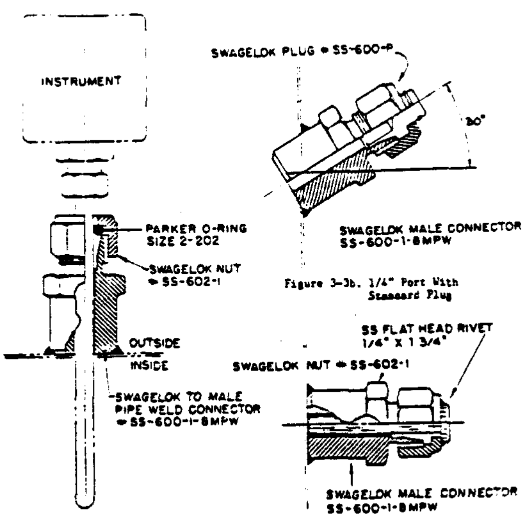


Figure 3-3a. 1/4" Port With Seal Nut Clamp

Figure 3-3b. 1/4" Port With Standard Plug

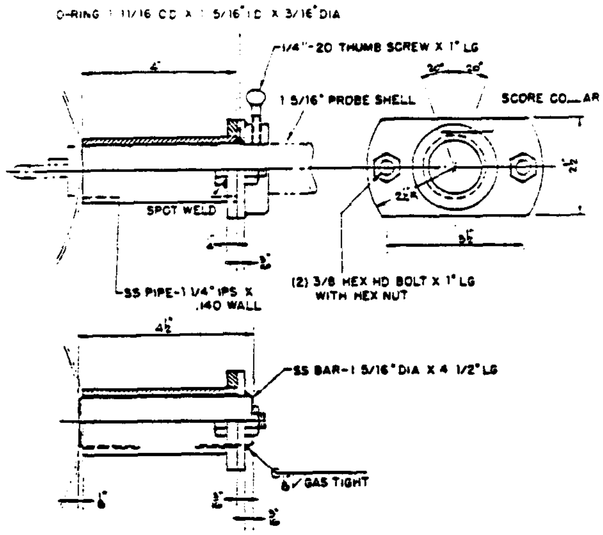
Figure 3-3c. 1/4" Port With Stem Type Cap

A sketch of a 1/4" inspection port is shown in this slide. This port is made from a standard Swagelock fitting which is welded to the side of the duct or wet scrubber wall. An O-ring seal prevents any gas leakage outward or ambient air infiltration.

For areas where accumulation of solids or sludge is likely, the port can be inclined 30° to permit drainage.

The port is sealed with a cap with a small rod attached. This fills the port recess when not in use. A simple cap plug could be used in situations where rodding out the port is not difficult.

SLIDE 4-82



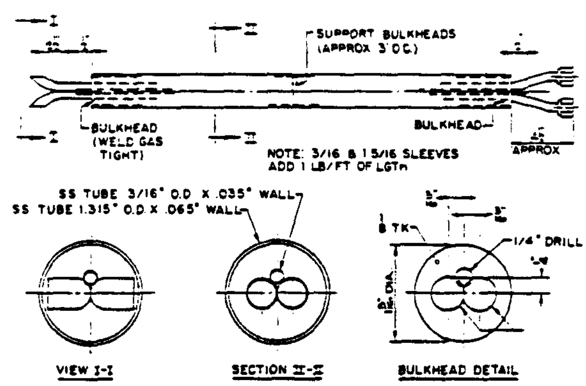
PITOT TUBE PORT WITH PLUG

A port useful for ductwork ahead of and following the wet scrubber vessel is shown here. This consists of a 1 and 5/16 inch diameter pipe welded to a flange. There is also a gas tight weld to the side of the duct.

This port serves as a support and alignment mechanism for a pitot tube. An outer flange allows rotation 10 to 20° in either direction to correct for minor cyclonic flow. An O-ring on the shoulder of the inner flange fits around the pitot tube to provide a gas tight seal. This again protects the inspector during the measurements and also prevents air infiltration on negative systems.

It should be noted that the hole in the duct wall is only 1 and 1/4 inches which is considerably smaller than the 4 inch holes common to stack sampling ports. While opening the port to put the pitot tube in or to pull it out, the inspector is subject to fumigation in positive pressure ports. With the smaller ports, the flow is only appoximately 10% that of the large ports.

SLIDE 4-83



MODIFICATION OF 3/8" STANDARD S-TYPE PITOT TUBE

NOTE: 3/16" & 1 5/16" O.D. SLEEVES ADD LESS THAN 1#/FT OF PITOT TUBE LENGTH

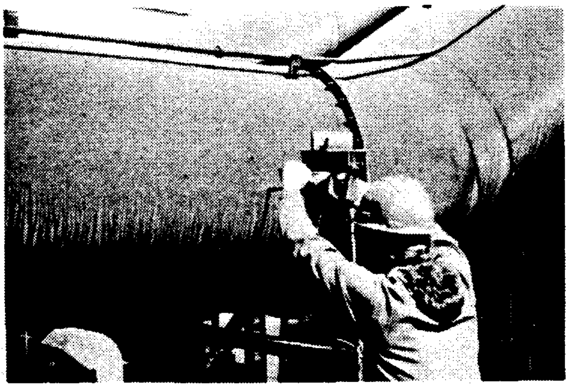
The pitot tube must have some minor modifications for use in the port described in the previous slide. These modifications are inexpensive and can be made to existing pitot tubes.

As shown here, the pitot tube has been encased in a 1" tube with gas tight seals at either end. There is also a bulkhead support at the middle of the tube. This converts the pitot tube into a round assembly which can be easily sealed with an O-ring.

The tube and seals add only about 4 to 5 pounds to the total weight of the pitot tube. This is a small price to pay for improved security against toxic gas and particulate fumigation. It also prevents yaw and pitch error.

Static grounding occurs inherently due to the direct contact between the pitot tube assembly and the port on the duct wall. Nevertheless, the grounding cable should be attached.

SLIDE 4-84



New inspection ports of the type shown above or any other type can only be installed when the system is off-line and the immediate area has been purged of explosive dusts or vapors.

INSPECTORS SHOULD NEVER REQUEST THAT THESE PORTS BE INSTALLED WHILE THE EQUIPMENT IS OPERATING OR BEFORE THE AREA HAS BEEN PROPERLY PREPARED.

Drilling or cutting could easily result in an explosion. In particulate control systems, a light layer of dust is common on the bottom of the ducts. Even a 1/16" layer can lead to a devastating explosion.

Many of the gaseous control systems can have pockets of explosive gases including but not limited to ammonia and carbon monoxide. The unit must be purged of these gases before hot work is begun.

SLIDE 4-85

SELECTION AND USE OF MEASUREMENT PORTS

1. Ports should be >½" and <2" diameter.
2. There should be safe access to the port to facilitate rod out prior to the measurement.
3. Never use ports connected to D/P transmitters.
4. Never have measurement ports installed while the system is running.

This slide summarizes some of the important points regarding the use of measurement ports in level 3 and level 4 inspections. Safety is the prime consideration. If significant climbing or inhalation risks are involved in making the measurement, it should not be attempted. All probes inserted into rapidly moving gas streams should be bonded to the duct using the grounding and bonding cable.

The port must be sealed well enough to prevent air infiltration related errors and to preclude loss of the probe into the duct.

When making measurements in ductwork, it is important to choose a representative location. Whenever possible, the measurements should be repeated at several locations as the probe traverses the gas stream. Single point measurements taken close to the wall should to be avoided to the extent possible.

In the slow moving gas streams found on the walls of scrubber vessels and demisters, the measurements must inherently be taken close to the wall surface. This is not a serious problem since there are lower temperature and static pressure gradiants across these areas.

Lecturer's Notes

The safety guidelines should be emphasized in the summary of this lecture. It should be noted that attendees should avoid the level 3 and 4 inspections until they are fully qualified. There is no need to rush into the use of portable instruments. However, once the use of these has been mastered and they are able to easily evaluate on-site instrumentation data, the speed and accuracy of their inspections will improve significantly.

LECTURE 4 REVIEW PROBLEMS AND QUESTIONS

4-1. Any or all of the first three (a,b,and c) could cause this increase in the measured oxygen concentration. Answer d is very improbable since there would not be enough dissolved oxygen in the liquor to cause this increase in gas stream oxygen levels. The point of this question is that the oxygen concentration of the effluent gas stream is influenced by both infiltration and absorption. Therefore, it is rarely measured.

4-2 Answers c and d are correct. The fan calculations are theoretically possible but prohibitively difficult due to the need to know the motor load factor. Also, the accuracy of the published fan curves for a specific unit can always be questioned. Answer b is for those who had a stack sampling course 6 years ago and forget that they talked about F Factors for estimating gas flow rates from combustion sources. Some may cry foul concerning tracer tests. These were not discussed. However, they are very effective for determining the gas flow rates in low velocity gas streams. As they should remember, a pitot tube is not effective below 600 feet per minute. You should point out that some new material is intentional being introduced in these sets of review problems and questions.

4-3. The gauge is certainly not in the best of shape and should be discarded if others are available. However, if this is the only one available, it is possible to struggle through by calibrating immediately before and after the inspection. As long as the two calibrations are similar, the curves can be used to correct the data. If there is a shift in the curves, the static pressure measurements are not good.

Attendees who are alert may question why the static pressure gauge should be used at all. The slack tube manometer must be available, otherwise how could this curve be generated? Good point! However, the slack tubes are miserable when some climbing is involved in reaching the various static pressure measurement ports.

4-4. Answers c and d are correct. The measurements should be taken. However, the calibration should be rechecked at the earliest opportunity. Those who have mastered the art of multiple choice questions should have been able to guess this just from problem 4-3.

LECTURE 4 REVIEW PROBLEMS AND QUESTIONS

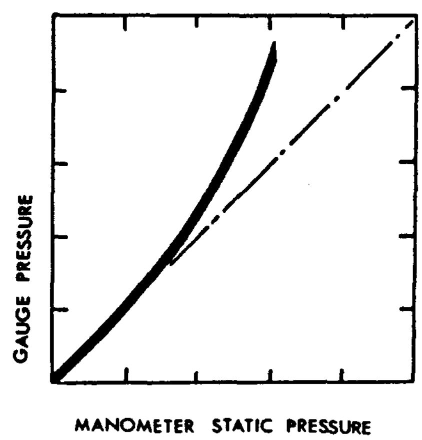
4-1. The oxygen concentration in the scrubber inlet is 8.5% and at the outlet is 10.8%. What are the possible explanations for this increase?

a. Severe air infiltration into the scrubber vessel
b. Absorption of some of the gas stream components
c. Measurement error
d. Stripping of oxygen from the liquor
e. None of the above

4-2. Gas flow rate can be accurately measured using which of the following techniques?

a. Fan calculations based on published fan curves
b. E factors
c. Pitot traverses
d. Tracer tests

4-3. During a routine calibration of a diaphragm valve the data plotted below is obtained. Is it possible to conduct an inspection using this gauge?



4-4. During an inspection, a diaphragm gauge is accidently dropped about ten feet to a hard surface. Upon reaching the unit it is noticed that the zero is no longer correct. However, it can be reset using the set screw on the front of the gauge. What should be done now?

a. The guage should be discarded.
b. The gauge should be used in the reminder of the inspection if no other operational gauge is available.
c. The gauge should be calibrated at the site, if possible. If this is not possible, it should be calibrated immediatly on return to the office.
d. The gauge is resistant to vibration and shock. Therefore it is not affected by this accident.

LECTURE 4 REVIEW PROBLEMS AND QUESTIONS

4-5. The static pressure drop across the scrubber vessel and the demister can not be determined from the data shown. It is necessary to know the static pressure in stream #3 and in stream #2 to calculate the static pressure drop.

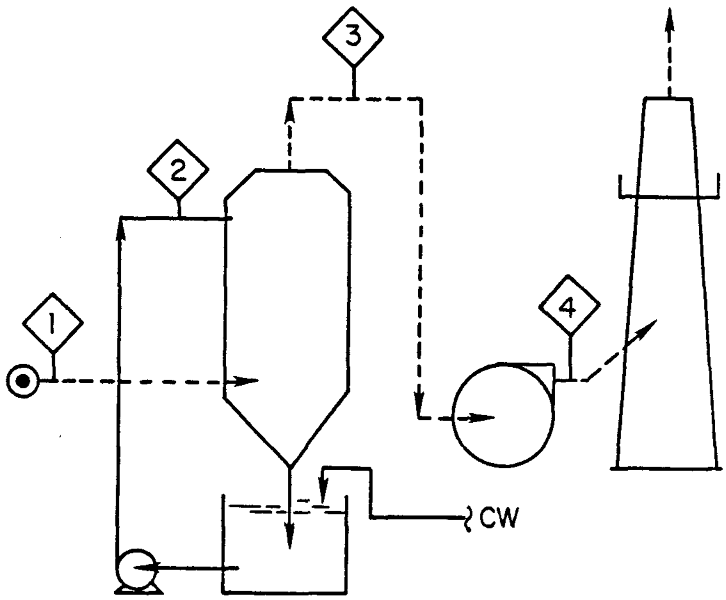
4-6. The most likely explanation is aspiration effect error during the measurement in stream #1. Another explanation would be an increase in the liquor flow rate which was not indicated properly by the liquid flow monitor.

4-7. No. Actually all of the data seems to be indicating a flow rate increase. Also, these instruments have a tendency to give a low reading if the suspended solids and/or low pH conditions have damaged the orifice plate. One way to check the liquor flow rate data is to determine if there has been an increase in the scrubber static pressure drop. Most, but not all, scrubbers have an increase in static pressure drop if the liquor flow rate increases while the gas flow rate remains constant. The latter is indirectly indicated by stable fan motor currents.

4-8. No. The data could be correct. This answer may catch those who try to answer to quickly. Without any information concerning the gas handling system preceeding the portion shown on the flowchart, there is no way to tell if there is also a fan ahead of the scrubber. It is not uncommon to find just such a "push-pull" arrangement with fans ahead of and following the scrubber vessel.

Opening a large port on stream #1 on the assumption that the port is at negative pressure could lead to fumigation of the inspector. The complete system flowchart should be reviewed and a check should be made of the actual gas handling system. All fans must be located so that a reasonable estimate of the static pressure drop at any location can be made before opening the port. This question again illustrates the value of system flowcharts during the inspection.

LECTURE 4 REVIEW PROBLEMS AND QUESTIONS



4-5. In the wet scrubber system above, what is the pressure drop across the scrubber vessel and demister if the static pressure in stream #1 is -16 inches and the static pressure in line #4 is -1/2 inch?

4-6. During an inspection of the scrubber system above, the static pressure in stream #1 is measured at -34 inches and the static pressure in stream #3 is measured at -5 inches. The fan motor current is close to typical values and the liquid flow rate monitor on stream 2 indicates close to baseline flow rates. What is one logical explanation for the increase in static pressure drop from baseline levels of 24 inches to the present 29 inches?

4-7. There is an orifice plate liquor flow meter in stream 2, downstream from the recirculation pump. The liquor has a suspended solids concentration of approximately 5% (by weight) and the pH is 5.1. The pump discharge pressure is lower but the motor current is slightly higher. The nozzle pressure has increased slightly. The liquid flow meter is indicating 15% higher liquid flows than normal. Can this liquid flow rate data be dismissed as being obviously in error? What can be done to check it further?

4-8. A static pressure measurement made at in stream #1 indicated a value of +4 inches W.C. Can this be dismissed as being obviously in error?

4-9. The correct answers are a and c. The entrained water droplets cause the meter to flucuate between the wet bulb and dry bulb temperatures. A short in the thermocouple probe would cause a similar problem. However, the flucuations would be even more intense and rapid. Answer b is very improbable. There may be a rapid step change in the gas temperature but there is rarely a series of rapid flucuations. The scrubber would tend to dampen any such flucuations thereby making these even less plausible. The inner surface of the duct wall would be slighly cooler than the gas stream but occassional touching of this wall with the probe would not cause rapid flucuations.

4-10. Only the battery powered pH meter should be used. The hypochlorite solution would attack the dye in the pH indicator paper.

4-11. Only answer e is correct. Answer d may make sense. However, it is hard to find a rubber stopper that large. Answer f has some elements of truth. However, sometimes it is necessary to use less than optimum ports. Answer f would be correct only if there were significant safety problems with the port also.

4-12. Nothing can be done except to go back to get it before starting any measurements. A grounding/bonding cable is necessary whenever a probe is used in any duct where static accumulation is conceivable. Inlet gas streams of scrubbers could have static accumulation.

4-13. Answer b is correct, the oxygen concentration remains 20.9%. Anyone answering c has a nasty habit of guessing and is very weak in geography.

4-14. Of the answers listed, only b makes sense. Answers a and c are done at the risk of a serious explosion.

LECTURE 4 REVIEW PROBLEMS AND QUESTIONS

4-9. An erratic reading is noted while making a temperature measurement downstream from a scrubber. Why?

a. The gas stream is not saturated and there are entrained droplets.
b. There are very rapid flucuations in the inlet gas temperature to the scrubber.
c. The probe is damaged.
d. The probe is occassionally touching the inner wall of the duct.

4-10. There is some apparent corrosion in a recirculation tank in a odor scrubber. The suspended solids level is less than 3% and the liquor temperature is 105 °F. The liquor being used is a hypochlorite solution. What should be done to evaluate the liquor pH.

a. Measure the pH using a battery powered pH meter.
b. Measure the pH using pH indicator paper.
c. Either a or b

4-11. A 4 inch diameter stack sampling port is to used to measure the gas stream temperature and static pressure. The static pressure is believed to be between -2 inches and -5 inches W.C. What can be used to seal the port at these static pressure levels?

a. Nothing is necessary at these low static pressures.
b. A hand
c. A glove
d. A rubber stopper having a diameter greater than 4 inches
e. A sanding disk having a diameter greater than 5 inches with a rubber stopper behind the sanding disk
f. A port this large should never be used under any circumstances.

4-12. During an inspection it is necessary to conduct a pitot traverse ahead of the scrubber to confirm a severe inleakage problem with the scrubber vessel. What can be done if you forgot to bring the grounding/bonding cable?

4-13. When calibrating the gas absorber type oxygen instrument, what oxygen value should the unit indicate when using ambient air?

a. 21.9% in the winter, 20.9% in the summer.
b. 20.9% in the summer, 20.9% in the winter
c. 19.9% north of the 20° longitude, 19.7% south of 20° longitude
d. 21.9% everywhere, all the time

4-14. A wet scrubber is strongly suspected to be out of compliance due to a large residual plume from the stack. There are no instruments on the unit and no measurement taps safely available. What should be done?

a. Demand ports be installed immediately so the inspection can be done.
b. Recommend to agency supervisors that the operators be requested to perform a stack test as soon as possible.
c. Offer to drill a 1/4" hole to facilitate the present inspection and request permanent ports for future inspections.

LECTURE 5

INSPECTION OF WET SCRUBBER SYSTEM COMPONENTS

SLIDE 5-1

INSPECTION OF WET SCRUBBER SYSTEMS COMPONENTS

1. Demisters
2. Pumps
3. Piping
4. Nozzles
5. Fans and Ventilation Systems

This lecture addresses some of the components used in most wet scrubbers. Evaluation of these compontents is a necessary part of most level 2 and level 3 inspections.

Demisters remove large droplets formed during the passage of the gas stream through the wet scrubber vessel. The removal of the droplets is necessary to protect the downstream fans. Failure of the demisters can also result in localized nuisance problems due to droplet rainout.

Pumps and fan problems can have a severe impact on the overall performance of the scrubber. The purpose of the inspection is to qualitatively estimate changes in liquid and gas stream flow rates.

Proper liquid-gas distribution can be achieved only when the proper nozzles are selected and when they are operating properly. Unfortunately, they are very susceptible to pluggage and erosion problems when there are high suspended solids in the recirculation liquor.

System piping is inspected to evaluate the potential for pluggage of lines and freezing of lines in the vicinity of the scrubber vessel. Problems with the pumps can also occur due to improper piping.

SLIDE 5-2

DEMISTERS

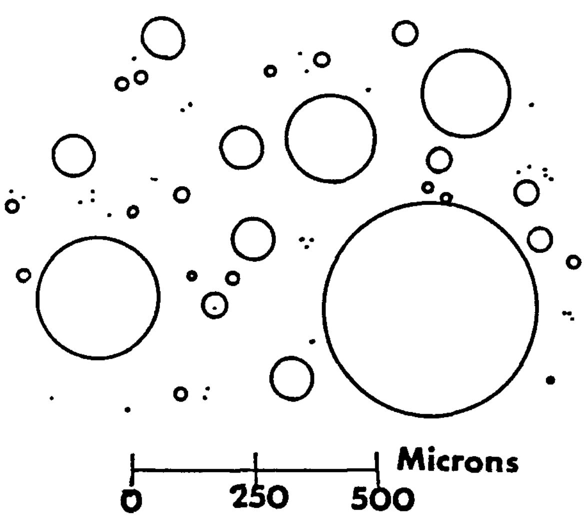
1. Prevent Stack Rainout
2. Protect Downstream Equipment
   a. Fans
   b. In-Line Reheaters
   c. Stack Liners
   d. Ductwork

One of the main functions of demisters is to prevent the rainout of liquor droplets from the scrubber system plume. At the very least, the deposited droplets are a nuisance to the general community near the plant boundry line. In some cases, damage to automobile finishes and house paints can occur.

An equally important function of demisters is to protect the downstream scrubber components listed in this slide. The gradual accumulation of solids on fan blades can result in corrosion or fan balance problems. The bypass stack for the system may have to be used while repairs to the fan are made.

The demisters are not part of the routine scrubber system inspection agenda. They are added only when the symptoms of demister problems are observed during initial phases of the inspection. Some of these include obvious rainout of droplets close to the stack, the presence of a mud "lip" at the stack discharge, the presence of a discolored area near the stack discharge, and/or moderate fan vibration. During level 2 inspections, the demister evaluation is limited to a review of demister cleaning system characteristics. Measurements can be performed in a level 3 inspection to isolate some of the common demister problems.

SLIDE 5-3

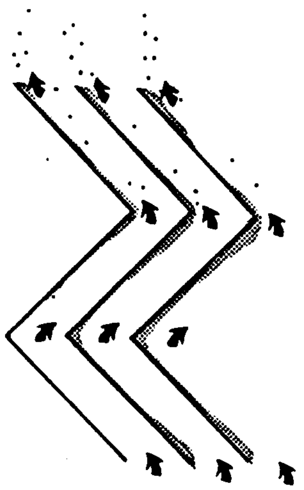


The droplets which must be removed from the gas stream by demisters are large in comparison to typical particles. It is common for these droplets to be in the 100 to 500 micron range. The largest of these has a mass which is more than 100,000 times that of a 1 micron duct particle. The projected areas shown in this slide illustrate the typical size distribution of entrained droplets.

Due to the large droplet sizes, all commercially available demisters use impaction to separate entrained droplets from the gas stream. The effectiveness of impaction is proportional to the gas stream velocity and to the square of of the droplet diameter.

Considering the large size of the droplets, they should be easy to collect. In fact, most demisters have very high removal efficiencies unless the gas velocities drop far below normal design ranges. The problems which are most common have nothing to do with initial capture of the droplets, but rather with what happens afterwards to the liquid on the demister.

SLIDE 5-4



Excessive gas velocities through the demister can lead to formation of droplets from the surfaces of the demisters. A common mechanism for droplet formation is shown on this slide.

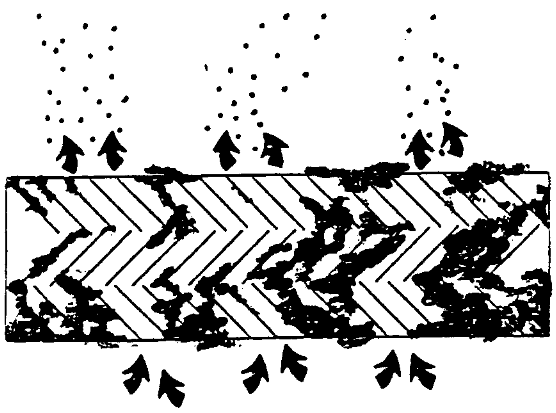
While gas velocity is the dominant factor, the configuration of the demister obviously plays a role in the tendency for reentrainment. Sharp edges on the downstream side of the demister favor droplet formation. The surface tension of the liquid is also important. As this decreases, the tendency for reentrainment increases.

Lecturer's Notes

This is one of the first times that the surface tension is mentioned as an important operating variable. It will be discussed later in the section concerning spray tower scrubbers and venturi scrubbers. It is also discussed with respect to nozzle performance. Unfortunately, there is rarely any data on surface tension.

If any of the attendees do not understand the meaning of surface tension, it should be discussed at this time.

SLIDE 5-5



High gas velocities can occur on demisters due to pluggage and scaling. Pluggage is the accumulation of suspended solids on the demister elements. Scaling is the precipitation of soluble materials out of solution onto the demister elements.

Regardless of the mechanism of solids accumulation, the area available for gas passage is drastically reduced. This leads to increased gas velocities through at least a portion of the demister. Reentrainment occurs in these areas due to the mechanisms presented in the previous slide.

In the previous slide, the reentrainment problem is due to the excessive design gas velocities for the demister. The solids accumulation related problems are due to inadequate demister cleaning, to excessive solids in the liquor droplets or to improper demister location.

SLIDE 5-6

DEMISTER TYPES

1. Cyclonic Demisters
   a. Standard Flow
   b. Reverse Flow
   c. Rotary Vane

2. Impaction Target Demisters
   a. Chevrons
   b. Baffles
   c. Mesh Pads
   d. Tube Banks

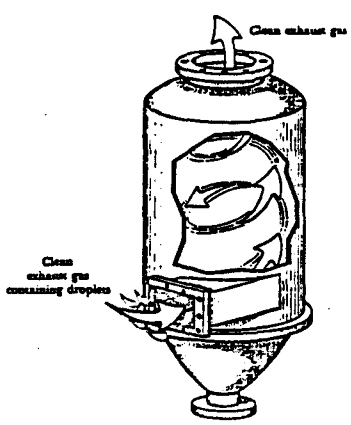
3. Dry Stages
   a. Trays
   b. Moving Beds

These are the most common types of demisters. They differ with regard to the tendency to plug and the velocities at which reentrainment becomes serious.

The standard flow and reverse flow cyclonic demisters are used primarily behind gas-atomized scrubbers, such as venturi scrubbers. All of the other styles primarily serve scrubbers having vertical cylindrical scrubber vessels. The latter includes tray towers, packed beds, moving beds and spray towers. Many of these can be installed in either a vertical or horizontal orientation. The latter has better liquid drainage and is less prone to reentrainment.

The dry stages can be used on moving bed and tray tower scrubbers which can achieve the necessary pollutant removal efficiencies without using all of the stages. The liquor inlet is moved to one of the lower stages and the top stage is operated dry. The droplets which are captured simply drain back down into the scrubber. This type of demister is rarely used on a new system. It has been used infrequently for some existing systems.

SLIDE 5-7



Source: Air Pollution Training Institute

This is a sketch of a standard cyclonic demister. Its most common application is downstream of a venturi or rod deck scrubber. Its effectiveness improves with increasing gas velocities due to the improved centrifugal forces on the droplets.

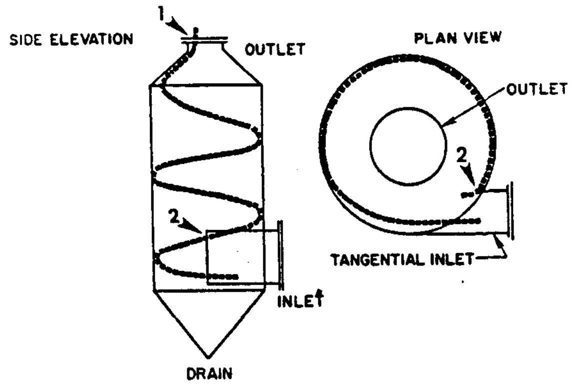
There is obviously nothing in this unit which can plug. Scaling can occur in the lower areas (the sump), but this does not lead directly to droplet re-entrainment.

There is very little to inspect on one of these units. They either work or they don't work. On level 3 inspections, it may be helpful to measure the outlet gas flow.

Lecturer's Notes

The measurement of gas flow is often complicated by the persistence of cyclonic flow in the stack. This is especially common on positive pressure units in which the cyclonic chamber outlet duct serves as the stack.

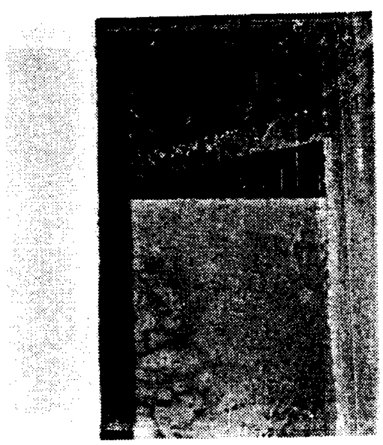
SLIDE 5-8



At high gas flow rates, the liquid which impacts on the inner wall of the cyclonic demister can spiral up the side and enter the stack area. This path is illustrated in this slide using a heavy dotted line. The point of reentrainment is the outlet of the demister (arrow #1).

Reentrainment can also occur as the spiraling liquid stream returns to the upper portion of the inlet gas duct. Here the liquid is sheared off the sharp edge by the high velocity gas stream. The location where most of the reentrain- occurs is shown by arrow #2.

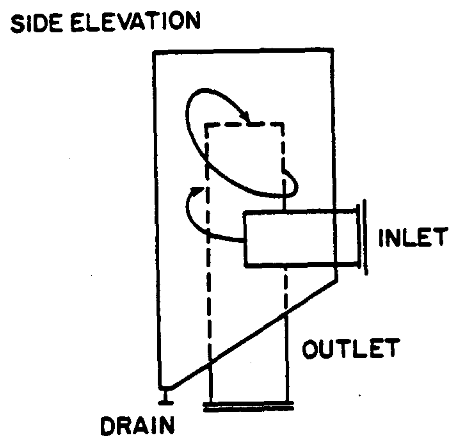
SLIDE 5-9



One simple procedure for eliminating reentrainment on the gas inlet duct (arrow #2, Slide 5-8) has been successfully demonstrated at a grey iron frtoundry. As shown in this slide, a small section of angle iron was been welded along the gas inlet duct. This serves as a scalper for the liquid spiraling around the demister. The liquid is directed down to the sump and away from the high velocity gas stream.

A similar approach may help reduce the spiraling stream passing up to the demister outlet duct. However, a long section of angle iron or similar material may also disrupt the vortex necessary for proper droplet capture.

SLIDE 5-10



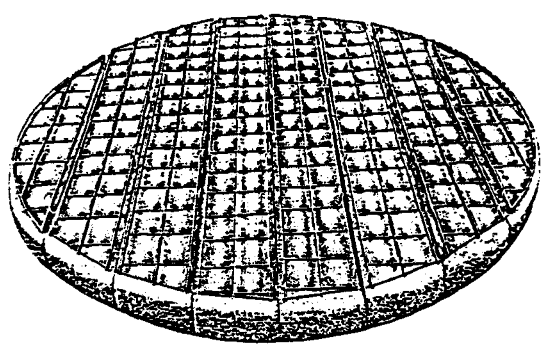
This is a reverse flow type cyclonic demister. The gas stream enters near the bottom and flows upward in the outer annular area. A 180° turn is made as the gas stream enters the downward point outlet duct. The bottom of the demister is sloped to facilitate drainage.

Removal of entrained droplets occurs due to both the cyclonic action and the sharp gas stream turn. These units are not prone to reentrainment. However, it is still possible to have some droplet formation at the lip of the inlet duct. With this style, it is especially important to keep the drain open so that the liquid level does not rise.

Lecturer's Notes

Inspectors who are not experienced with wet scrubbers may not be able to identify these initially during an inspection. There is a natural expectation to have the gas stream exit from the top of scrubbers and demisters and this leads to the confusion.

SLIDE 5-11



Source: Air Pollution Training Institute

This is a sketch of a mesh pad demister. Collection of droplets occurs due to impaction on the filaments of the mesh pad. These are oriented horizontally and the liquid simply drains back down into the scrubber.

To prevent flooding (excessive liquid hold-up), some units are inclined slightly to improve the drainage. Also, it is possible to install a standpipe and trap to drain the liquid above the pad.

It is important that the mesh pads be installed tightly against the wall. There should be no obvious voids which gas could pass through. All of the individual sections should be wired together and to the retainer supports. It should not be possible to manually move the mesh pad sections if they are installed properly.

SLIDE 5-12

$$U_{max} = K\sqrt{\frac{P_l - P_g}{P_g}}$$

Mesh pad pluggage and reentrainment are minimized by properly gas velocities. As a general guideline, the velocity should not exceed the value indicated by the equation in the slide.

The face velocity is simply the actual gas flow rate (ACFM) divided by the total open area of the demister. The latter is calculated by subtracting the area of supports, grids and retainers from the demister total area.

The empirical "K" factor for metallic meshes having densities of 5 to 9 pounds per cubic feet is 0.4, and for metallic meshes having densities of more than 9 but less than 12 pounds per cubic feet is 0.35. For mesh pads composed of Teflon, Polypropylene or Kynar use a "K" factor of 0.3. The equation yields velocity in feet per second.

Lecturer's Notes

For a rough approximation, the density of the liquor can be taken as 62.4 pound per cubic foot and the density of the gas can be taken as 0.06 pounds per cubic foot (-10 inches static pressure, 130 °F). This makes the square root term equal to 32.25.

SLIDE 5-13

CHRONIC PLUGGAGE PROBLEMS WITH MESH PADS

1. Use Coarser Mesh
2. Flush With Clean Water

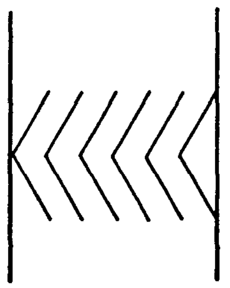
For mesh pads having chronic pluggage conditions, the alternatives listed here may be of use.

Mesh pads are especially prone to pluggage due to the low open area and the difficult drainage path. A coarser mesh partially alleviates these problems. This will also lead to a slightly lower pressure drop. However, this is done at the risk of lower droplet capture effectiveness in the coarser mesh pad.

Sprays should generally be used whenever there is appreciable solids levels in the scrubber liquor. With mesh pads, it is important that these sprays be pointed downward. Upward sprays can drive the solids deeply into the mesh pad and partially blind the demister. Demisters with high solids deposits can suffer reentrainment and high static pressure drop. If the conditions are sufficiently severe, the entire demister can be ripped from its supports and sucked into downstream I.D. Fans. For example a completed blinded demister 8 feet in diameter with a 10 inches W.C. static pressure on the downstream side is subjected to a force of over 2500 pounds!

The initial sign of mesh pad pluggage is an increase in the static pressure drop at a given gas flow rate. Baseline data is helpful for identifying the onset of pluggage. In any case, a static pressure drop over 0.5 inches W.C. is a sign of trouble.

SLIDE 5-14



2 PASS

Source: Electric Power Research Institute

This is a side view of a two pass chevron demister. The gas stream enters from the bottom and must pass up through the twisted passages. Droplets impact on the blades and drain down.

These are available in two, three and four pass designs with the capture improving with the number of passes. The inside angles of the chevrons vary from a low of 60° to maximum of 120°. Droplet collection improves with increasing angles.

Various blade designs are available to reduce reentrainment tendencies. These involve small channels and scalpers to aid the liquid drain downward without any wave action which could result in droplet formation. These also prevent liquid from reaching the downstream edge of the blades where the liquid could be sheared off by the gas stream passing out of the demister. The main disadvantage of these pockets and channels is the tendency to plug when high suspended solids are collected. This can accelerate pluggage of the entire demister since washing is inhibited. These special blade designs are used most frequently on demisters in which the chevrons are mounted vertically and the gas flow is horizontal. These demisters have inherently improved drainage so the pluggage is less of a problem.

SLIDE 5-15

GENERAL GAS VELOCITY LIMITS FOR CHEVRONS

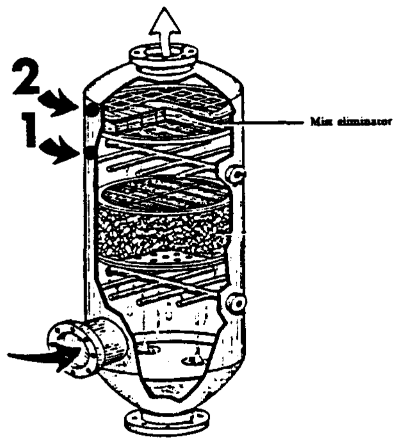
Vertical Gas Flow
5 to 15 Feet Per Second

Horizontal Gas Flow
7 to 25 Feet Per Second

Chevron demisters are subject to droplet reentrainment at high gas velocities as indicated in the equation shown in slide 5-12. The "K" factors for a typical 3 pass chevron with vertical gas flow is 0.2 to 0.5. The value of the constant for the same 3 pass unit having horizontal gas flow is 0.2 to 0.8. The large range is needed due to differences in the blade angles, blade geometry, and liquor surface tension. At typical liquid and gas stream densities, this equation indicates that the superficial velocities should be between the values shown in this slide.

Most chevrons are designed for a gas velocity between 10 and 20 feet per second, depending on the specific characteristics of the application. The accumulation of solids can result in an unintentional increase in the gas velocities and increased reentrainment. To minimize solids build-up, it is common practice to spray the demister sections on a regular basis. The sprays can be either above or below the demisters.

SLIDE 5-16



To facilitate early identification of the solids accumulation on chevron demister sections, there should be static pressure measurement taps before and after the demister. An increase in the pressure drop at a constant flow rate is a clear sign of emerging pluggage (and reentrainment). The static pressure drop should be measured during the baseline period to serve as a comparison when problems are suspected later.

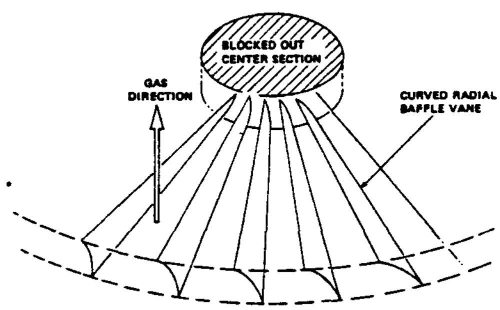
There should also be a viewing port or hatch in the demister area so that the conditions can be evaluated when the scrubber is down for service.

When comparing against baseline pressure drops, it is necessary to correct for differences in the gas flow rates. The equation shown below can be used to make this correction. This is intended only as a rough approximation and is based on the fact that pressure drop is related to the square of the gas flow rate. Production data can sometimes be used as a rough indicator of the gas flow rate.

$$\Delta P = \Delta P \left[Q^2 / Q^2 \right]$$

Where: ΔP = Corrected Pressure Drop
ΔP = Observed Pressure Drop
Q = Baseline Gas Flow Rate
Q = Present Gas Flow Rate

SLIDE 5-17



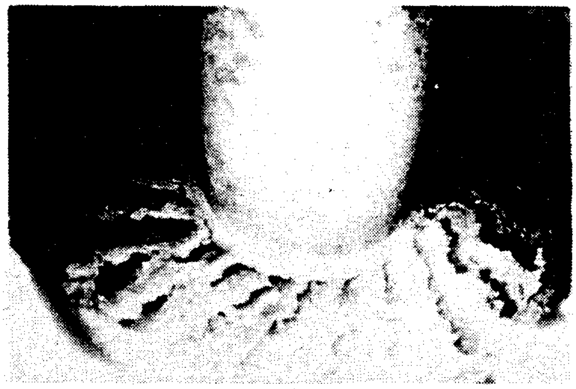
Source: Air Pollution Training Institute

A radial vane type demister is shown here. There are curved baffle vanes which are attached to the hub and to the outer spool. As the gas stream passes around the curved vanes, it is accelerated and spun. Droplets impact the wall of the scrubber vessel due to centrifugal force. The accumulated liquid is continuously drained from the annular area between the scrubber wall and the radial vane demister.

For adequate performance, it is important that there is some clearance above the demister for the spinning gas stream. A minimum clearance of one-half the scrubber diameter is necessary to complete droplet removal.

As with any demister, solids accumulation must be removed frequently. This can be done with sprays either above or below the demister. It is also necessary to keep the drain line open. It can plug at the entry point or at the discharge point

SLIDE 5-18



This is the downstream side of a radial vane demister. Note the heavy deposits on the blades and the restricted gas passages between the blades. A unit in this condition is prone to reentrainment. The solids accumulated on this demister primarily because it had to be cleaned manually and this was done on a once per week basis.

SLIDE 5-19

EVALUATION OF
RADIAL BLADE DEMISTERS

During Level 3 inspections of the radial vane demisters, the static pressure drop should be checked. Increases over baseline levels (after correction for gas flow rate changes) indicate the accumulation of solids. Any pressure drop in excess of 2 inches W.C. is a possible indication of pluggage.

SLIDE 5-20

DEMISTER CLEANING SYSTEM INSPECTION

1. Liquor Turbidity
2. Liquor pH
3. Liquor Pressure
4. Operating Frequency
5. On-Time

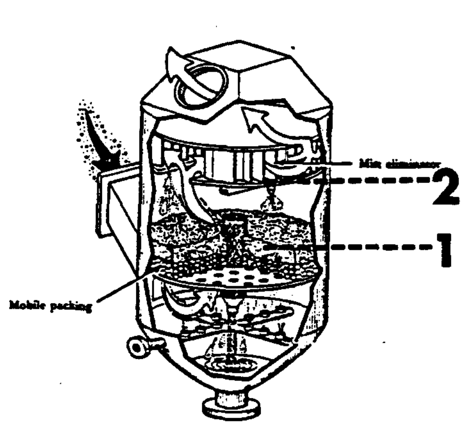
During all inspections of demisters, the washing system layout and operation should be checked. Some of the important points are listed on this slide. However, some of this operating data is often unavailable.

The cleaning system must be run often enough and at high enough pressure to remove the solids which accumulate. The nozzle type and spray angle must ensure complete coverage of the demister.

If possible, a sample of the liquid used as demister wash should be checked. This should be low in total solids so that the wash water does not contribute to a scaling and/or pluggage condition. The pH should also not be so high that scaling is inevitable.

In some scrubber systems, the demister wash system is used as the scrubber system make-up water line. This is a good practice since the make-up water supply is normally clean and close to a neutral pH.

SLIDE 5-21



Another factor of importance is the distance between the top stage of the scrubber and the and the bottom of the demister (see distance from #1 to #2). This is termed the "freeboard" distance.

The demister must be high enough above the last scrubber tray so that it is not subject to the very high liquor loadings close to the trays (or beds). There must be a sufficient distance for large settleable drops and liquid jets to fall back to the tray without hitting the demister.

Excessive freeboard distance does not affect demister performance. However, this does add to the scrubber vessel height and cost.

SLIDE 5-22

SUMMARY
DEMISTER INSPECTION

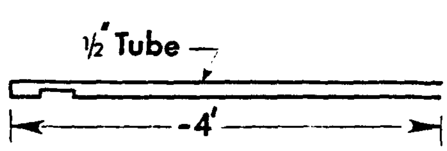
1. Wash Water Quality
2. Cleaning Operating Times
3. Liquid Pressures
4. Static Pressure Drop
5. Gas Flow Rate

This is a brief summary of the common inspection points for suspected demister problems. The presence of a water wash system and the quality of wash water should be checked during all inspections. The distance of the demister from the top of active trays or beds should also be checked, especially when gas velocities through the unit are high.

On Level 3 inspections, the pressure drop should be compared against the baseline values. Even slight shifts after correction for gas flow changes indicates the onset of pluggage. The ceiling value pressure drops listed earlier should generally not be exceeded. The gas flow rate can be measured to determine if the capacity of the demister has been exceeded.

On scrubber systems that are down, an internal check should be made for deposits on the demister and for the condition of the washing system spray nozzles. Under no circumstances should the inspector enter the scrubber vessel since there could be toxic gases trapped in portions of the off-line scrubber system. It is also possible to crush fragile chevron blades and rotary spin vanes which are often made of plastic.

SLIDE 5-23

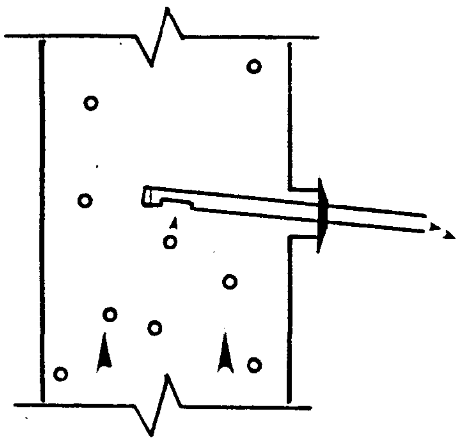


Source: Shifftner

When symptoms of demister problems are noted during Level 3 inspections, the probe shown in this sketch can help to determine the source of the liquor droplets observed. This is a section of 1/2 inch O.D. copper tube with a slot cut out near the top. The tube is sealed with an end cap and the other end includes fitting which reduce down to a nipple. A flexible piece of tubing leads from the probe nipple down to a sample bottle.

The probe is inserted into the stack to determine if there are droplets in the gas stream. Checks are also made to determine if liquor is moving up or down the scrubber stack.

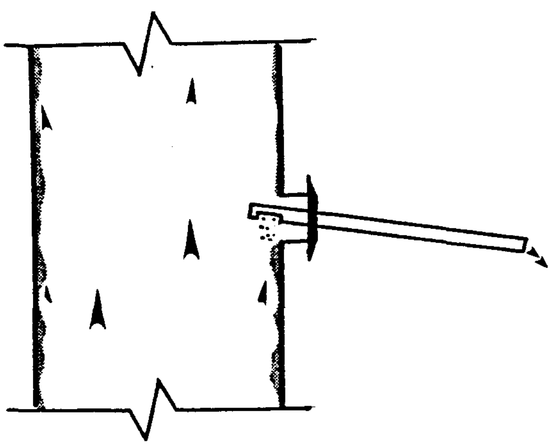
SLIDE 5-24



The rate of liquor capture should be noted when the probe is placed near the center of the stack. Droplets in this portion of the stack clearly indicate that there is excessive liquid carry-over from the scrubber vessel. The demister should be inspected in detail.

Anything that would contribute to droplet reentrainment should be removed from the stack and placed elsewhere in the system, if possible.

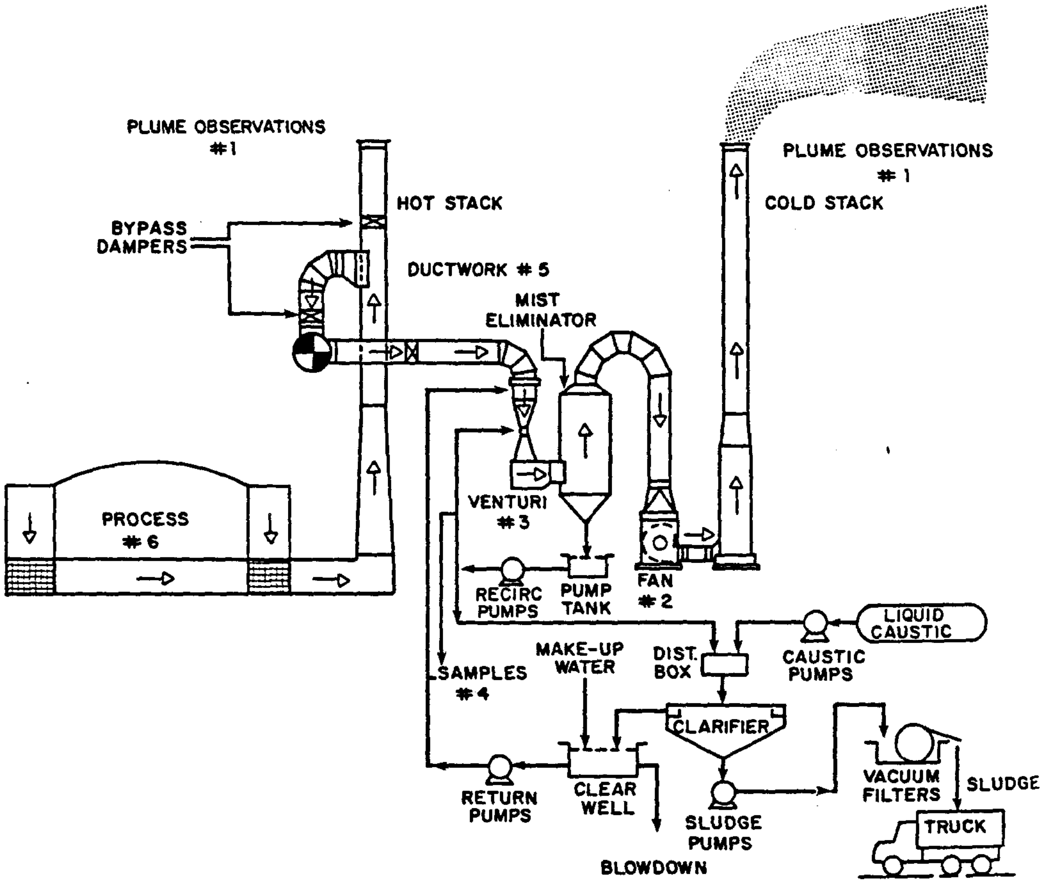
SLIDE 5-25



When the probe is placed in the position shown here, the presence of ascending wall flow can be determined. The liquor moving up the interior wall can be due to demister failure or simply to the condensation of water vapor in the cold stack. The latter is possible when ambient temperatures are low. Normally, the stack velocity must be more than 35 feet per second to push the liquor up the wall.

This is one possible explanation for slight rainout conditions in the absence of any demister malfunctions.

SLIDE 5-26



This flowchart shows the typical locations of pumps in a wet scrubber system. The recirculation pump is the one that most directly affects the performance of the wet scrubber and is, therefore, the one of most interest to control agency inspectors. This pump must be capable of delivering the liquor at the design flow rates and pressures at the inlet to the scrubber. It must be able to withstand the suspended solids and corrosive materials which accumulate in the recirculation liquor.

To maintain the suspended solids and corrosive materials at an acceptable maximum concentration, some of the liquor is either purged from the system or sent to a liquor treatment circuit. This purge line pump handles only 5 to 20% of the capacity of the recirculation pump. However, it is subject to the same liquor quality. The make-up pump delivers relatively clean process water or liquor to replace that lost due to evaporation, lost in the sludge removed, and lost as stack reentrainment. This pump usually has a capacity similar to the purge pump.

Other pumps are used for alkaline supply and for metering in additives for foam suppression, odor control, surface tension control, and solids settling. Sludge pumps may be used under clarifers for removal of high solids liquid streams.

SLIDE 5-27

A failure of any one of the main pumps could result in temporary outage of the scrubber and the bypassing of the effluent gas stream. The recirculation pumps and the purge line pumps are most susceptible to these sudden problems due to the characteristics of the liquor often handled. However, the loss of the alkaline supply pump or additive supply pump could lead to serious corrosion conditions which demand immediate corrective actions.

The recirculation pump operating data can provide a useful, indirect measurement of the liquor flow rate. Comparison of the discharge pressures and pump motor currents with baseline values can indicate if the liquor flow rate has probably increased or decreased significantly since the baseline period. The pump discharge pressure and the general operating conditions can help determine if the pump is the cause for decreases in either the liquor flow rates or the pressures at the scrubber inlet.

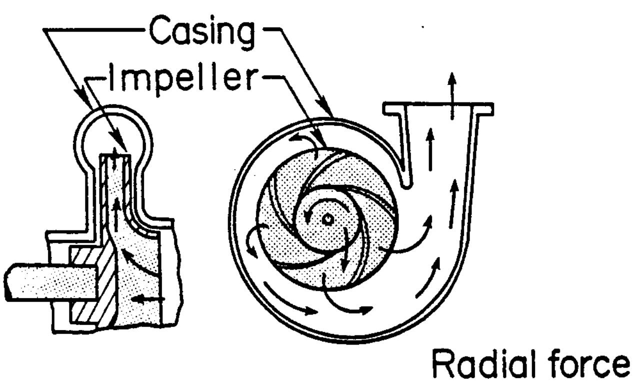
SLIDE 5-28

There are numerous pump designs. However, for wet scrubber applications the pump types listed in this slide are the most common. The centrifugal pumps are used most frequently for liquor recirculation and liquor purge since they can handle large quantities of liquor which are abrasive and corrosive. The centrifugal pumps usually operate at 400 to 900 rpm and deliver liquor at 40 to 200 psig. These are relatively modest demands compared to the requirements for centrifugal pumps in other applications.

The types of centrifugal pumps can be further divided into a number of individual categories which are primarily based on the pump impeller design. These different types are discussed in more detail in later slides.

The diaphragm pump is a type of positive displacement pump (one of the major categories of pumps) which is used almost exclusively for the movement of very high solids content slurries. These are most common on the clarifier and thickener underflows. The progressing cavity pumps are useful for the movement of high solids, large suspended particles and/or potentially clogging type solids.

SLIDE 5-29



RADIAL CENTRIFUGAL PUMP

Source: Chemical Engineering
June, 1972

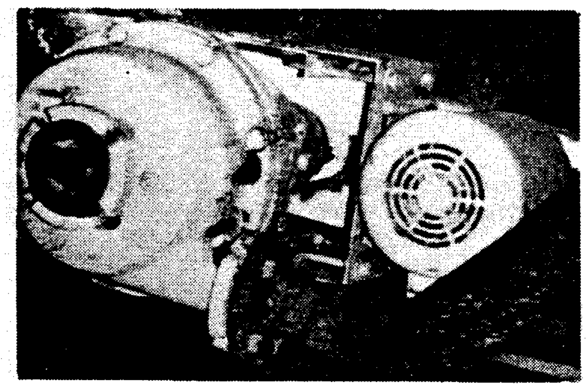
The radial flow centrifugal pump is the most common type of pump used for wet scrubbers. The liquor enters the pump axially and is accelerated by the rotating impeller. The flow from the impeller into the casing area is radial with respect to the impeller.

As the liquor leaves the impeller, it decelerates somewhat which results in the conversion of some of the velocity head to pressure head. The general relationship between the two is provided in the equation below:

$$V = \sqrt{2} \times (GH)$$

Velocity, V, is in feet per second, G is gravitation acceleration in feet per second squared, and pressure head, H, is in feet.

SLIDE 5-30



The centrifugal pumps can either be oriented in the vertical or horizonal directions. The most common is the horizontal arrangement shown in the top portion of the slide.

A vertical arrangement is useful to obtain greater suction head (a very important operating requirement to be discussed later) and to minimize the required floor space.

The pump body configurations in the vertical and horizontal orientations are somewhat different. However, the differences do not change the way in which pump performance is analyzed, and it does not significantly change the types of problems which are most common.

SLIDE 5-31

COMPONENT OF A PUMPING SYSTEM

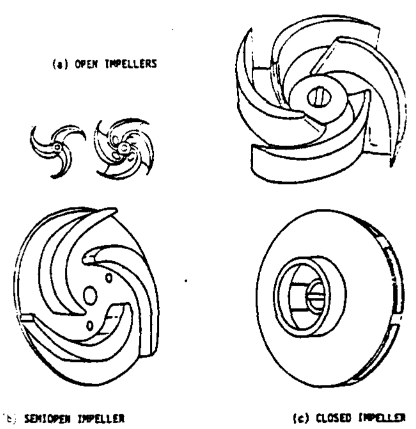
The components of a pumping system include the suction pipe, strainer, suction side check valve (termed foot valve in slide), discharge check valve, and discharge valve. The latter is termed a gate valve (a specific type of control valve). Not all of these are necessary for each system.

The strainer removes tramp iron and large particulate which would damage the pump impeller and/or liner. The strainer is usually used on all new systems but is sometimes removed when there is a tendency for the liquor to blind the strainer. This would cause serious pump damage.

The foot valve (or check valve) prevents air infiltration into the suction side of the pump during outages. If air enters the pump it must be primed and there is a risk of cavitation (a serious operating problem). The eccentric reducer on the suction line allows connection of the suction line to the pump flange without the creation of air pockets which can also cause cavitation under some operating conditions. The suction line is angled downward to also prevent air pockets.

The flow of liquid out of the pump is controlled by the discharge line valve. This is normally a gate valve (valve designs are discussed in a later part of the lecture). Although not shown, there is often a discharge line pressure gauge on the line before the discharge valve.

SLIDE 5-32

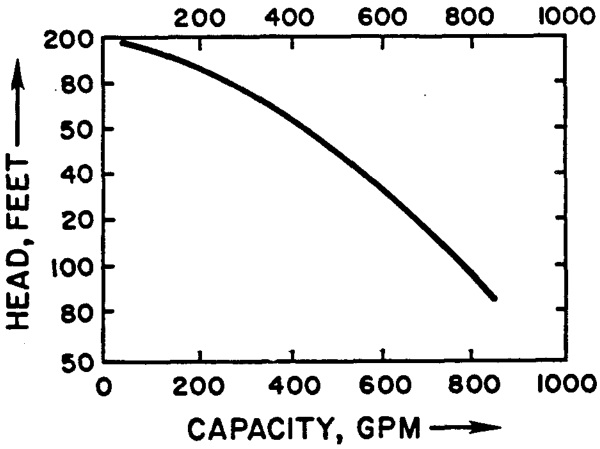


Several examples of the large number of available impeller designs are shown in this slide. The open and semi-open impellers are often used on heavy slurries and other abrasive liquors. The nonclogging impeller is useful for heavy slurries including stringy materials.

The closed impeller design is suitable for relatively clean liquors with little or no solids. This design provides higher efficiency.

The quantity of liquor and the pressure of the liquor supplied by the pump depend on the impeller configuration and the impeller iameter. When impellers are replaced, identical units should be reinstalled. The use of smaller diameter impellers with or without the identical configuration can result in less than the desired pump performance.

SLIDE 5-33



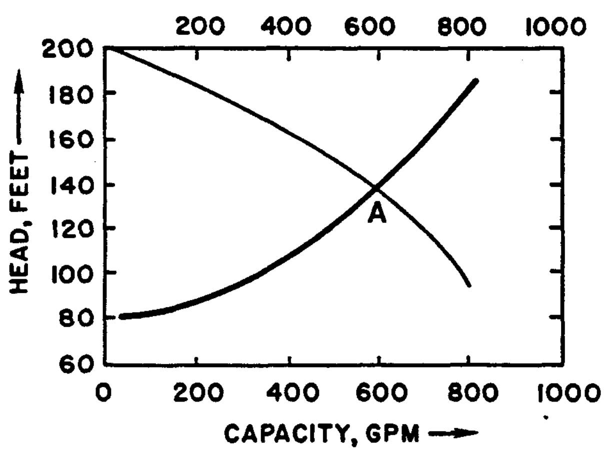
The characteristic curve of a centrifugal pump is shown. As the quantity of liquid delivered increases, the head developed decreases slightly.

The position and shape of this curve is determined by a number of design factorsincluding: (1) impeller shape, (2) impeller diameter, (3) casing shape, and (4) pump rotational speed.

Under normal conditions, the pump will perform on this curve at a position determined by the piping system resistance. However, problems such as cavitation and impeller wear can cause reductions in both flow rate and head.

Field inspectors and maintanence personnel will rarely have these curves for use in evaluating pump performance. The curves are used simply to illustrate the meanings of the pump instrumentation such as the discharge pressure gauge and the pump motor ammeter.

SLIDE 5-34

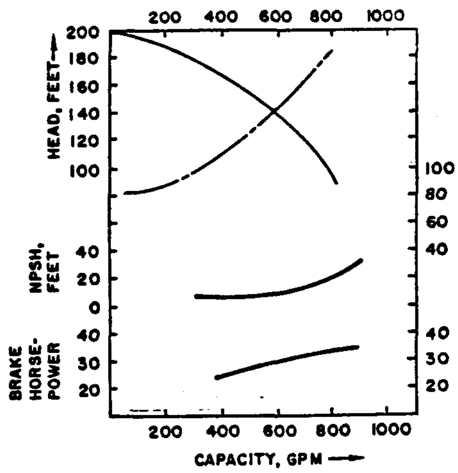


The system resistance curve is shown in this graph along with the pump curve introduced in the previous slide. At the origin, the system resistance is equal to the discharge head, which is equivalent to the vertical distance that the liquor is being lifted. The system resistance increases with the square of the flow rate due to frictional losses in the pipes and valves.

The system resistance curve is calculated for a new system based on the piping layout, liquor velocities and the pipe characteristics. The intersection of the pump curve with the system curve defines the intended operating point (point A on this graph) of the overall system.

Unfortunately, several factors can lead to a change in the position of the system resistance curve. Some designers may assume higher estimated resistances than actually exist in order to provide a "safety factor". This can lead to lower resistance than intended. There can also be pluggage of control valves, nozzles and piping which leads to higher resistance than desired. In either case, the pump selected may not be appropriate for the actual conditions which exist.

SLIDE 5-35



The brake horsepower curve is now added to the pump and system curves discussed in the last two slides. The horsepower rises as the quantity of liquor pumped increases.

The brake horsepower is the total energy being used by the pump motor. It includes the energy imparted to the liquid stream and the portion of the energy which is wasted and dissipated as heat in the pump motor. It is related to the motor current by the relationship shown in the equation below.

$$Hp = \sqrt{3} \times V \times C \times P.F.$$

Where : Hp = Total Horsepower
V = Volts, A.C.
C = Current, A.C.
P.F.= Power Factor, dimensionless

While there is obviously a direct proportionality between the motor current and the horsepower, it is not possible to calculate the present horsepower from the motor current and operating voltages. The power factor is not generally known, is not generally constant, and is difficult to measure. For this reason, it is not possible to use a pump curve to calculate the flow rate from the motor currents and voltages. Variable liquor characteristics and pump impeller wear also make this impossible. However, a decrease in the motor current usually means that the liquor flow rate has decreased from baseline levels.

The total pressure head (see vertical axis) is the total of the liquor velocity presqure and the absolute liquid pressure. These two components of the total pressure head are convertible from one form to the other and are related by the equation shown below. Application of this equation for typical pipe velocities will illustrate that the velocity head is much smaller than the absolute pressure component.

$$V = \sqrt{2} \times G \times H$$

Where: V = velocity of liquor in feet per second
G = gravitational acceleration, in feet per second squared
H = liquid pressure, in feet

While the measured pressure will depend on the velocity of the liquor at the point of measurement, the discharge pressure does provide a general indicator of the overall pressure head being supplied by the pump. Many pump operating problems result in a significant reduction in the pressure head.

One complicating factor in the use of the discharge pressure, is the pluggage of downstream valves and nozzles. This can increase the measured discharge pressure slightly, while reducing the flow.

SLIDE 5-36

PUMP OPERATING PROBLEMS

There are many common operating problems of wet scrubber system pumps. Most of these have a direct impact on the performance of the pump by reducing the quantity of liquor delivered and/or the pressure of the liquor.

In the slides that follow, some of the possible reasons for these problems will be presented to help inspectors determine if the corrective actions planned have a reasonable chance of success. However, it is usually not possible for an inspector to determine the exact cause of the problem

There are more than 90 commonly reported causes of pump failure due to both mechanical and hydraulic factors. Some of these can be identified by observing pump operation and some can be identified when the pump is torn down for maintenance. The reasons for repeat failures of certain components, however, can be a complicated issue best left to pump specialists.

The inspector's role is to confirm: (1) that the operators are aware of a change in pump performance which may be an emerging scrubber problem, that (2) the operator's corrective actions will probably prevent or minimize the condition, and that (3) the operator is not tolerating frequent pump problems without attacking the fundamental cause(s).

SLIDE 5-37

LOW LIQUOR FLOW RATE

1. CAVITATION
2. FROZEN PIPES
3. PLUGGED STRAINER
4. IMPELLER EROSION
5. PLUGGED PIPES OR NOZZLES
6. PARTIALLY CLOSED DISCHARGE VALVE
7. SOLIDS ACCUMULATION IN CASING

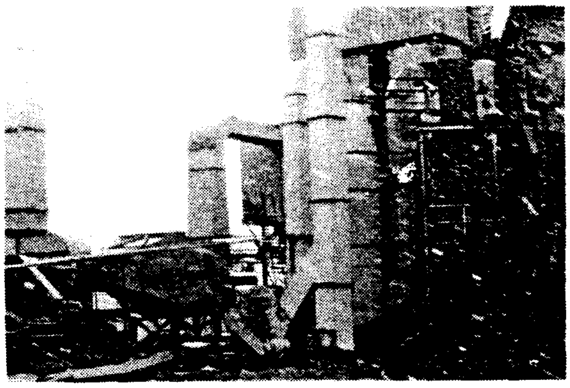
The lack of liquor flow can be due to a number of pump problems, all major. Most of these listed on the slide result in burnout of the pump motor.

Other possible causes for the lack of liquor flow include a closed discharge line valve and pluggage along the discharge line and/or nozzles.

The source of the problem can rapidly be identified by checking the pump operation. If the drive shaft is still spinning, the problem is in the discharge valve or piping. The pump should be shut down immediately.

If the shaft is not spinning, the pump is either already shut off or has bound up. Before starting up the pump again or starting up a spare pump, the condition of the nozzles and other potential areas for line pluggage should be checked. Loads placed on the pump by the piping should also be visually evaluated.

SLIDE 5-38



One cause of the no flow condition is the freezing of exposed piping from the pump discharge to the top portion of the scrubber vessel. Ways to minimize line freezing include:

1. Maintaining flow through lines even when scrubber is down.

2. Insulating lines.

3. Draining and flushing lines during outages.

4. Placing pumps in heated and/or sheltered pump house

The last two steps are common during operation in cold climates. Maintaining flow during all periods can also help prevent the settling of solids in the piping. Insulation of lines will be of help for short periods but will not prevent freezing when systems are shut down for weekends or other extended periods.

SLIDE 5-39

This is a view of a recirculation pump within the pump house. The heated area protects the pump from freezing conditions during extreme weather and during outages.

The suction line of a pump must be kept full of liquid so that the pump will not cavitate (problem defined in a later slide) during start-up. Since the line can not be drained, the pump must be kept in a heated area.

Freezing of the seal water line or the packing material could also lead to pump damage.

SLIDE 5-40

PUMP IMPELLER WEAR

1. CORROSION DUE TO LOW pH
2. EROSION DUE TO CAVITATION
3. EROSION DUE TO SUSPENDED SOLIDS
4. EROSION DUE TO TRAMP METAL
5. CORROSION DUE TO CHLORIDES

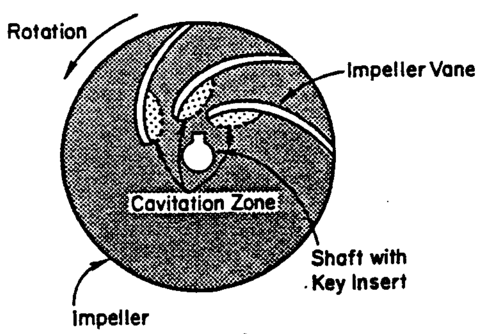
Impeller wear and damage can be caused by the problems listed in this slide. Corrosion occurs when the liquor composition and/or pH is not compatible with the impeller materials of construction. The pH measurement provides one indication of impending corrosion problems. The condition of the casing can also provide some warning.

Cavitation conditions usually result in pump vibration and high noise levels. Rapid corrective action is necessary in this case.

Abrasion occurs due to high suspended solids levels and large particle sizes of the suspended materials. Low pump speeds can minimize this problem.

The consequences of impeller wear include reduced liquor flow rate and reduced discharge line pressures. The pressure gauge will provide one indication of this problem. However, there are a number of conditions which can reduce the pressures.

SLIDE 5-41



Source: Plant Engineering
October 3, 1974

Cavitation is a serious operating problem which occurs when a portion of the liquor being handled in the pump vaporizes while passing over the impeller blades. This slide illustrates the location of the bubble formation on the impeller surfaces.

As the liquor proceeds outward, the pressures increase and the bubble implodes. The energy released during this action can destroy protective liners on the impeller and can even remove metal from the impeller itself. The imploding bubbles also result in noise and pump vibration.

Due to the rapid damage to the impeller and the casing liners (if present), cavitating pumps should be shut down as soon as possible. The source of the cavitation should be corrected before returning the pump to service. Some of the most common causes of this condition include, air infiltration, inadequate net positive suction head, and gas pockets in the suction line. These problems are discussed in the next set of slides.

SLIDE 5-42

$$(NPSH)a = (H - Pv)/\delta - hf - he$$

Where:
H = Absolute suction pressure at the pump inlet
Pv = Vapor pressure of the liquid at the given temperature
δ = Specific weight of liquor
hf = Frictional lossed in suction
he = Entry losses

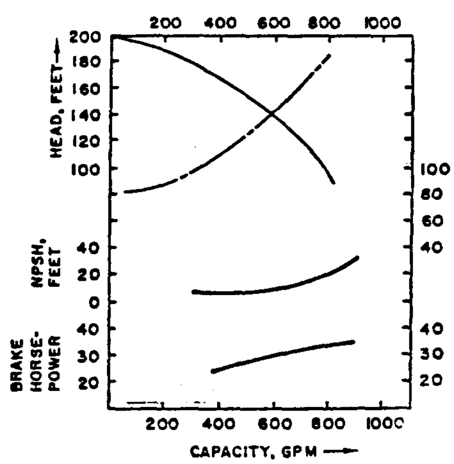
The available net positive suction head is the difference between the existing absolute suction head and the vapor pressure of the liquor at the operating temperature of the pump. This is a characteristic of the system in that it is determined by: (1) the liquor composition, (2) the elevation of the suction point relative to the pump, and (3) the frictional losses in the suction line. The procedure for calculating the available net positive suction head (NSPH)a is shown in the equation.

It is apparent that the available net positive suction head depends on the elevation of the reservoir supplying the pump (or the depth of the suction line in a pond). Another important factor is the flow rate of the liquor since this determines the magnitudes of both the frictional losses and the suction pipe entry losses.

The required net positive suction head is a function of both the pump design and the liquor flow rate. It must be specified by the manufacturer of the pump. Selecting the appropriate pump for the system available net positive suction head is the responsibility of the system operator.

Inadequate net positive suction head is reported to be one of the most common reasons for inadequate pump performance.

SLIDE 5-43



Source: Plant Engineering
August 8, 1974

The net positive suction head required for a given pump, along with the system resistance curve and the pump characteristic curve are shown in this slide.

This data is always presented for liquid liquid at standard temperatures and specific weights. It should be corrected for temperature and solids content for the actual system before the pump is selected.

SLIDE 5-44

REDUCING CAVITATION PROBLEMS

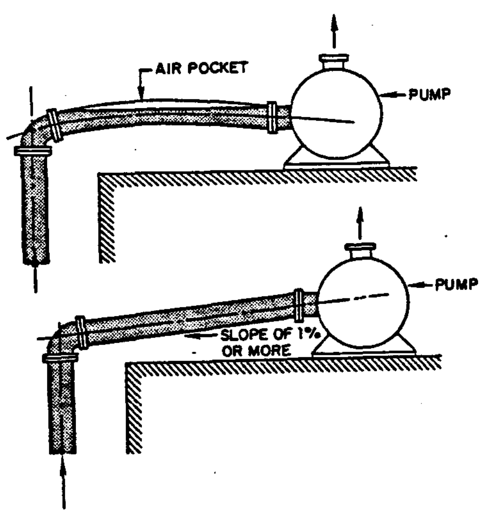
1. INCREASE HEIGHT OF INTAKE
2. DECREASE ELEVATION OF PUMP
3. ELIMINATE AIR INFILTRATION ON INTAKE PIPE
4. ELIMINATE GAS POCKETS ON INTAKE PIPE
5. MODIFY INTAKE CONFIGURATION
6. INSTALL FOOT VALVE ON INTAKE

If the pump is subject to cavitation, problems, one or more of the following steps could be taken to prevent the condition.

Raising the height of the recirculation tank and/or the scrubber sump is often uneconomical. Lowering the intake point of the suction line is more practical. Converting to a vertical pump can also be done with a minimum of system modification.

Operation at lower flows can have some beneficial impact for the pump, but adversely affect scrubber operation. Also, the required net positive suction head increases slightly at very low flows, as indicated on the earlier slide.

SLIDE 5-45

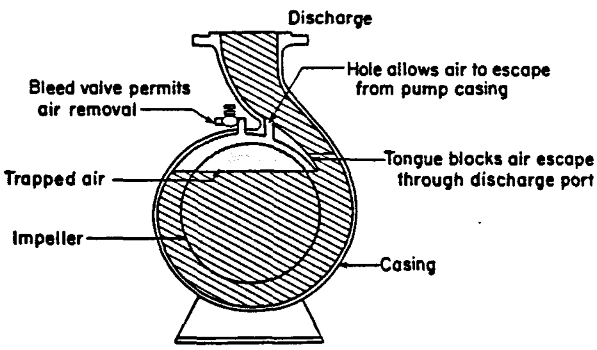


Source: Machine Design
May 8, 1980

Another source of cavitation is the presense of gas pockets in the suction line of the pump. Three ways to avoid gas pockets are shown in the slides which follow.

The suction pipe leading to the pump slopes upward a minimum of 1° so that gas pockets can not occur in a high point of this piping.

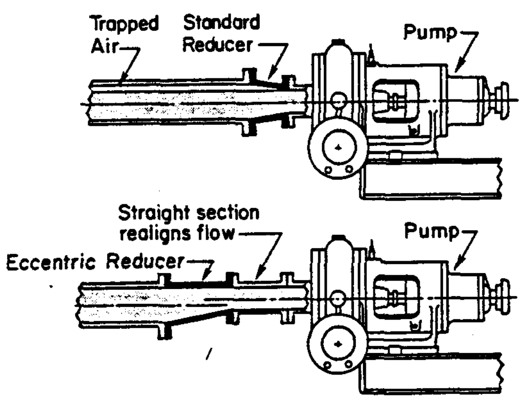
SLIDE 5-46



The volute casing of the pump may accumulate some air at a high point of the casing behind the tongue. A vent at this point allows bleeding off of any air trapped in this area during start-up of the pump.

Source: Machine Design
May 8, 1980

SLIDE 5-47

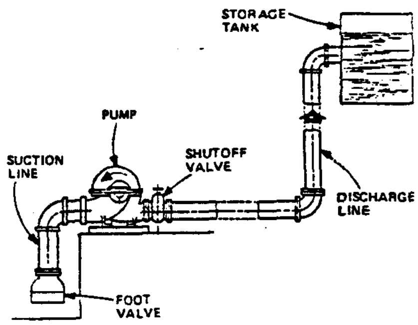


Eccentric reducers should be used to connect the suction line to the pump itself. In this way, gas pockets can not develop.

Any flange gaskets should be cut with an oversize opening so that a portion of the flange does not extend into the liquid stream as shown.

Source: Machine Design
May 8, 1980

SLIDE 5-48

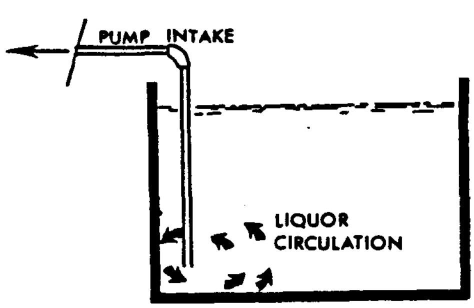


A foot valve is advisable when the suction line is drawing liquor up out of a tank or pond. This acts as a float type check valve which closes off the suction line if the liquid level drops.

This type of check valve is not necessary when there is a flooded suction line. Systems in which the pump pulls from the scrubber sump generally have flooded suction. It is important to fill the sump (necessary as a water seal anyway) before starting the pump.

Source: Plant Engineering
July 6, 1978

SLIDE 5-49



When the pump pulls from a tank, it is important to place the intake line(s) at the proper position to avoid vortices. Air can be drawn into the line if the pick up point is too close to these vortices.

There are published guidelines on the minimum depth of the suction line for the size of the suction pipes. Also, information is available to design the tank to prevent air pick-up.

SLIDE 5-50

PUMP MATERIALS OF CONSTRUCTION

1. CARBON STEELS
2. STAINLESS STEEL
3. NICKEL ALLOY STEELS
4. RUBBER LINED CARBON STEELS
5. FIBERGLASS REINFORCED PLASTICS

Typical materials used in pumps are listed here. The carbon steels are adequate for general service. However, life will be very limited when the pH is below 6 and/or there is high solids content.

The stainless steels provide greater corrosion resistance except for liquors having high chloride and fluoride levels When the concentrations of the halogen materials exceeds 500 ppm, pitting of the stainless is rapid.

The nickel alloys provide generally excellent corrosion resistance, but at a substantial cost penalty. These materials also have moderate to excellent abrasion resistance.

SLIDE 5-51

SUMMARY
PUMP EVALUATION

This is a summary of the inspection points for recirculation pumps of wet scrubber systems.

The discharge pressure provides a useful index of the flow rate. An increase from the baseline level generally means a decrease in the liquor flow rate.

An increase in the pump motor current is another flow indicator. As it increases, the flow increases unless the viscosity has changed dramatically (which is unlikely in most air pollution control systems). A major increase in the solids content can also affect the pump currents.

An increase in the pump noise and/or vibration is a possible indication of cavitation. This is often accompanied by a decrease (possibly slight) in the discharge pressure and a decrease in the liquor flow. Whenever cavitation is suspected, the suction line should be examined carefully for sites of gas pockets, sites of air infiltration, the elevation of the suction line intake, and the configuration of the intake.

For pumps using water seals, there should be a small quantity of seal water continually draining from the stuffing box. The lack of visible drainage is a sign of inadequate seal water supply and this can lead to premature failure of bearings and corrosion of the shaft.

Another factor which should be checked is possible pump misalignment conditions due to forces imposed on the pump by the discharge piping. The provisions for flushing out any pumps handling slurries (total solids contents greater than 3% by weight) during outages and the provisions to prevent freezing during system outages should be checked.

SLIDE 5-52

EVALUATION OF LIQUOR FLOW RATE AND PIPING SYSTEMS

The objectives of this section include: (1) the evaluation of liquor flow rates in systems without flow monitors, and (2) the evaluation of operation and maintenance problems due to piping and valve related conditions.

The principal problems associated with the piping included pluggage or erosion in systems handling slurries. Improper piping supports can place undesirable loads on the pump and the nozzle headers. If the piping system is not designed properly, it is difficult to flush out settled material, it is difficult to drain lines during cold period outages, and it is difficult to replace worn or corroded segments.

SLIDE 5-53

1-IPS-40-CS

In order to make a rough estimate of the flow in a pipe, it is necessary to know the pipe dimensions. The pipe sizes are often specified as shown in the example on the slide.

The first number is the nominal pipe size. This may be followed by an alphabetic code which denotes the type of pipe, such as IPS for standard pipe. The next code specifices the schedule which is an indication of the pipe's ability to withstand internal pressures The letter directly following the schedule codes represents the types of materials used for the pipe. Any letters following the hyphen present information concerning liners or other special design requirements.

If it is impossible to get the piping data from drawings or other plant records, the dimensions should be measured. Either the outside diamter (termed the O.D.) or the pipe circumference should be measured. These values can then be used with standard pipe dimension tables and flow rate guidelines to estimate the flow rate.

SLIDE 5-54

PIPING INSPECTION

PIPE SIZES

Nominal Size (Inches)	Schedule Number	Inside Diameter, (Inches)	Outside Diameter, (Inches)
1	10S	1.185	1.315
	40	1.049	1.315
	80	0.957	1.315
3	10S	3.260	3.500
	40	3.068	3.500
	80	2.900	3.500
5	10S	5.345	5.563
	40	5.047	5.563
	80	4.813	5.563

This slide presents the pipe inside and outside diameters for certain common nominal pipe sizes. It should be remembered that the nominal diameters used in standard piping handbooks (and established in ASTM standards) do not exactly match the measured diameter.

The table value is actually closer to the inside pipe diameter (termed the I.D.) for most of the pipes. In the case of very small pipes, there are substantial differences between the nominal value and both the inside and outside diameters.

This data has been excerpted from tables applicable to steel pipes. The values are different for each major class of pipe including polyvinyl chloride pipe (PVC), iron pipe, fiberglass reinforced plastic (FRP), and copper pipe.

SLIDE 5-55

SCH. No. = 1000 P / S

P = Pressure, lb_f / in^2
S = Allowable Stress, lb_f / in^2

The next task is to estimate the pipe inside area which is related to the pipe schedule. The schedule number represents the ability of the pipe to withstand the actual internal pressures It is approximated by the equation shown here.

As the schedule number goes up, the pipe can take higher pressures.

The most common schedule pipe used in wet scrubber systems is the schedule 40 which is approximately equivalent to pipe which was characterized as "standard strength" before the schedule designation was common. If no other information is available, it should be assumed that the pipe of interest is a schedule 40.

Other typical pipes include schedule 80 and 160. There are schedule numbers ranging from 5 to 160. The wall thickness increases as the schedule number increases.

SLIDE 5-56

TYPICAL LIQUID VELOCITIES IN PIPES

Type of Liquid	Average Velocities (Feet Per Second)
Clear Water	8 to 15
Light Slurries	6 to 12
Heavy Slurries	5 to 8

Once the pipe inside dimensions are identified in the applicable table, it is necessary only to use a standard pipe velocity factor to calculate the flow rate. Unfortunately, there is a substantial range in the design flow rates based partially on engineering perogatives and partially on the characteristics of the materials.

A range of typical values for pipes handling water, light slurries and heavy slurries are shown in this figure. Note that flow rates in the suction lines of pumps are considerably lower than those specified in the slide. Also, lines with only gravity flow are much lower.

For a pipe with a nominal size of 2 inches (circumference 7 and three quarters inches), the capacity at an assumed rate of 5 feet per second would be 52.25 gallons per minute. At an assumed rate of 15 feet per minute, the capacity would be 156.75 gallons per minute.

High liquor velocities can be used whenever there are no abrasive materials in the stream which would erode the piping and/or pipe liners. Low liquor velocities are used for slurries. However, they must not be so low that settling of the liquor is facilitated.

Once a pipe is installed, the actual inside dimensions may vary from those specified in the table. Erosion will result in some enlargement of the pipe while settling can reduce the area open for flow. Nevertheless, use of this approach allows calculation of "ballpark" liquor flows and thereby aids in the evaluation of the overall system conditions.

SLIDE 5-57

REDUCING PIPE EROSION

1. REDUCE SUSPENDED SOLIDS LEVELS
2. INCREASE TURN RADII
3. DECREASE LIQUOR VELOCITIES
4. INCREASE pH ABOVE 6
5. DECREASE CHLORIDES CONCENTRATION
6. INCREASE PIPE WALL THICKNESS
7. INSTALL WEAR PLATES ON ELBOWS

Possible ways to minimize pipe erosion are listed on this slide. By far the most effective is to reduce the suspended solids level and solids particle sizes through improved treatment of the recirculation liquor. This has other obvious benefits for the pump and nozzles.

The liquor velocities can be decreased by use of a slightly larger pipe size. Evaluation of the tables presented in the Appendix will demonstrate that major reductions in the velocity will occur by increasing the pipe diameter by 1 inch.

A higher schedule pipe can be used to increase the time necessary before replacement of pipe segments. This simply provides more metal to be lost before the pipe is seriously weakened.

SLIDE 5-58

DECREASING PLUGGING OF PIPES

1. REDUCE SUSPENDED SOLIDS LEVELS
2. FLUSH OUT DEPOSITS ON A REGULAR BASIS
3. SELECT PROPER CONTROL VALVES
4. ELIMINATE SAGGING PIPES AND OTHER LOW SPOTS IN SYSTEM
5. SLOPE ALL PIPES

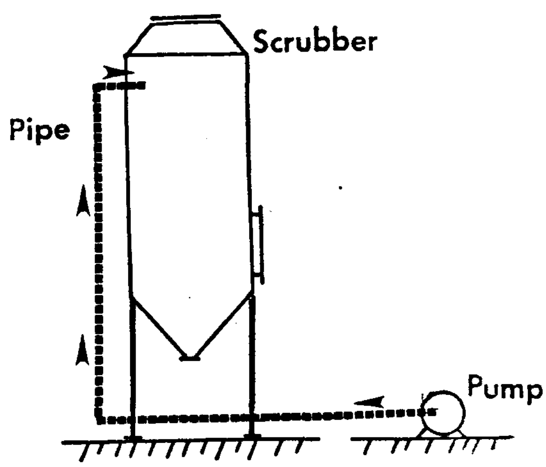
Pluggage is also best reduced by lowering the suspended solids content of the liquor. This is accomplished by (1) increasing the purge rate, (2) improving solids settling and/or filtering, and (3) decreasing the liquor pH. The latter would reduce the quantity of calcium and magnesium compounds which are precipitating from solution.

The pipe sizes should be selected to provide sufficient velocity to continually cleanse the pipes. If this is not possible due to erosion conditions, then provisions for routine clean-out should be included.

The lines are flushed by connecting a clean water source to Tee fittings located at every major turn of the piping. All the piping should be sloped slightly downward and have drains at low points so that the solids can be easily removed. The sloped pipe with drain connections also aids in draining the system during cold weather periods to avoid freezing.

Piping systems with chronic problems should have flanged pipe connections so it is possible to easily remove and clean out a section. This also helps when replacing worn or corroded piping.

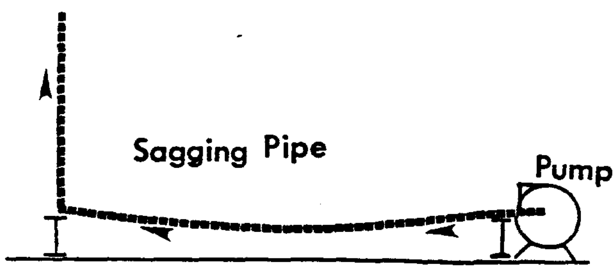
SLIDE 5-59



The piping system should be rigidly supported so that loads are not transmitted to either the pump or the scrubber. The vertical pipe run illustrated in this slide needs a pipe support either at the base or a hanger near the top to carry the load. It should be remembered that the weight consists of both the pipe and the liquor within - and this can be considerable. For a 50 foot vertical run of 4 inch Schedule 40 steel pipe, the contained liquor weighs approximately 275 pounds and the pipe itself weighs 540 pounds.

The weight of the full pipe combined with normal vibration and shock can cause misalignment of the pump and/or leakage at pipe fittings and flanges.

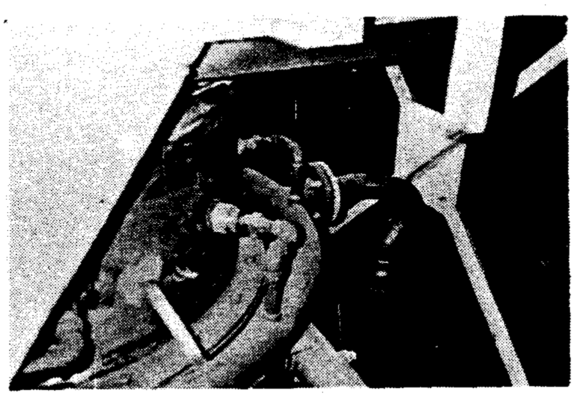
SLIDE 5-60



The weight of the pipe can cause sagging in long unsupported horizontal runs. As shown in this sketch, the sagging places undesirable loads on the pipe fitting at each end. It also allows a low spot in the line which complicates draining of the line for freeze protection and the removal of solids during flushing.

Pipe supports should be provided at regular intervals to reduce deflections and the line should be intentionally sloped to facilitate drainage.

SLIDE 5-61



Bleed valves should be placed at points of the line where air is likely to accumuluate. This slide shows a pipe leading to a header around the scrubber throat. The high point next to the shut-off valve is one common point of air accumulation.

Another common area of accumulation is the nozzle header itself. The nozzles should be oriented at a point which has a lower elevation than the top portion of the header.

While the air will often be carried away harmlessly, it could damage the control valve and the nozzles. It should be bleed off after start-up of the scrubber system.

SLIDE 5-62

TYPES OF VALVES

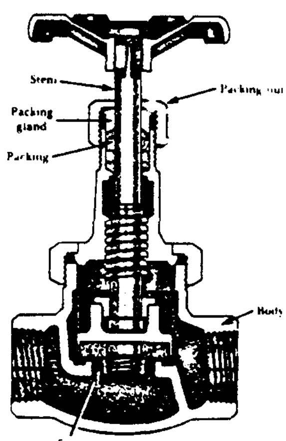
1. GATE
2. GLOBE
3. CHECK
4. BALL

There are a number of valve designs, each having different applications and service limits. The major categories are listed on the adjacent slide.

The main considerations are the usefulness for shut-off service versus the usefulness for flow control. Also, the vulnerability of the materials with respect to slurry abrasion and pluggage and with respect to corrosion must be considered when selecting valves.

The next set of slides presents the basic design features plus the advantages and disadvantages of each type. The drawings presented will demonstrate that many of these appear similar from an external view.

SLIDE 5-63

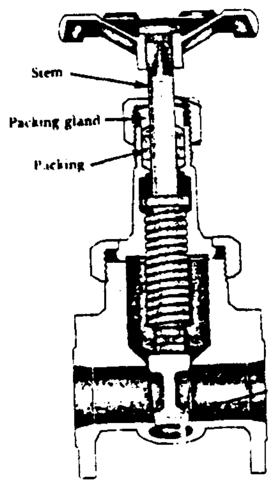


A globe valve is shown in this slide. All globe valves have a disc or plug on the valve stem which rests against a metallic seat to provide the seal. The name for these valves was derived from an earlier design which used a globe on the valve stem rather than the disc or plugs now common.

All of these have high pressure drop due to contorted path through the valve. These are used for both throttling and shut-off.

Due to the partition in the lower half of the valve body, this type of valve impedes line drainage. Also, solids can accumulate on the metallic seat and prevent an adequate seal. These valves are rarely used on slurry carrying lines.

SLIDE 5-64



Source: Air Pollution Training Institute

The gate valve shown here is intended for shut-off service rather than flow control. While it is theoretically possible to control flow with this design, the high liquor velocities at the bottom of the disc would cause damage.

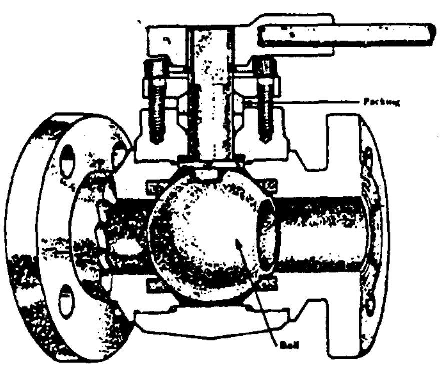
Since the disc on the valve stem moves entirely out of the path of the liquid, there is very low pressure drop through the valve.

Deposition of solids within the valve body could prevent closure of the valve Therefore, this style is not used for heavy slurries.

Due to the straight through flow conditions of a gate valve, there is no restriction to drainage of the line. This also minimizes the accumulation of solids within the valve.

The quick closing action of gate valves can cause water hammer down the piping system. This can damage both the pipe connections and the pump.

SLIDE 5-65



Source: Air Pollution Training Institute

A ball valve is shown in this slide. The control element is a ball having a large open area. When closed, the flow passage is oriented normal to the pipe direction and the ball is pressed against plastic xseat rings. These valves are used both shut-off and throttling.

SLIDE 5-66

SWING CHECK VALVES

Swing check valve are designed to prevent flow of liquid in a reverse direction. These may be used to prevent the drainage of liquid down out of an elevated pipe back through the pump.

Modest liquid pressure in the forward direction easily opens the valve. The pressure drop to flow in the forward direction is very low since there is no flow obstacle.

Under no flow conditions, the force of gravity causes the valve element to drop into the closed position. The flow of liquid in a reverse direction forces the valve element against a seal and thereby prevents leakage.

These valves must be installed in a horizontal position to allow for the movement of the check valve element.

Source: Air Pollution Training Institute

SLIDE 5-67

EVALUATION OF SPRAY NOZZLES

Nozzles disperse a liquor stream into a gas stream. The important factors to be considered when selecting a nozzle type include:

1. Droplet Size Distribution
2. Spray Angle
3. Spray Pattern
4. Droplet Initial Velocity

There are a large number of nozzle designs to provide different spraying requirements.

Improper nozzle selection can prevent adequate performance of a wet scrubber system due both to poor liquor-gas contact and to weak particle capture conditions. Nozzles are also subject to operating problems due to high liquor velocities. Liquors with high suspended solids levels can erode critical nozzle components and can plug the nozzles. There are substantial differences with respect to the abilities to handle erosive and corrosive liquids.

SLIDE 5-68

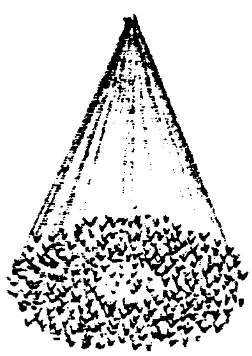
GENERAL TYPES OF NOZZLES

1. PRESSURE
2. TWO FLUID
3. ROTARY

The are three main categories of spray nozzles. Most nozzles are the pressure type in which the energy is supplied by the pressure of the liquid stream. There is limited use of the two fluid nozzles. These are only used when very small liquid droplets are necessary. In two fluid nozzles, the energy for atomization and dispersion is primarily supplied by an air or steam line under high pressure. The rotary nozzles are not used for air pollution control applications.

The pressure nozzles can be further subdivided into the full cone, hollow cone, fan, and jet type units. The jet nozzles are used for surfaces cleaning and other applications where the energy of droplet impact can be used. The other three types are all used extensively in particulate and gaseous wet scrubber systems.

SLIDE 5-69



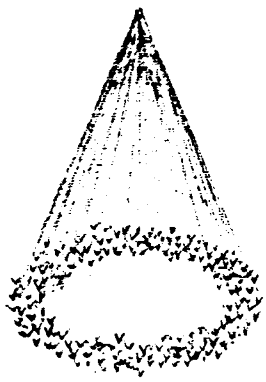
The spray pattern for the full cone type of pressure nozzles is shown in this slide.

The full cone spray has relatively even distribution of drops across the entire circular cross section of the spray. In some nozzles types, there can be a small center area which is dry. Nozzles are available which develop either the circular or square patterns.

The uniformity of the distribution is affected by extremes in the liquid pressure. Under very low pressures, the cone can deteoriate to a weak "jet" which resembles a household kitchen faucet.

The spray angles usually range from 30° to 90°. Typical operating pressures range from 20 psig to 120 psig in air pollution control systems.

SLIDE 5-70

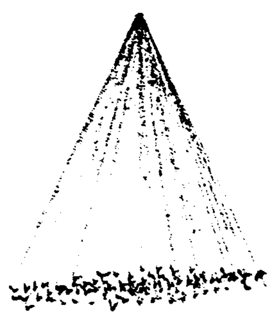


This is a typical hollow cone spray. As the name implies, the droplets are released in a narrow band. On a cross section, the liquor appears as an outer ring around a dry circular area inside.

This type of nozzle operates with design spray angles from 30° to 90° and these angles are relatively constant under differing liquor conditions.

Operating pressures are similar to the full cone nozzles. However, the flow rates are often slightly smaller at a given pressure.

SLIDE 5-71

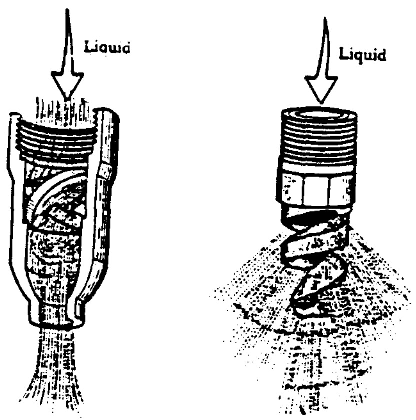


Nozzles generating a jet type spray pattern are less common than the other two types of pressure nozzles. These are used primarily to provide a screen of liquid droplets across an inlet duct to a control device.

The spray forms a fan-like pattern. The spray angles range from almost 0°(jet sprays) to up to 100°.

Due to this pattern, nozzles of this type are inappropriate for the distribution of liquor across circular and rectangular areas.

SLIDE 5-72



Several example full cone type pressure nozzles are shown in this slide. The top nozzle includes an internal spinner vane for distribution of the liquor leaving the nozzle. The lower unit is termed a "helix" nozzle. The flow of liquid past the helix results in a modified full cone spray. There is usually a small dry circular area in the middle of the spray pattern due to the nozzle tip.

The nozzles with the internal spinner vanes are very difficult to rod out after they become plugged. They must be removed for cleaning. Care is necessary for the helix type nozzles when rodding out since it is possible to damage the metal tip.

The droplet size distribution is normally finer for the spinner type full cone nozzles. They operate at higher liquid pressures than the helix nozzles. These nozzles are usually not directly interchangable.

SLIDE 5-73

DEFINITION OF DROPLET SIZE

1. VOLUME MEAN DIAMETER
2. SAUTER MEAN DIAMETER

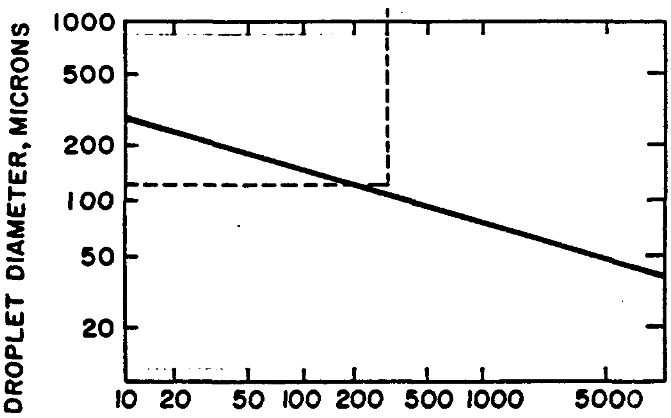
The droplet size distribution is one of the more important characteristics of an operating nozzle. Unfortunately, it is difficult to measure and difficult to even define droplet sizes. The most common definition is the volume mean diameter which is simply the diameter in which 50% of the liquid collected is less than the specified value as shown on the following graph.

Another common definition is the Sauter mean diameter whih is the droplet diameter having a volume-to-surface ratio equal to the overall droplet population. This definition is used in most of the theoretical scrubber models.

Other water droplet definitions include the surface median diameter and the number median diameter. The definition of "droplet size" must be specified along with the value.

The measurement of water droplet sizes is more difficult than solid particulate since cascade impactor and diffusion battery techniques can not be used. Most of the data is based on photography and light scattering. These tests are expensive and can not be performed well under field conditions. Therefore, little droplet size data is available.

SLIDE 5-74

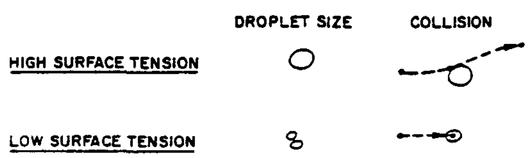


The general relationship between the nozzle operating pressure and the mass average droplet diameter (another term for the volume mean diameter) is shown in this figure. As the pressure rises, the droplet size decreases.

Since the majority of wet scrubber systems operate between 20 and 120 psig, it is apparent that the droplets are relatively large. This can have some effect on the tendency to become reentrained and on the efficiency of collecting particles.

The two fluid nozzles have droplet sizes below that shown for typical pressure nozzles. Nevertheless, the spray droplets are usually above 25 microns and usually in the range of 50 to 100 microns. Generally, as the capacity of a nozzle increases, the droplet sizes produced increases (at constant pressures).

SLIDE 5-75



The physical characteristics of the liquor have an influence on the droplet sizes generated in the nozzle. As the surface tension decreases, the droplet sizes also decrease. A decrease in the liquor viscosity has a similar effect. A decrease in the liquid density, which is related to the solids content, has an opposite effect in that the size range increases.

The surface tension of scrubber liquor could be altered by the additon of either surfactants (reduction in surface tension) and of flocculants (increase in surface tension usually). The liquid density is a function of the solids content of the recirculation liquor. Changes in the liquor temperature and the solids content could influence the viscosity. Because of these factors, it is unlikely that the droplet size distribution is constant in many wet scrubber systems.

SLIDE 5-76

$$\frac{GPM_1}{GPM_2} = \frac{\sqrt{PSI_1}}{\sqrt{PSI_2}}$$

This equation shows the relationship between the nozzle liquor flow rate and various operating conditions.

For a nozzle in good condition and handling liquor of consistent surface tension and density, the flow rate is related to the square root of the nozzle manifold pressure. A decrease in this pressure since the baseline period would supposedly provide an indicator of decreased liquor flow.

Unfortunately, the flow rate through the nozzle is also a function of the liquor density. Another complicating factor is that nozzle condition can rarely be verified. Pluggage of the nozzle will increase manifold pressure while decreasing flow. Erosion of the nozzle orifice will decrease manifold pressure while increasing flow. The erosion and pluggage effect factors have the opposite effect on manifold pressure than normal changes in flow rate for a nozzle in good condition.

SLIDE 5-77

COMMON NOZZLE PROBLEMS

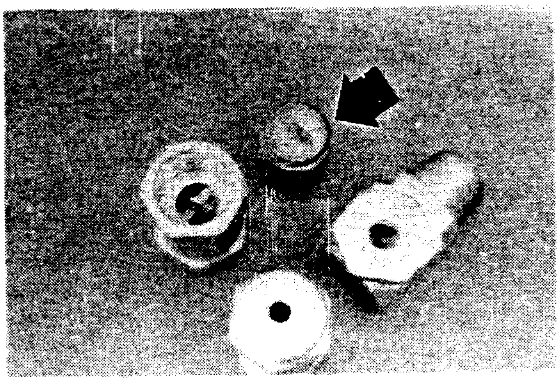
1. COMPLETE PLUGGAGE
2. PARTIAL PLUGGAGE
3. ORIFICE EROSION
4. ORIFICE CORROSION
5. MISALIGNMENT
6. LOW LIQUID PRESSURE
7. IMBALANCED FLOW TO MULTIPLE HEADERS

This list includes the most common nozzle problems for wet scrubber systems.

As a consequence of the nozzle problems, there can be: (1) inadequate gas-liquor contact, (2) low liquor flow rate, and (3) poor particle capture. All of these can singly or collectively have a severe impact on the scrubber performance.

The inspection steps outlined in the next set of slides will be helpful in identifying any problems that exist.

SLIDE 5-78



Pluggage of nozzles can occur due to high suspended solids levels in the liquor and due to scale from ductwork and scrubber walls which is entrained in the liquor stream. Nozzles with small orifices and internal spinner vanes are most susceptible.

The nozzle shown in this slide is a typical full cone unit. This was taken from a unit in which pluggage of all nozzles occurred on almost a daily basis.

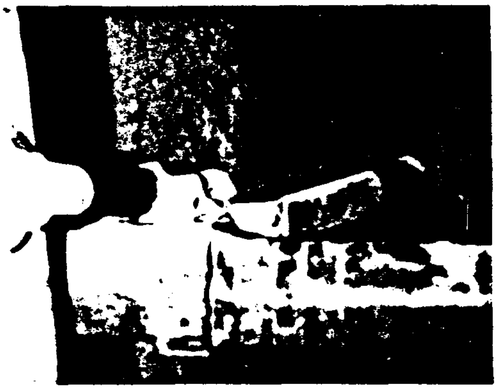
SLIDE 5-79

When the nozzle begins to plug, the spray angle is distorted. Less than adequate gas-liquor contact results for those units in which the main dispersion technique is the nozzle.

After the nozzle is completely blocked, the liquor flow reaches zero for this nozzle.

Symptoms of nozzle pluggage include (1) high suspended solids levels, (2) high pH liquor, (3) increased nozzle discharge pressures, and (4) increased effluent residual opacity. If a number of the nozzles are plugged, the liquor flow rate monitor may indicate reduced liquor flow.

SLIDE 5-80

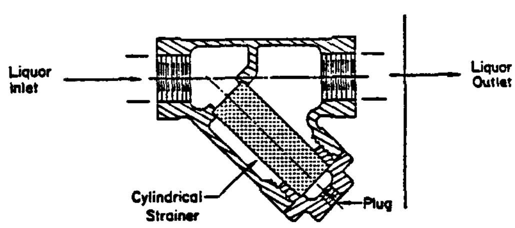


One means of reducing the severity of pluggage problems is to use a nozzle with manual or hydraulic rod-out capaability. The nozzle shown in this slide is equipped with a small rod which can move through the nozzle orifice. Obviously, only nozzle types in which there is no spinner vane or distributor can have this type of rod-out apparatus. The whirl type hollow cone nozzles (which are inherently non-plugging) are the most appropriate nozzle type to be equipped with the mechanical rod-outs.

In order to use the mechanical rod-out, the nozzle must be mounted on the wall of the scrubber. This is often possible in the case of venturi scrubbers, but is impractical for both the packed tower and tray-type scrubbers.

The hydraulic rod out systems are composed of a clean liquor supply at moderate to high pressures which is connected to the nozzle manifold through an isolation valve. On regular intervals, the high suspended solids liquor flow is discontinued and the fresh water is briefly supplied to flush out both the manifold and the nozzles.

SLIDE 5-81

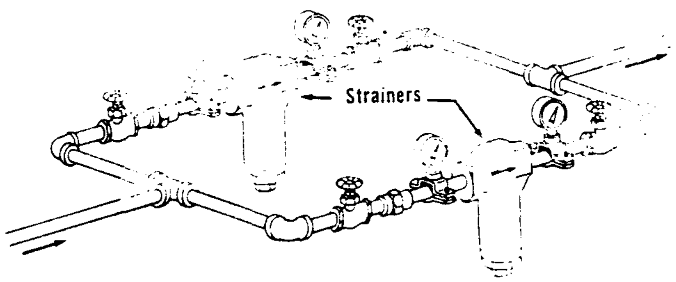


Source: Spraying Systems, Inc.

Another means of reducing pluggage is to use strainers in the recirculation line. They can either be placed before the recirculation pump or before entry to the nozzle headers. The latter is shown in this figure. For each header at different elevations in the spray tower scrubber, there should be a strainer outside the scrubber shell. This will prevent scale and other large material from jamming in the small passages of the nozzle.

The strainer is not effective for solids which are precipitating out of solution or other relatively small particle size solids.

SLIDE 5-82



Source: Spraying Systems Inc.

The strainer can itself be a source of pluggage. In fact, if it becomes blinded, the entire nozzle header is shut down. For this reason, it is important that the strainer be cleaned on a frequent basis.

To prevent scrubber outages during cleaning of strainers, a double arrangement, as shown in this slide, can be used. One line at a time can be isolated and the strainer cleaned while flow continues through the other. There is also a "double basket" unit which can be shifted from one filter to the other without interruping flow.

The strainer can also be placed before the recirculation pump. In this location, it also provides some protection against erosion of the pump impeller.

SLIDE 5-83

SYMPTOMS OF NOZZLE EROSION

1. HIGH LIQUOR SUSPENDED SOLIDS
2. REDUCED NOZZLE HEADER PRESSURE
3. REDUCED PUMP DISCHARGE PRESSURE
4. CORROSIVE CONDITIONS
5. UNSATURATED CONDITIONS AT THE SCRUBBER OUTLET

Erosion of nozzles is caused by the mechanical action of suspended solids passing through the nozzle orifice. As the nozzle wears, the spray angle gradually decreases, thereby affecting the effectiveness of gas-liquid contact.

One symptom of erosion is a decrease in the nozzle manifold pressure from baseline values. This decrease is more severe than the slight drop in the pump discharge pressure which occurs at the same time.

SLIDE 5-84

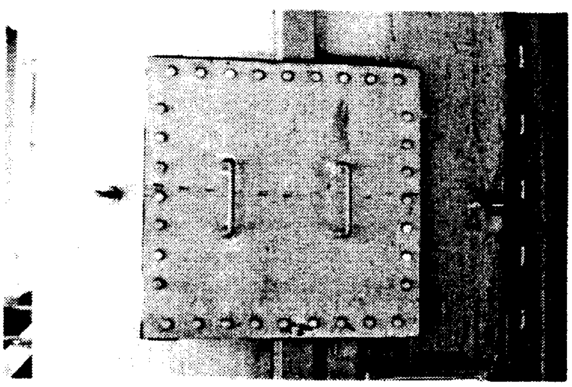
A sample of the recirculation liquor should be obtained in a transparent container as shown in this slide.

The presence of high suspended solids in itself can demonstrate the potential for nozzle erosion (and pump impeller erosion). However, it is the settling rate which is most indicative of this problem. If the materials settle rapidly, the particle sizes of this suspended material are large. It is this large material which has the most erosive effect.

The pH of the sample should also be measured since this provides one indication of the corrosive nature of the liquor. Obviously, a material which is subject to corrosive attack will be more vulnerable to erosive action as the surface layers of metal become corroded. If nozzle wear is severe and/or frequent, the sample of liquor should be brought back to the lab for both chloride and fluoride analyses.

Ways to minimize erosion are similar to those for reducing plugging of nozzles. These include reductions in the suspended solids levels, the use of strainers before the pump or before each nozzle header, and the use of the proper nozzles for the service intended.

SLIDE 5-85



To check for nozzle erosion and/or pluggage in the absence of nozzle header pressure gauges (and pump discharge pressure gauges), it may be possible to observe the nozzle spray patterns.

When the scrubber is OUT-OF-SERVICE AND HAS BEEN PURGED OUT, the hatch above the nozzles should be opened. Once the main recirculation pump has been turned on, the conical spray patterns should be observed. If there is damage, both full cone and hollow cone type nozzles exhibit a severely distorted pattern. Often a high powered flashlight is necessary to see the sprays.

Under no circumstances should the inspector attempt to see the nozzles from below the spray headers since the liquor pH levels are often below 4 and above 9. Under both conditions, eye damage is possible if some of the liquor splashes into the eye. Also, the scrubber vessel should not be entered. Footing is difficult inside most scrubbers, the protective liners can be damaged, and the vessel is poorly ventilated.

SLIDE 5-86

NOZZLE MATERIALS OF CONSTRUCTION

1. BRASS
2. STAINLESS STEEL
3. CERAMIC
4. TEFLON
5. POLY VINYL CHLORIDE
6. POLYPROPYLENE
7. NICKEL ALLOY STEELS

The proper materials of construction should be chosen for the nozzles. Most suppliers have a very wide selection of materials for various corrosive and erosive conditions.

One option which is not available for nozzles is the use of rubber linings. While this approach is very useful for the protection of pump impellers and casing and for the protection of some pipes, it is not applicaple to nozzles. The velocities are too high and the clearances to small to permit the use of linings.

A partial list of nozzle materials is presented in this slide. Brass is generally the least expensive material. However, it is subject to erosion, corrosion and pluggage. Teflon is good for corrosive conditions. Stainless steels are excellent for corrosive conditions with the exception of chloride and fluoride containing liquors. Nickel alloy stainless steels and the silicon carbide nozzles are excellent for abrasion resistance and corrosion resistance. The price of the nozzle increases rapidly as the more resistant materials are selected.

SLIDE 5-87

NOZZLE EVALUATION SUMMARY

1. NOZZLE HEADER PRESSURES
2. PUMP DISCHARGE PRESSURES
3. LIQUOR TURBIDITY
4. LIQUOR pH
5. PHYSICAL CONDITION OF NOZZLES
6. SPRAY PATTERNS

A summary of the inspection points for nozzles is provided in this slide.

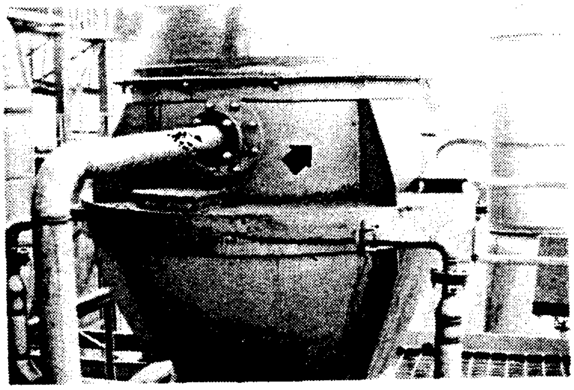
For operating systems, the inspection is normally limited to the nozzle manifold pressures, the pump discharge pressure, the liquor turbidity, the rate of solids settling and the pH.

For units out of service, the nozzles can be visually inspected. However, it is often not possible to clearly see internal deposits and mild erosion conditions.

A more accurate nozzle evaluation can be performed by observing the spray patterns during the operation of the recirculation pump (when the scrubber is out-of-service). With this approach it is possible to see the internal deposits and to see the effects of slight erosion. However, a safe vantage point is rarely available.

Scrubber performance deteoriation is usually significant with only one nozzle plugged or eroded. For this reason, the evaluation of nozzle condition is important.

SLIDE 5-88



Many existing scrubber systems do not have pressure gauges on the manifolds leading to the nozzles. The arrow in this slide illustrates one possible location for a gauge.

There should be a separate gauge for each header so that it is possible to identify pluggage or erosion of a single nozzle in the group served by the header Also, a separate gauge is needed for each level of spray bars since the liquid pressures will be different by values equivalent to the difference in head.

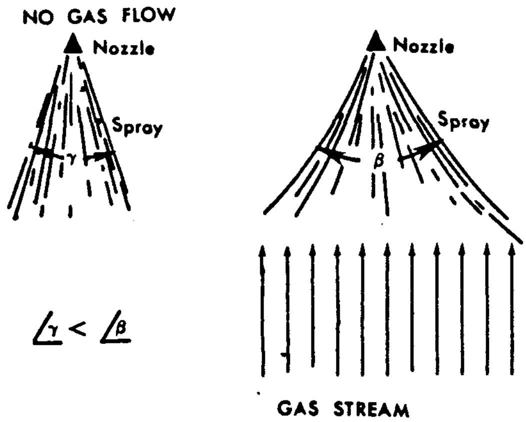
SLIDE 5-89

STATIC CHARGE GENERATION DURING DROPLET FORMATION

There is very little known about the generation of static electricity during the spraying of liquor in wet scrubber systems. The action of the liquor passing over the nozzle orifice should generate considerable static charges on both the nozzle body and the droplets.

The static charges on the droplets could conceivably affect both the droplet size distribution and the effectiveness of particle capture. The charges on the nozzles are probably drained away continuously down the grounded header and piping.

SLIDE 5-90



The persistance of the spray pattern when the nozzle is spraying against the flow of the gas stream is not well known. The spray angle will increase as the gas velocity increases.

Since the gas flow inside scrubber vessels and inside venturi throats is not uniform, the effect on the sprays is not equal throughout. This could conceivably lead to areas within the scrubber with poor gas-liquor contact.

Scrubbers with persistant compliance problems may benefit from some trial and error analyses of different nozzle types and operating pressures.

Anything which increases the droplet velocity leaving the nozzle should favor penetration across opposed gas streams. This includes the use of small spray angle nozzles, the use of full cone nozzles, and decreased liquor pressures. Also, nozzles which generate larger droplets should be considered. If none of these are successful, then a redesigned nozzle pattern may be necessary.

SLIDE 5-91

EVALUATION OF FANS AND VENTILATION SYSTEMS

The fans, ductwork and hoods of air pollution control systems are checked on all level 2, 3 and 4 inspections.

The effectiveness of pollutant capture at the point of generation is checked by observing visible emissions from the process equipment. The static pressure at the hood also provides an indirect indication of the capture velocities.

Leakage through the ductwork can lead to significant fugitive emissions, regardless of whether the system is under positive or negative pressure. There is no sense in fine tuning a scrubber system while tolerating massive fugitive emissions from either the ducts or the process equipment.

The fans on wet scrubber systems are more vulnerable to operating problems than those on other types of air pollution control systems. This is due to build-up of entrained droplets and solids on the fan blades, the corrosion of the fan blades, and the high static pressures which must be developed. During the inspection, the potential for fan problems which could lead to wet scrubber system outages is evaluated. Also, the fan performance data is used as an indirect indication of the gas flow rate through the scrubber vessel.

SLIDE 5-92

TYPES OF FANS

1. RADIAL BLADE
2. BACKWARD CURVED
3. FORWARD CURVED

Due to the high positive and negative pressures which are required in wet scrubber systems, the centrifugal fan is the only type of fan which is suitable. The three main categories of centrifugal fans are listed in the adjacent slide. Only the radial blade and backward curved blade types are generally used on wet scrubbers.

The radial blade fan is slightly less efficient than the backward curved blade, but is less susceptible to solids build-up on the fan blades.

SLIDE 5-93

EVALUATION OF FAN PERFORMANCE

1. CHANGES IN GAS FLOW RATE
2. CHANGES IN SYSTEM RESISTANCE

While approaching a wet scrubber system, the vibration of the fan should be noted. IF THE FAN IS VIBRATING SEVERELY, THE AREA SHOULD BE LEFT IMMEDIATELY. THE DISINTEGRATION OF THE FAN AND HOUSING CAN SEND METAL PARTS (LIKE SHRAPNEL) OVER A WIDE AREA.

This problem, although not common, happens frequently enough that all regulatory agency inspectors must respect the seriousness of this condition. Responsible plant personnel should be notified of the severe vibration, if they are not aware of it already.

To prevent this accident, it is necessary to shut down the fan immediately. This means that the pollutant laden gases must be temporarily vented through the bypass stack. Regulatory agency inspectors should not oppose the temporarily bypassing of the scrubber while the plant personnel conduct an orderly shut-down of the process equipment.

SLIDE 5-94

CAUSES OF FAN VIBRATION

1. EXCESSIVE TIP SPEEDS
2. BEARING FAILURE
3. AERODYNAMIC INSTABILITY

Wet scrubber systems are especially prone to fan vibration problems due to the conditions listed in this slide. Excessive tip speeds result when plant operators change sheaves of belt driven fans without consulting the fan manufacturers. They exceed the structural capability of the fan wheel at the higher than anticipated rotational speed.

As with most maintenance problems, severe fan vibration related outages should not occur frequently at a given plant. The fundamental problem should be identified by plant personnel and corrected before the unit is restarted. All similar units at the plant should also be fixed as soon as possible.

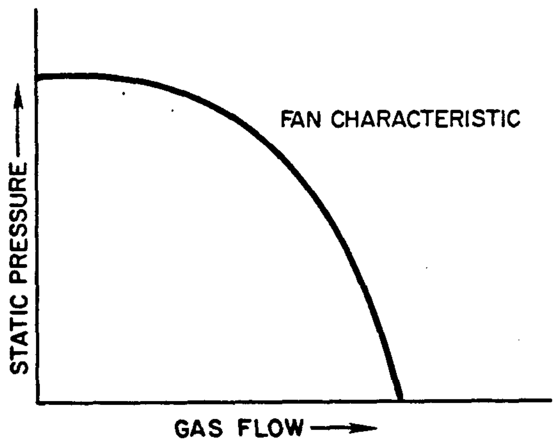
SLIDE 5-95

EVALUATION OF GAS FLOW CHANGES

The main reason for evaluating the fan performance is to determine if the fan can deliver the necessary gas flow rate under the present conditions in the scrubber vessel and the ductwork. No attempt should be made to quantify the flow rate. Instead, the objective is to determine if the flow rate has changed significantly since the baseline period.

The next set of slides concerns the operating principles of centrifugal fans. The performance curves are very similar to those discussed earlier with respect to centrifugal pumps.

SLIDE 5-96

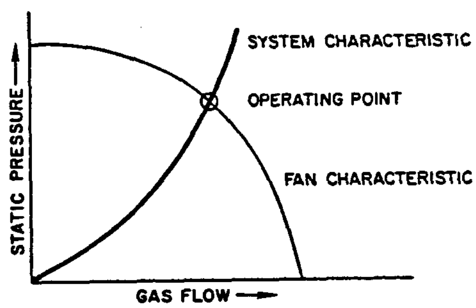


This is a typical fan performance curve. The unit must operate at some point along this line.

The "No Flow" point is the intersection of the curve with the vertical axis. This is the point at which the maximum static pressure is provided by the fan. The "Free Flow" point is the intersection of the curve with the horizontal axis. The maximum gas flow is delivered here, but at a negligible static pressure. The fan normally operates in a middle position, away from both extremes.

The position and shape of this curve depends on the type of fan blades, the fan housing, and the inlet duct configuration. Each fan has à different fan performance curve. The only factor which can change this curve for an existing fan is a change in the rotational speed.

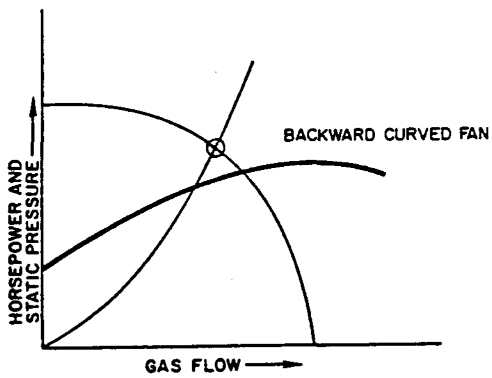
SLIDE 5-97



The new curve added in this graph is the system resistance curve. This is the static pressure required to move the specified quantity of gas against the resistance of the ductwork, hoods, and wet scrubber vessel. The system flow resistance is proportional to the square of the gas flow rate.

The point at which the system resistance curve intersects the fan performance curve is the system operating point. The fan and system reach this automatically as the unit is started.

SLIDE 5-98



The fan motor horsepower curve is shown in this graph. It rises as the gas flow increases in much the same way that the pump motor horsepower increases with liquor flow.

Since the fan motor current is proportional to the brake horsepower, the motor current serves as an indirect indication of gas flow rate. Even slight changes in the currents mean major changes in the gas flow rates.

As with pump curves, no attempt is made to quantify the gas flow rate based on the motor currents. The relationship between motor currents and brake horsepower (the form in which characteristic fan curves are presented) involves the load factor. This can not be measured easily during an inspection. There is also some question concerning the accuracy of fan characteristic curves when applied to existing systems. The geometry of the inlet and outlet ducts of the fans can modify flow characteristics to the extent that the characteristic curves are no longer strictly applicable.

SLIDE 5-99

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

where

Q = flowrate, ACFM
d = density factor, dimensionless

Before making the comparison of the present motor currents to the baseline data, it is necessary to correct for the gas density. The equation shown in this slide is used to correct the present data.

Obviously, it is necessary to know the gas temperature in the fan to perform this correction. If on-site temperature monitors are not available, it is necessary to measure the temperature (level 3 and 4 inspections only). For fans downstream of the scrubbers the gas temperature is normally in the range of 120°F to 140 °F.

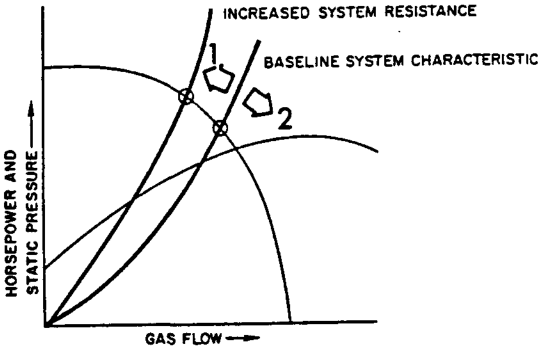
This correction is necessary since a fan it behaves like a shovel, moving a certain volume of gas during each rotation. However, the density of the gas being moved is a strong function of the temperature and is also influenced by the local static pressures and humidities. The work being done by the fan increases as the density increases (cold gas temperatures).

The correction factors which should be used are presented below for common static pressures and temperatures. Since most fans are on the downstream side of wet scrubber vessels, the data here is for saturated conditions. For fans ahead of the wet scrubbers, psychrometric charts should be used to determine the density at the specific gas temperatures and mois-ture level. This should then be corrected for the fan inlet static pressure.

GAS DENSITY CORRECTION FACTORS

Gas Temperature, °F	Static Pressure, Inches of Water				
	-0	-20	-40	-60	-80
120	1.15	1.20	1.28	1.35	1.44
130	1.18	1.25	1.32	1.40	1.49
140	1.22	1.29	1.37	1.46	1.56
150	1.27	1.35	1.43	1.50	1.63
160	1.33	1.40	1.50	1.60	1.72
170	1.42	1.49	1.53	1.70	1.83
180	1.52	1.60	1.71	1.83	1.98
190	1.64	1.73	1.86	2.00	2.18

SLIDE 5-100



The operating point of the system can change if there has been a shift in the system flow resistance. An increase in the resistance lowers the curve in the direction shown by arrow #1. Decreases in resistance result in a shift to the left as shown by arrow #2.

Air infiltration lowers flow resistance since the gas stream travels a shorter path through the system A decrease in the liquid flow rate or a decrease in the gas velocities through the scrubber results in significantly lower gas flow resistance.

An increase in the flow resistance is less common in wet scrubber systems. It can occur due to pluggage of packed beds or demisters. Increased liquor flow rates can also have this effect. However, it is more common to have decreases in the liquor flow rate due to nozzle pluggage, line freezing and pump impeller wear.

SLIDE 5-101

TYPES OF FAN DRIVES

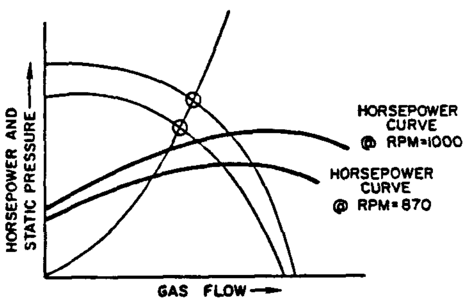
1. DIRECT DRIVE
2. BELT DRIVES
3. VARIABLE SPEED DRIVES

There are three common fan drive arrangements used on wet scrubber systems. In direct drive units, the fan rotational speed is fixed by the motor speed. On alternating current motors this means that the fan speed can not vary. The speed of direct current motors can be easily varied over a wide range. However it is very rare to find a direct current motor on a wet scrubber fan.

The most common arrangement is the belt drive fan. This has small sheaves on the motor and large sheaves on the fan. A set of from two to six belts is used to drive the fan. Fan rotational speed can be changed by changing the sheaves.

Some of the large scrubber installations can use variable speed drives. These have hydraulic couplings for transfer of the shaft energy from the motor and the fan. The rotational speed of the fan can be easily and rapidly varied over a wide range in response to process operating conditions.

SLIDE 5-102



These curves illustrate the shifts in the operating point when the rotational speed of the fan changes. Even a slight change in the fan speed can make a noticeable change in the gas flow rates.

Increased fan speed allows higher gas flow rates and better pollutant capture at the process source. Fan speed is sometimes increased when the capacity of the process equipment is being increased. All increases in fan speed are intentional.

Decreases in fan speed are usually the result of a change in the sheaves (on belt driven units). This may be done in an effort to reduce the energy cost of the fan which is often the single largest operating cost of the wet scrubber system. On direct drive (alternating current) fans, the fan speed can only be decreased by replacing the motor.

Belt slippage can result in a 100 to 300 r.p.m. reduction in the fan speed. This is usually accompanied by a very annoying and noticeable squeal.

SLIDE 5-103

FAN EVALUATION SUMMARY

If there has been a significant change in the fan motor current (after the gas density correction), but the fan rotational speed has not changed, then there has been a change in the system resistance. The most common explanations include air infiltration and reduced liquor flow.

If there has been both a significant change in the corrected fan current and the fan speed, then the operators have been making adjustments to the system. This may have been done to increase gas flow rate or to reduce energy consumption. In the case of reduced gas flow rate, it is advisable to check for fugitive emissions from process equipment.

During the evaluation of fan operation, the condition of the fan housing should be noted. Obvious corrosion here is often accompanied by corrosion of the fan wheel and the ductwork leading to the fan.

SLIDE 5-104

HOOD AND DUCTWORK PROBLEMS

1. Erosion due to Abrasive Particulate
2. Corrosion to Acidic Gases and Moist Duct Surfaces
3. Severe Thermal Expansion and Contraction

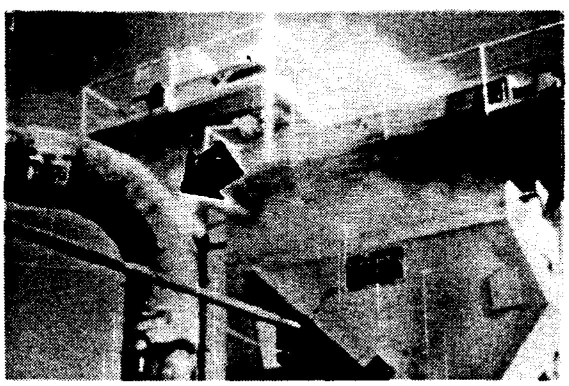
The physical condition of the ductwork and hoods (if present) should be checked whenever there are symptoms of gas flow rate decreases or there are fugitive emissions. There is considerable potential for trouble with these non-moving parts of the wet scrubber system. Some of the contributing factors are listed on this slide.

Erosion is a common problem on wet scrubbers handling high concentrations of large diameter particulate. Unlike most air pollution control devices, the gases accelerate when they enter scrubbers. This aggravates the erosion potential.

Most wet scrubber systems handle gas streams with one or more corrosive components. During start-up, absorption of these gases can occur on downstream ductwork which has a light coating of moisture on the surfaces.

It is common for gases leaving process equipment to be at temperatures of 500 to 2000 °F. While passing to the scrubber vessel, these gases are cooled to temperatures less than 300 °F. During start-up and shut-down of the system, there can be major differences in the rates of expansion and contraction of the ductwork. This can lead to air infiltration points due to the ductwork deterioration.

SLIDE 5-105



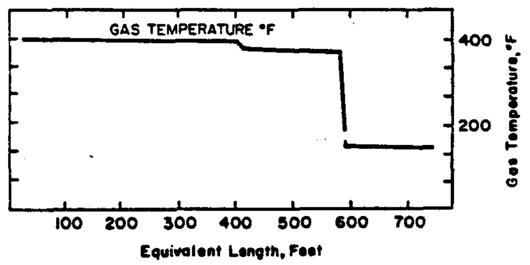
One of the most common sites of duct erosion is at sharp turns. The inertia of large diameter particles results in severe erosion of a portion of the duct as shown in the top part of the slide.

It is common practice to install wear plates on the outer surfaces of the elbow to minimize the frequency of duct replacement.

Another approach is to reduce the duct velocity by reducing the gas flow rate or by increasing the radius of the turn.

Erosion may become a problem on systems in which the fan speed has been increased to increase overall production capacity. The gas velocity will increase in direct proportion to the increase in the actual cubic feet per minute of gas flow. The normal gas transport velocities range from 3000 feet per minute to 4500 feet per minute. However, erosion can occur even in this range.

SLIDE 5-106

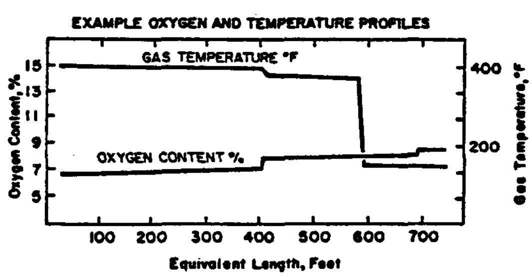


Air infiltration sites are often hard to find due to the inaccessibility of the ductwork and due to the combined effect of a large number of small erosion and corrosion holes. A duct temperature profile can be prepared to determine if infiltration does exist and to determine the most probable areas for the problem.

The profile is constructed by measuring the gas temperature in the duct at all points with safe and convenient access. The data is plotted as shown in this slide. The graph starts with the location of the process equipment and proceeds along the ductwork to the scrubber. The sudden drop near the right of the graph shows is the effect of the scrubber.

Although this approach can not be used on all wet scrubber systems, it is convenient in many cases. It is necessary to have some baseline data so that normal temperature decreases due to radiation and convection can be differentiated from the cooling which results from the infiltration of ambient air.

SLIDE 5-107



A similar duct profile can be prepared using the oxygen concentrations in gas streams from boilers and similar combustion systems. The measured oxygen data is plotted along the ductwork line from the combustion chamber to the scrubber.

The oxygen concentration should not change much. There will usually be some slight infiltration across the fan and the scrubber vessel, but this is usually slight.

This type of profile can only be prepared for combustion sources having oxygen concentrations in the range of 2 to 12%. It is not very effective for most driers since these often operate at 17 to 19% oxygen. These values are too close to the ambient level of 20.9% to provide any reasonable sensitivity in detecting air infiltration.

SLIDE 5-108

$$\overline{V} = C\sqrt{S_h}$$

$\overline{V}$ - Average Velocity
C - Constant
S_h - Hood Static Pressure

Another means to check the significance of air infiltration is to compare the hood static pressure with the baseline values.

The hood static pressure is proportional to the velocity pressure in the duct leading from the hood. The constant "C" is primarily determined by the geometry of the hood. However, with the baseline comparison, it is not necessary to know "C" unless the hood configuration has been modified significantly.

The hood static pressure is normally in the range of -0.5 inches W.C. to -2.0 inches W.C. Therefore, it should be measured by an inclined manometer or by a low-range diaphragm gauge. The measurement port should be in the duct immediately after the hood. For maximum accuracy, there should be 4 ports spaced 90° around circular ducts. Due to the potential for pollutant exposure near the hoods, direct accessibility to the port location is usually not desirable. Instead, the port should be connected by means to tubing to a safe and convenient measurement location.

Lecturer's Notes

Some of the attendees may ask why a complete traverse should not be done to get very accurage static pressure data across the entire duct. It should be pointed out that the effort required for this is equivalent to simply doing a complete velocity pressure traverse and calculating flow rate directly. The static pressure measurement is meant to be a convenient short-cut. Also, it is often unsafe directly adjacent to a hood and a pitot traverse can not be conducted.

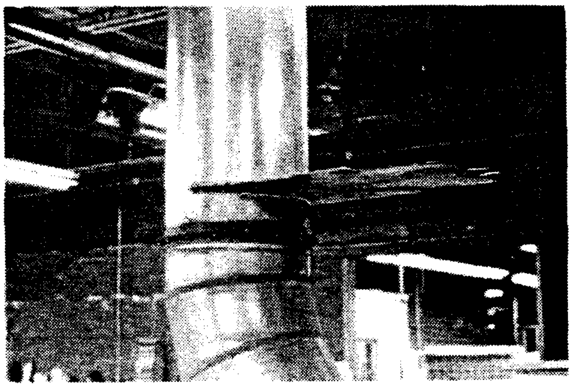
SLIDE 5-109

Source: National Audiovisuals Center

Even if the gas flow rate through the hood has not changed since the baseline period, it is possible to have poor pollutant capture. This can be caused by a damaged hood or by cross drafts.

The hoods can be damaged by overhead cranes. When the hood partially restricts access to the process equipment, the operators often move the hood away permanently. Both of these mean that the hood is not handling some plant area and less of the pollutant laden gases.

SLIDE 5-110



Two explanations for reduced gas flow at the hood are the partial closure of the blast gates in the downstream duct and the accumulation of solids which serve as a "damper" on the system.

A photograph of a blast gate is shown here. It is simply a guillotine damper which can close off all or part of the duct when the process is not being operated. Some operators can change the positions of these on several of the ducts without being aware that the entire system is adversely affected.

In systems handling large quantities of large diameter particulate or which have oversized ducts with low gas velocities, it is possible for solids to accumulate. Initially this simply restricts gas flow. If the deposits exceed the load bearing capability of the duct supports, the entire duct will sag or fall. Clean-out ports can be used to remove accumulated materials when the scubber system is out-ot-service.

SLIDE 5-111

MATERIALS OF CONSTRUCTION FOR WET SCRUBBER SYSTEMS

The next few slides address the wet scrubber system materials of construction. The proper selection and maintenance is largely responsible for the successful performance of the system.

As an inspector, it is important to understand what can go wrong. The goal is to minimize both the obvious and the repeat mistakes.

The selection of materials of construction is not a single decision, but a long series of judgements concerning each individual component of the system. Rarely are the same materials appropriate in each portion of the unit. These judgements must be based on reasonable estimates of the chemical and physical conditions to which the materials will be exposed. It is important to consider both the steady-state conditions and the exposures during process upset and start-up.

SLIDE 5-112

TYPES OF MATERIALS

1. METALS
2. ORGANIC COATINGS AND LININGS
3. CERAMIC AND INORGANIC MATERIALS

The three basic categories of materials are listed in this slide. The metals commonly used include, but are not limited to: carbon steels, austenitic, ferritic and martensitic stainless steels, and various types of high nickel stainless steels.

There are a large variety of organic liners for metal surfaces. These include polyester and epoxy materials. The polyester materials can be provided with a flaked glass reinforcement. Included in this category are the natural rubber and neoprene sheet materials.

The ceramic and inorganic materials include, but are not limited to prefired brick, hydraulic bonded concretes and chemically bonded concretes. These materials provide both corrosion and erosion resistance in especially vulnerable areas of the wet scrubber system.

Lecturer's Notes

The selection of the specific materials to be used is a complicated task and should remain the sole perogative of the plant operator and designers. The regulatory agency should not encourage the use of certain materials simply because these were used successfully elsewhere. There are too many site specific factors which must be considered in the selection of materials.

SLIDE 5-113

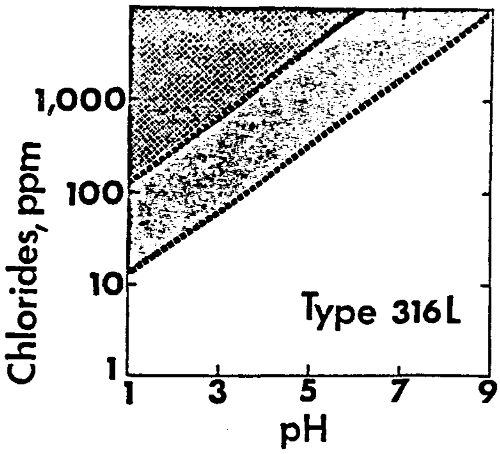
IMPORTANT FACTORS WHICH AFFECT CORROSION RATES

1. Liquor pH
2. Chloride Concentration

The areas subject to corrosion are all the wetted parts of the scrubber system These include the scrubber vessel, pumps, piping, outlet ductwork, fans, and recirculation tanks.

In these wetted areas, the most important factors affecting the corrosion rate are the pH and the chloride concentration. Neither of these are constant in a scrubber system. The pH is generally lowest in the scrubber outlet. The chloride concentration can be higher in solids deposits than in the recirculating liquor.

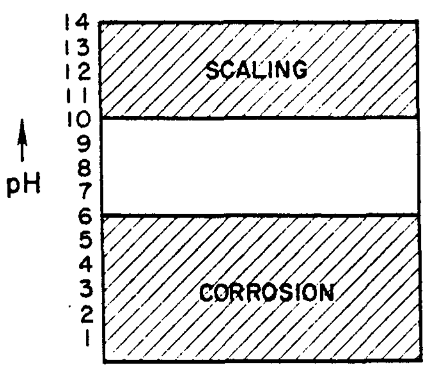
SLIDE 5-114



Source: Chemical Engineering
June 5, 1978, Page 163

This graph illustrates the general relationship between pH and chloride concentration on the rates of pitting and crevice corrosion (two common modes of metal damage) for AISI 316L stainless steel. At the pH levels of 4 and above which are common in wet scrubber systems, the chloride concentrations above 1000 ppm result in severe damage. Even at levels as low as 100 ppm, there can be damage. It is apparent that higher chloride concentrations can be tolerated at higher pH levels.

SLIDE 5-115



It is apparent from the slide provided above that pH levels in the range of 1 to 4 are especially prone to corrosion, even at very low chloride levels. It is important that the unit always be maintained above this level. Problems often occur when the scrubber system is shutdown and not purged of acidic gases. Also, the failure of an alkaline addition system can lead to sudden drops in the pH.

A short term drop in the pH levels can initiate corrosion of materials that would not otherwise be damaged. Once the pitting action has started, it can continue under the conditions which were previously acceptable.

Only the nickel alloys are relatively immune to the low pH related types of corrosion damage. These are rarely used due to the very high cost of the materials.

SLIDE 5-116

CONDITIONS WHICH FAVOR LOCALIZED CORROSION

1. CREVICES
2. SOLIDS DEPOSITS
3. HIGH CHLORIDES LEVELS
4. LOW pH
5. EROSIVE LIQUORS

Localized deposits of solids should be avoided wherever possible. They can be rich in chloride levels and create oxygen depleted areas near the metal surface. This can result in accelerated corrosion in localized portions of the scrubber.

Crevices should also avoided. These provide sites for crevice corrosion.

SLIDE 5-117

ORGANIC LINER PROBLEMS

1. Blistering
2. Debonding
3. Chemical Attack by Scrubber Liquor
4. Nonuniform Coating
5. Erosion of Liner

Organic linings are less costly than corrosion resistant metals. However, they are susceptible to the problems listed here.

Temperature excursions are a common factor in liner failure. They can lead to both blistering and debonding of the liner from the base metal it was intended to protect. The loss of liquor flow can lead to short term temperature spikes.

Proper surface preparation is critical to the success of the liner. The metal surface must be cleaned and then coated with a primer. The coating must be applied uniformly and at the proper thickness. There should be no voids or pinholes in the liner. Surface preparation is also important when repairs are being made to damaged portions of the liner.

Organic liners can have a limited life in the high liquid and gas stream velocity areas of the scrubber. It does not take long to remove portions of a liner which is typically 40 to 80 mils thick (0.04 to 0.08 inches) when highly abrasive particulate is present.

SLIDE 5-118

TEMPERATURE LIMITS
OF
ORGANIC LINERS

1. Polyesters - 250 °F
2. Epoxy - 250 °F
3. Vinyl Esters - 360°F
4. Fluoropolymer - 400 °F

The temperature limits of common types of organic liners are presented in this slide. Slightly higher short term transient temperatures can usually be tolerated, but continuous operating conditions should be lower.

Th fluoropolymers have the highest allowable temperature and a relatively high cost. These material are used mainly in areas where high temperatures during shut-down or system upsets are expected.

The temperatures listed above are for dry conditions. The maximums for wet conditions are lower.

The temperature limits for all of these materials could easily be exceeded if the recirculation pump fails. Systems in which there is a presaturator or evaporative cooler are obviously less susceptible to this type of damage since two separate pumps must fail in order to have a sudden excursion.

Bypassing is necessary on any system when the gas exceeds normal temperatures. On units where the bypass is controlled by manually activated dampers, the damage to the liners may have already occurred before the hot gas is directed up the bypass stack. In any case, the scrubber system should be purged of hot and pollutant laden gas trapped inside.

SLIDE 5-119

RUBBER LINERS

1. MINIMIZE LIQUID PENETRATION UNDERNEATH LAYERS
2. PREPARE SURFACE PROPERLY TO ACCEPT ADHESIVES
3. MINIMIZE TEMPERATURES EXURSIONS

The rubber liners are applied as sheets. It is important that they be layered properly so that scrubber liquor will not be forced underneath the layers and attack the adhesive.

As with the organic liners, it is important to maintain the temperature at low levels to prevent damage. It is also necessary to prepare the surface to accept the adhesive.

SLIDE 5-120

TEST SPOOLS FOR EVALUATING MATERIALS OF CONSTRUCTION

1. WEIGHT LOSS
2. PITTING
3. CREVICE FORMATION

For existing systems, there is sometimes a need to evaluate changes in the materials of construction in order to minimize system failures. One way of performing these tests is to use a test spool containing samples of a number of different metals with or without liners. The spool is placed in the portion of the scrubber system experiencing frequent materials problems.

The materials are compared based on the general rate of weight loss, the rate of pitting and the depth of crevice formation. This can be done on several occasions so that the rates of corrosion can be compared with present materials.

LECTURE 5 - REVIEW PROBLEMS AND QUESTIONS

5-1. The correct answer is "b". Pluggage is not a likely explanation for the observed rainout. The gas velocity through the demister is 29.03 feet per second, assuming that the entire demister is open. This velocity is above the normally accepted limits for chevron demisters. The rainout is probably due to the reentrainment of droplets from the downstream edges of the demister. The demister is undersized. Those who answered "a" may protest that pluggage is also conceivable. While this is true, it would only aggravate the situation with the obviously inadequate demister. Their answer is wrong since correction of the pluggage condition would not alleviate the rainout conditions, only improve it slightly.

5-2. Answer "b" is correct. It takes much less energy for a fan to move a cubic foot of gas at 325 °F than at 125 °F. The gas has a much lower density at higher temperatures. As an analogy, relate the effort involved in shoveling a light fluffy snow to that of shoveling a wet snow If anyone is having trouble with this concept, go back and review the section of motor current correction factors. It may also be helpful to briefly review the ideal gas laws.

5-3. Those who have been answering "b" are on a hot streak. It is correct again. However, answer "c" is equally correct. The squeal usually indicates drive belt slippage. The reduction in the fan rotational speed leads directly to a reduction in the gas flow rate. It would be worthwhile to check the scrubber pressure drop since this is related to the square of the gas flow rate. The presence or absence of fugitive emissions should also be checked.

5-4. The correct answer is "b" again. Pipe sizes for different materials are not identical. It is necessary to consult standard tabulations of sizes to determine the actual inside and outside diameters denoted by the pipe nominal size.

5-5. The correct answer is "d". The increase in the nozzle header pressure and the decrease in the scrubber pressure drop both suggest a reduction in the liquor flow rate due to nozzle pluggage. The high liquor turbidity also suggests the potential for nozzle pluggage. Cavitation, answer "a", would also lead to a reduction in the liquor flow rate and a drop in the scrubber pressure drop. However, it would also decrease the nozzle header pressure.

LECTURE 5 - REVIEW PROBLEMS AND QUESTIONS

5-1. The gas flow rate measured downstream from a 3-pass chevron demister is 87,500 ACFM. The average gas temperature at the port used to measure the gas flow rate is 126 °F. The demister static pressure drop is 1.2 inches of water and the diameter of the circular demister is 8 feet. Is pluggage a likely explanation for the observed rainout from the stack?

a. Yes.
b. No.
c. Maybe.

5-2. Does it take more energy for a centrifugal fan to move a cubic foot of gas at 325 °F than it does to move a cubic foot at 125 °F?

a. It takes more energy at 325 °F than at 125 °F.
b. It takes less energy at 325 °F than at 125 °F.
c. There is no difference in the energy requirements.

5-3. During an inspection of a wet scrubber system, a squeal is heard in the vicinity of the fan. Is this a symptom of an operating problem?

a. Yes, the gas velocity at the fan inlet is excessive.
b. Yes, the fan rotational speed has probably decreased.
c. Yes, the gas flow rate through the scrubber system has probably decreased.
d. No, this is normal around fans.

5-4. Is a 1 inch PVC pipe the same size as a 1 inch steel pipe?

a. Yes.
b. No.
c. The outside diameters are the same, but the inside diameters differ.
d. The inside diameters are the same, but the outide diameters differ.
e. The hydraulic diameters are identical.

5-5. The recirculation liquor has a very high turbidity. The liquid pressure at the nozzle header has increased from a baseline average of 45 psig to 62 psig. The scrubber pressure drop has decreased from a baseline average of 17 inches W.C. to 14 inches W.C. The gas temperature of the scrubber inlet stream has decreased from 350 °F to 334 °F. What possible problems should be checked during the remainder of the inspection?

a. Pump cavitation.
b. Erosion of the spray nozzles.
c. Process operating conditions.
d. Pluggage of the spray nozzles.
e. None of the above.

LECTURE 5 - REVIEW PROBLEMS AND QUESTIONS

5-6. Only answers "c" and "e" are correct. All of the others listed, with the exception of guillotine valves, are for shut-off type service. There is no such thing as a guillotine valve for liquids.

5-7. No. Pump cavitation does not conclusively demonstrate air infiltration into the suction line of the pump. Cavitation is the localized vaporization of liquor components near the impeller due to low pressures in this part of the pump. It can be caused by air infiltration or anything which reduces the Net Positive Suction Head.

5-8. The seal water is meant to protect the bearings, therefore answer "a" is correct. Following the bearing damage, excessive vibration and pump failure will occur. Therefore, answers "c" and "d" are also correct. Anyone having answers "b" and "e" needs to review the pump section.

5-9. The main objective of this question is to illustrate that there is a lot which can be done during a level 2 inspection. In this case, the following answers are correct - "b", "d", "f", "h", and "j". The reason for checking the pH is to determine if there is potential for scaling due to chemical precipitation on the demister blades. Answers "d", "f", and "h" all help evaluate the effectiveness of the cleaning action. Answer "j" is correct since it is possible that an increase in overall gas flow rate due to production increases has resulted in more carry-over of liquor from the top stage of the scrubber to the demister. The latter is especially troublesome if the freeboard distance is small.

LECTURE 5 - REVIEW PROBLEMS AND QUESTIONS

5-6. What types of valves are normally used for throttling liquid flow rates?

a. Check valves
b. Foot valves
c. Globe valves
d. Gate valves
e. Ball valves
f. Guillotine valves
g. All of the above

5-7. Does cavitation of a pump conclusively demonstrate that air is infiltrating the suction line of the pump?

a. Yes.
b. No.
c. Maybe.

5-8. A recirculation pump is handling a liquor having a suspended solids level of 2%. If the seal water is accidently stopped, what possible problems can occur?

a. Bearing failure
b. Accelerated impeller wear
c. Excessive vibration
d. Pump failure
e. Reduced Net Positive Suction Head
f. All of the above

5-9. A demister is suffering chronic rainout problems and there have been a large number of community complaints During a level 2 inspection, it is determined that there is a demister cleaning system which is operated at least once per shift. Is there anything else which should be checked during this level 2 inspection?

a. No. A level 3 inspection should be conducted in the near future.
b. Yes. Plant personnel should be asked to measure the pH of the demister wash liquor.
c. No. A stack test is obviously necessary.
d. Yes. The duration of the cleaning cycle should be determined.
e. No. Slight rainout is inevitable from demisters.
f. Yes. The pressure of the demister wash water line during cleaning should be determined if possible.
g. No. Obviously cleaning should be discontinued to reduce the quantity of water on the demister which can be reentrained into the gas stream going up the stack.
h. Yes. The turbidity of the demister wash liquor should be qualitatively evaluated.
i. No. Small gaps should be opened between demister sections to reduce the gas velocity through the demister to more reasonable velocities.
j. Yes. The freeboard distance and production rates should be checked.

LECTURE 5 - REVIEW PROBLEMS AND QUESTIONS

5-10. Answer "d" is correct, the inlet damper serves all of these functions. This is a subject that was not addressed during the lecture. It is included to illustrate that some useful information can be obtained only by working the problems.

5-11. The correct answer is "b". The objective of the demister spray nozzles is to clean off the entire demister surface. The hollow cone nozzles would miss large areas directly below the nozzles.

5-12. The chloride concentration of 0.2% is equivalent to 2000 ppm which is a very high level! The pH of the liquor should be determined (answer "a"), if at all possible since there is a strong relationship between the rate of corrosive attack and the pH. If the pH is less than 7, most metals are vulnerable. The type of metal is important since there is a major difference in susceptibilities. Those with higher molybdenum, chromium and nickel are less vulnerable. The nickel alloys may experience no problems under these conditions. Answer "d" is also correct for obvious reasons.

There can be considerable room for disagreement on answer "e". The plant should have the right to use whatever materials are most economical as long as they do not cause unnecessary excess emission conditions. If they can shut down the system before violations occur, it may be possible to use cheap sacrifical materials. On the other hand, they should not claim that corrosion control is a "mysterious art" and that frequent bypass conditions are inevitable.

5-13. The plant data is not reasonable. Answer "b" is correct. The pipe velocity assuming Schedule 40 pipe is approximately 19 feet per second which is about 50% higher than normally used <u>maximum</u> transport velocities.

5-14. Answer "c" is correct. This is another one of those education questions buried in the midst of the review problems and questions. Those who answered "e" should get at least partial credit for recognizing a question which is not central to the job of agency inspector. This is just a "nice-to-know" fact.

5-15. The Austenitic stainless steels are not magnetic while the carbon steels obviously are. A magnet is a convenient and quick way to determine the difference.

5-10. What is the purpose of the damper on the inlet to the fan?

a. To improve gas stream loading into the fan wheel
b. To control the gas flow rate through the system
c. To protect the fan motor from overloads
d. All of the above

5-11. Would a hollow cone spray nozzle be appropriate for demister cleaning service?

a. Yes.
b. No.
c. Maybe.

5-12. The measured chloride concentration in the effluent liquid stream of a scrubber is 0.2%. What should be done to evaluate the potential for serious corrosion?

a. Determine the pH of the scrubber liquor.
b. Nothing. The chloride concentration is below the threshold levels necessary to contribute to corrosion.
c. Request information of the type of metals used in the scrubber.
d. Check for obvious corrosion.
e. Corrosion is strictly a plant economic consideration and not an appropriate concern for regulatory agency inspectors.

5-13. During an inspection an attempt is made to calculate the present liquid-to-gas ratio for a scrubber. However, there is no liquid flow monitor. Plant personnel report that the 3" steel pipe supplying the scrubber is handling 435 gallons per minute. Is this data reasonable?

a. Yes.
b. No.
c. Maybe.

5-14. Is AISI 316L stainless steel different from AISI 316 stainless steel?

a. No. They are just trying to confuse us.
b. Yes. The AISI 316L has less alloy materials and is cheaper and more subject to corrosion.
c. Yes. The AISI 316L has less carbon. It is both easy to fabricate parts and less subject to a certain type of corrosion.
d. I really don't think this is one of the better questions.

5-15. Is it possible to differentiate a carbon steel from a 300 series stainless steel during a level 2 inspection?

a. Yes. But only on a good day.
b. Yes. I can also leap over tall scrubbers in a single bound.
c. Yes. With a magnet.

LECTURE 6

LIQUOR ANALYSES

SLIDE 6-1

LIQUOR ANALYSES

1. Suspended Solids
2. Dissolved and Total Solids
3. Turbidity
4. pH
5. Sulfates
6. Alkalinity
7. Surface Tension
8. Conductivity
9. Oxidation-Reduction Potential

This lecture concerns the analyses of liquor samples obtained while inspecting wet scrubber systems. These tests help to identify the fundamental causes of corrosion, erosion and pluggage of the scrubber components.

The surface tension affects the rate of solids settling, the spray droplet size, and the ease of particle capture.

The conductivity and the oxidation/reduction potential are of interest when evaluating odor scrubbers. The alkalinity and sulfates levels are important to sulfur dioxide removal systems.

With the exception of the pH measurement, all of the analyses must be conducted at the control agency laboratory. The type of instrumentation required and the quantity of sample necessary are discussed in this section. The importance of proper sample acquistion techniques are emphasized.

SLIDE 6-2

SAMPLING PRINCIPLES

1. Take Representative Samples
2. Use Proper Sampling Techniques
3. Protect the Samples

There is very little sense in performing highly accurate and demanding analyses on samples that have been taken at the wrong location or handled improperly. These three sampling principles must be satisfied and thisis not as easy as it may seem.

The logical starting point in acquiring samples is to review the scrubber flow chart to determine the locations at which samples should be taken. Sampling times should be carefully chosen to provide the maximum diagnostic information.

The procedures used to acquire any samples should be briefly but completely described in the field inspection notes. The names of plant persônnel authorizing sample acquistion should also be recorded in the notebook.

Obviously, all samples should be labeled with information such as location of sample collection, date and time of collection, and notation of any information that may change before analysis (temperature, pH, appearance). Also, if a sample must be stored for any period of time, the general practice is to refrig -erate it at 4 °C.

SLIDE 6-3

GRAP SAMPLES
VS.
COMPOSITE SAMPLES

One of the first questions faced in sampling is whether to use a grap or a composite sample.

A grap sample is one taken at one particular time and indicates the condition of the stream at that one time. A composite sample is a mixture of smaller grap samples taken over an extended period of time and is representative of the stream over that longer period of time.

In the case of a liquor analysis, a number of grap samples taken at half hour intervals and analyzed separately could be preferred over a composite sample covering the same time period. This is because the composite could average out any irregularities which, as an example, may have occurred because of an increased gas flow to the scrubber. Also, these grap samples can be taken as a set at the scrubber inlet and outlet, so a comparison can be made and the performance of the scrubber determined.

SLIDE 6-4

SAFETY PRECAUTIONS

1. Open all Sample Valve Slowly and Wear Eye Protection at All Times.
2. Avoid Rotating Mixers in Tanks and Other Moving Equipment.
3. Avoid Direct Contact with Liquor.
4. Do Not Drop Objects Into Tank of Vessel.

Safety procedures deserve special consideration when discussing sampling. The potential safety hazards listed in this slide should be considered prior to beginning any sampling work.

The most common problem is splashing liquor from taps downstream of the recirculation pump. With typical line pressures in the range of 20 to 100 psig, it is possible to get an eyeful if the valve is opened rapidly. Highly alkaline liquors can cause severe eye damage. This liquor is also almost always hot.

Direct skin contact with the liquor being sampled is almost never wise. Some of these may contain pathogenic bacteria and viruses and most contain skin irritants.

When leaning over mixing and recirculation tanks, it is easy to drop pens and other materials carried in shirt pockets into the tank. It is conceivable that this will be carried into the pump suction line and damage the pump impeller. The dropped material may also contribute to pluggage of the pump suction line strainer.

SLIDE 6-5

The turbidity of the liquor is one of the most important operating parameters when anaylzing systems with chronic nozzle plugging problems and/or bed plugging problems.

Turbidity is the measure of the clarity or cloudiness of the liquor. It is caused by the presence of suspended matter in a finely divided state. Particulate matter, precipitates, and organic matter all contribute to the turbidity. The terms "suspended matter" and "turbidity" should not be confused, although they are closely related. Suspended matter is the amount of material in a sample which can be trapped by a filter. Turbidity is a measurement of the optical scattering and absorption of light through a sample.

The turbidity should be evaluated qualitatively as soon as the sample is obtained since it can change rapidly. If quantitative data is desired, the analyses should be done the same day. In most cases, the sample can be stored in the dark for up to twenty-four hours if it is wrapped in aluminum foil and not exposed to extreme temperatures.

SLIDE 6-6

TURBIDITY

JTU - NTU

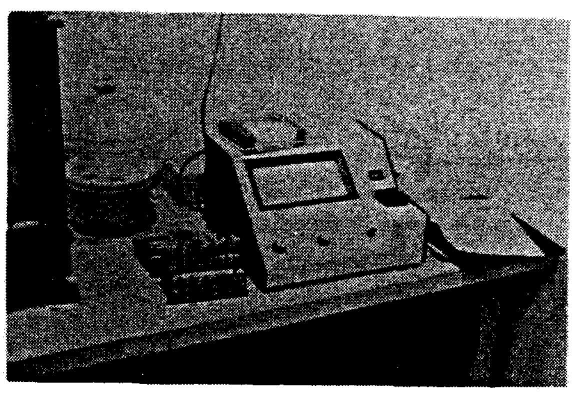
?????

It is important to understand the test methods for turbidity since some plants measure this on a regular basis. In a few cases, the inspector may also wish to have the agency lab perform the analysis.

The standard method for determining the turbidity has been based on the use of the Jackson candle turbidimeter. However, the lowest value that can be measured on the instrument is 25 units.

With the need to measure samples in the range of zero to five units, an alternative method is used incorporating nephelometers which measure the intensity of light scattered at right angles to the incident beam. Since there is no direct relationship between the optics of the two methods, turbidities measured on a nephelometer are expressed in nephelometric turbidity units (NTU) and those measured on the candle turbidimeter as Jackson turbidity units (JTU). The nephelometer is preferred because of its greater precision, sensitivity, and range.

SLIDE 6-7



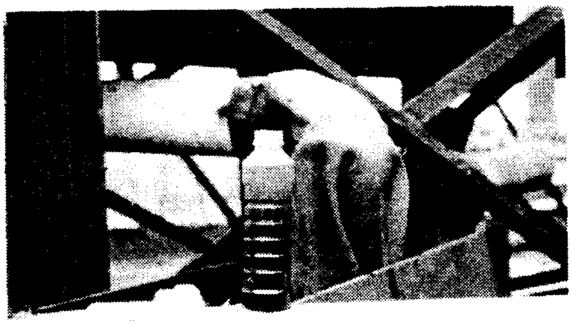
A typical nephelometer is shown here. This instrument must be calibrated using standards in each turbidity range anticipated.

The sample is shaken vigorously and then poured into the turbidity tube after air bubbles have been allowed to escape. It is important that the tube be scrupulously clean and have no flaws or scratches. Fingerprints on the tube and air bubbles clinging to the sides will also cause erroneously readings.

For samples above 40 NTU, the sample should be diluted with one or more volumes of distilled water until the turbidity falls into a measurable range. The turbidity of the original sample is simply the turbidity of the diluted sample multiplied by the dilution factor. For example, if two volumes of distilled water were added to one volume of sample and a reading of 30 NTU was obtained, the turbidity of the original sample would be 90 NTU.

Manufacturers of turbidimeters often use different optical designs in their units and this can result in different turbidity reading of a particular sample. Therefore, analyses performed by the agency lab may differ somewhat from values routinely recorded by plant tests. Changes in the sample during transport to the agency lab can also contribute to observed differences.

SLIDE 6-8



The solids which quickly settle out of solution should be removed before taking the turbidity measurement.

The more material that settles to the bottom of the sampling tube in a short time, the greater the potential for erosive wear of pump impellers, valves and nozzles. This is because rapidly settling solids have large diameters. This large material is naturally erosive in high velocity areas.

When taking the sample, the presence of rapidly settling solids should be noted since this is as important as the sample turbidity.

SLIDE 6-9

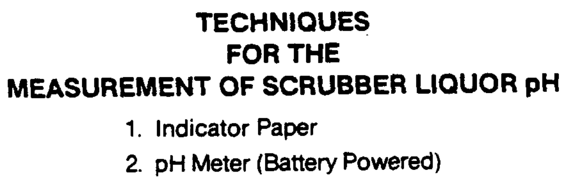
SUSPENDEDED SOLIDS
+
DISSOLVED SOLIDS
=
TOTAL SOLIDS

The suspended solids are of interest whenever the system being evaluated has had erosion or pluggage problems. The dissolved solids are important in any system prone to scaling. Both the dissolved and suspended solids are important when liquor is being sprayed into an evaporative cooler or a presaturator for gas cooling.

This is not an absolute distinction between suspended and dissolved solids. The nature of the filter used in seperating the materials influencing the results. Some of the important factors include: (1) the nature of the material in suspension, (2) the pore size of the filter, (3) the area and thickness of the filter, and (4) the amount of material on the filter mat.

The temperature used to dry the sample has an important influence on the results because weight losses due to the volatilization of organic mater, mechanically occluded water, water of crystallization, and gases from chemical decomposition are all dependent on the drying temperature. Most residuals are dried at 103 to 105 °C (217 to 221 °F). At this temperature, some mechanically occluded water and water of crystallization are retained. Volatilization of organics will be inconsequential. The temperature used for drying the sample should be specified along with the results.

SLIDE 6-10



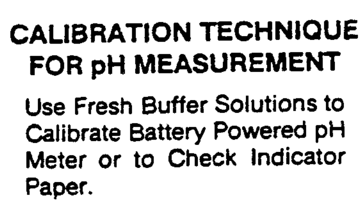
The pH of both the scrubber inlet and scrubber outlet liquors should be tested In the majority of cases, the inlet liquor has a higher pH than the outlet liquor due to the absorption of acidic gases such as sulfur dioxide and carbon dioxide.

The same sample used for qualitatively evaluting the turbidities can be used for the pH tests.

The two available techniques for pH analysis are listed here. Indicator paper should not be used whenever highly accurate data is necessary since it is good to only plus or minus a full pH unit. As the paper ages, the accuracy decreases. The battery powered pH meters generally provide data good to plus or minus 0.1 pH units.

Solutions which chemically attack the pH paper dyes include, but are not limited to hypochorite and permanganate. These units and those with highly colored liquors should not be evaluated using pH paper.

SLIDE 6-11

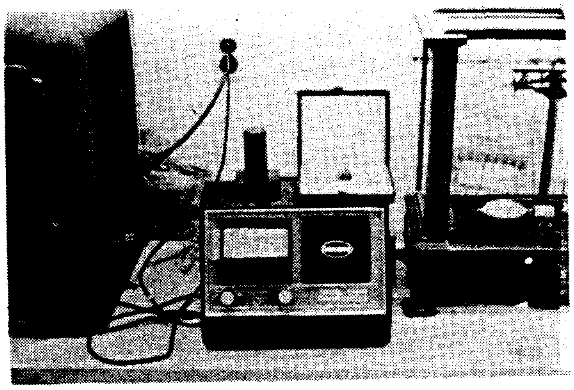


Liquor pH should be measured immediately after obtaining the sample since it is subject to change. Prior to each measurement, the pH meter should be adjusted using buffer solutions of approximately 4, 7 and 10. Since these buffers can age, fresh solutions should be obtained on a regular basis.

If indicator paper is being used, it is a good practice to occassionaly check the response of this paper against buffer solutions. This can be done at the agency lab before leaving for any field work.

It is important to check all instruments prior to beginning the field work. In the case of the battery powered pH meter, the battery should be checked and the condition of the pH electrode checked. A spare battery is usually advisable. A small quantity of deionized water is necessary for washing the pH electrode during measurements.

SLIDE 6-12



Tensionmeters are used to quantify the surface tension of a liquor sample. After centrifuging for removal of the suspended solids, the sample is placed in a holder having a large surface area. The sample is raised into position so that the platinum-iridium ring of the tensiomenter is submerged approximately 3 mm.

After approximately 30 minutes, the sample holder is slowly lowered until the ring breaks through the surface. The force involved in breaking the surface is measured and converted to a reading in dynes/cm. The evalution is usually done several times.

Unfortunately, there are no reliable field checks for changes in the surface tension. This can change signficantly in day-to-day operation due to the addition of surfactants and flocculants.

SLIDE 6-13

ALKALINITY = $CO_3^- + HCO_3^- + OH^-$

Alkalinity is the capacity of a liquor to neutralize a strong acid to a designated pH. The alkalinity of a sample is the combined effect of carbonate, bicarbonate and hydroxide ion concentrations in the liquor. It is usually expressed as the equivalent concentration of calcium carbonate.

The analysis procedure involves the titration of the sample with an acid endpoint. First phenophtalein is put into the liquor and the sample is titrated until the phenolphtahlein turns from red to colorless. This is approximately a pH of 8.3. The quantity of acid and its normality can be used to calculate the "phenolphtahlein" alkalinity.

Next a small quantity of methyl orange indicator is placed in the solution and the titration is resumed. This has an endpoint at approximately 4.5 pH. The total quantity of acid necessary to reach the methyl orange endpoint can be used to calculate the "total" alkalinity.

The alkalinity is of most interest in the evaluation of sulfur dioxide control systems. The removal of sulfur dioxide can be a function of the alkalinity under some operation conditions.

SLIDE 6-14

ANALYSES FOR SULFATES

1. GRAVIMETRIC
2. TURBIDIMETRIC

There are two general methods of testing for sulfates in scrubber liquors: gravimetric and turbidimetric. The gravimetric is the most accurate. However there are a number of chemical interferences in the analysis. The turbidimetric procedures are subject only to suspended solids and liquor color problems. In most cases, the turbidmetric procedure is satisfactory.

In this technique, the sulfate ion is precipitated as barium sulfate after the addition of barium chloride. The resulting turbidity is determined by a nephleometer, filter photometer or spectrophotometer and compared to a curve prepared from standard sulfate solutions.

SLIDE 6-15

ANALYSES FOR CHLORIDES

1. SPECIFIC ION ELECTRODE
2. SILVER NITRATE TITRATION

The chlorides concentration is of interest whenever corrosion is observed or anticipated.

Due to the high solubility of chloride compounds, there is very little which can happen to a sample during transport which would affect the chlorides concentration. For this reason, the sample precautions which are discussed earlier for other analyses, are not as important for chlorides.

The chlorides can be determined using a specific chloride ion electrode similar to that used for pH determinations. It can also be measured using a silver nitrate titration. Potassium permanganate is used as the endpoint indicator in this test. Both analytical approaches are accurate for the concentrations of concern in wet scrubber systems.

SLIDE 6-16

Fluorides are of concern in particulate wet scrubbers only because of the corrosive action. The concentration of fluroides in some gaseous scrubbers is important since this potentially limits the absorption of fluoride materials in the gas stream.

The fluorides can be determined by a specific fluoride electrode test. The colorimetric test is more accurate. However, it is much more time consuming.

Due to the interferences caused by chlorides, sulfates and carbonates, it is necessary to distill the sample before starting a fluoride colorimetric test.

The fluoride concentration is determined photometrically at a specific wavelength. The absorbance is compared against known concentrations of fluoride prepared for known solutions.

SLIDE 6-17

HOW MUCH IS ENOUGH?

Test	Volume (ml)
Alkalinity	100
Chlorides	100
Fluorides	200
Solids	
Suspended	1000
Dissolved	1000
Sulfates	1000
Surface	
Tension	200
Turbidity	1000

The sample volumes necessary to conduct the analyses discussed in the lecture are provided in this slide. In all cases, 1 liter (1000 ml) is sufficient to conduct the specific test. It should be noted, however, that more than this amount will be needed if multiple tests of a single parameter are needed or if there is interest in several parameters.

Samples should be stored in bottles which will not affect the material to be tested. Polypropylene bottles are the most common containers since these are relatively inert and unbreakable.

The analyses should be performed as soon as possible. The maximum holding times are generally considered to be 7 days for all of the tests except the turbidity test which has a limit of 1 day. Of course, exposure to significant temperature changes can result in changes in the samples.

SLIDE 6-18

TEST METHODS

Parameter	S.M.	EPA	ASTM
Suspended & Dissolved Solids	208	160	D 1888
Alkalinity	403	310	D 1067
Chlorides	408	325	D 512
Fluorides	414	340	D 1179
Surface Tension	None	None	D 1590
Sulfates	427	375	D 516

This is a brief summary of the test methods used for liquor analyses. These test numbers should be specified when discussing the test results so that there is no confusion regarding the specific analytical procedures used.

The abbreviation S.M. stands for standard methods as published in Standard Methods for the Examination of Water and Wastewater, 14th Edition.

The EPA test procedures numbers are from publication EPA-600/4-79-020, dated March, 1979.

The abbreviation ASTM stands for the American Society of Testing Materials, 1984 Standards.

LECTURE 6 - REVIEW PROBLEMS AND QUESTIONS

6-1. The correct answer is "c". The type of sample which is most representative of the conditions being evaluated should be used. Long term averages are usually evaluated using composite samples. Short term extreme conditions are usually evaluated using grap samples.

6-2. There is no direct relationship between the two different measures of turbidity. The correct answer is "d".

6-3. The correct answers are "b", "c", and "d". All of these affect the degree of light scattering within the instrument. The large diameter particulate do not cause a "measurement error" since they contribute to the sample turbidity.

6-4. The correct answer is "d". Higher temperatures can result in the volatilization of organic compounds and other problems discussed in the lecture.

6-5. There are no field instruments available for spot checking the liquor surface tension. The tensionmeter is too susceptible to problems to permit field use. The correct answer is "d".

LECTURE 6 - REVIEW PROBLEMS AND QUESTIONS

6-1. Are composite samples more useful than grap samples?

a. Yes
b. No
c. It depends on the purpose of the liquor analyses
d. None of the above

6-2. If the measured turbidity is 34 JTUs, what is the value of the turbidity expressed in NTUs?

a. 68 NTUs
b. 34 NTUs
c. 17 NTUs
d. It can not be determined from the information given.

6-3. Which of the conditions listed below can cause errors in turbidity measurements?

a. The presence of large diameter suspended particles
b. Fingerprints on the sample tube
c. Scratches on the sample tube
d. Air bubbles
e. All of the above

6-4. What temperature is generally used for drying of solids samples?

a. 50 to 75°F
b. 100 to 105°F
c. 150 to 175°F
d. 215 to 220°F
e. 250 to 265°F
f. 295 to 305°F
g. 345 to 355°F

6-5. What field instruments are useful for spot checking the liquor surface tension?

a. Tensionmeters
b. Bubbleometers
c. Nephleometers
d. None of the Above

LECTURE 7

INSPECTION AND EVALUATION
OF
PARTICULATE WET SCRUBBER SYSTEMS

SLIDE 7-1

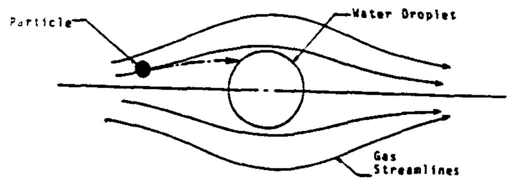
INSPECTION AND EVALUATION OF PARTICULATE WET SCRUBBERS

The single most important factor which affects the performance of particulate wet scrubber systems is the particle size distribution. This lecture starts with a discussion of particle size and the changes in size which can occur in the scrubber.

Scrubber static pressure drop has been used extensively in the past to judge the adequacy of scrubber operation. The uses and limitations of pressure drop are briefly examined.

Inspection procedures for each major category of scrubber are addressed. The purpose of these sections is to present the data and observations which are most useful for identifying commonly reported problems.

SLIDE 7-2

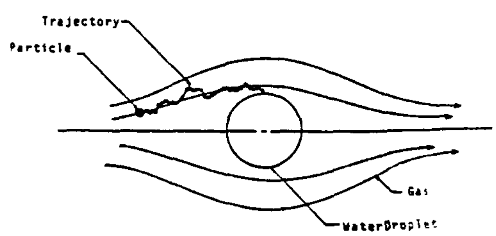


The two mechanisms primarily responsible for particle capture in scrubbers are impaction and diffusion.

Impaction occurs when the particle inertia is so high that the particle can not move around an obstacle in the gas stream. As shown in the slide, the inertia is proportional to the square of the particle diameter. Impaction is much higher for large particles than for very small particles. This is one of the reasons that particle size is important to scrubber performance.

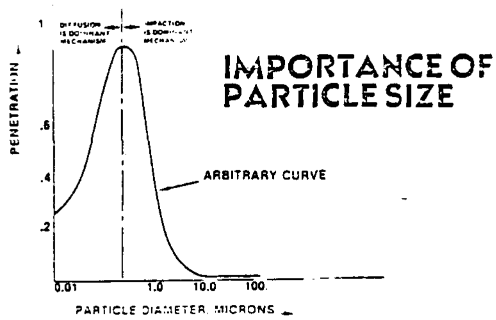
In addition to the particle size, impaction is related to the difference in particle and obstacle velocites. This is important since the relative velocities developed in scrubbers differ substantially.

SLIDE 7-3



Diffusion is the random movement of small particles due to collisions with gas molecules. The rate of diffusion is inversely proportional to the particle diameter. It is significant only for very small particles which have very little total mass.

SLIDE 7-4



The combined effect of impaction and diffusion is a performance curve similar to the one shown here. Impaction is very effective for particles which are larger than 10 microns, but becomes less effective as the particle size decreases to the 0.2 to 0.5 micron range. Diffusion begins to exert some influence in the 0.2 to 0.5 range and becomes more effective as the particle size decreases.

The peak of the curve represents the particles in the range where neither impaction nor diffusion are especially effective.

Lecturer's Notes

The left side of the curve is often not important when considering mass emissions from the scrubber system. Particle size data for this range is also more difficult to obtain.

SLIDE 7-5

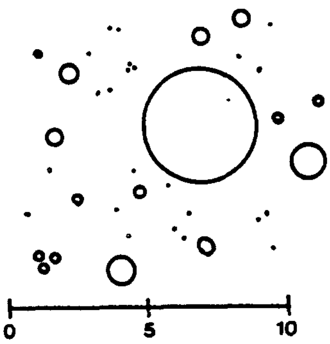
FACTORS WHICH AFFECT WET SCRUBBER PERFORMANCE

1. VARIATIONS IN PARTICLE SIZE DISTRIBUTION
2. PARTICLE SURFACE CHARACTERISTICS
3. LIQUID SURFACE TENSION
4. GAS-LIQUID DISTRIBUTION

If the performance curve for a given scrubber were known, and the particles had a uniform size, it would be a simple matter to design a wet scrubber. Unfortunately, there are a number of very important factors which make this impractical. These include: (1) the wide variation in particle sizes, (2) the influence of particle surface on impaction, and (3) the influence of liquor characterisitics on impaction.

The most important of these is the variation in the particle size distribution in the scrubber inlet gas stream.

SLIDE 7-6



The untreated gas stream never contains particles with a uniform size. There is a distribution of sizes as suggested in this slide.

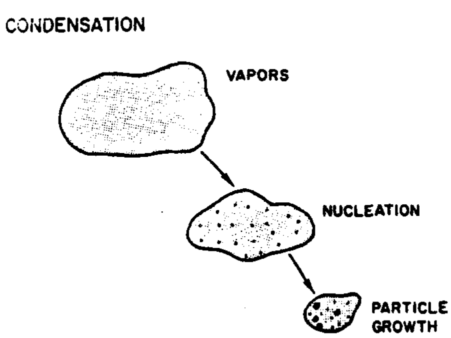
The largest of the particles are in the range of 50 to 100 microns. As a frame of reference, this is approximately the diameter of a human hair! The smallest particles (of any significance to air pollution emissions) are in the range of 0.1 microns. A particle of this size has approximately one millionth the mass of a 100 micron particle.

One of the challenges in designing a scrubber system is determining the type of scrubber vessel that is most appropriate for the size distribution which exists. It is obviously easier to collect particles in the 10 to 100 micron range than it is to collect the particles in the 0.1 to 10 micron range. In fact, all of the scrubber types perform very well on the 10 to 100 micron particles. However, there are substantial differences in the capability to remove the 0.1 to 10 micron material.

Lecturer's Notes

In addition to differences in physical size, there are also differences in particle shape and in particle specific gravity. All of these have an impact on the behavior of the particle in the scrubber.

SLIDE 7-7

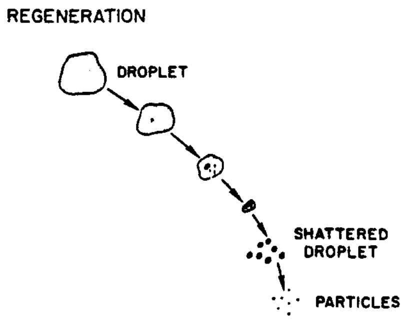


Condensation of vapors can occur as the gas stream cools while passing through the scrubber vessel. These vapors could result from a variety of causes including, but not limited to incomplete combustion, vaporization of raw material components, and the generation of high concentration of acidic compounds in the process equipment.

If this material condenses on the surfaces of existing particles, the overall size distribution shifts slightly. If it condenses as a homogeneous particle, a large number of very small particles are created. These homogeneous particles often grow to reach final particle sizes in the range of 0.1 to 1.0 microns.

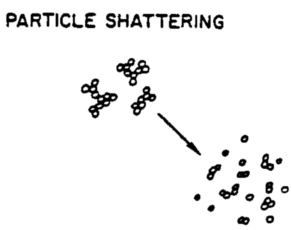
It is important to realize that the condensation and particle growth processes require a finite amount of time. It starts as the gas stream enters the scrubber and continues until the gas stream is no longer supersaturated with the vaporous material. This means that some of the very small particles may not exist as particles until the gas stream is partially through the scrubber. Also, the particle size distribution is changing as the gas stream passes through the scrubber. Scrubbers differ with respect to their capability to handle this complicated situation.

SLIDE 7-8



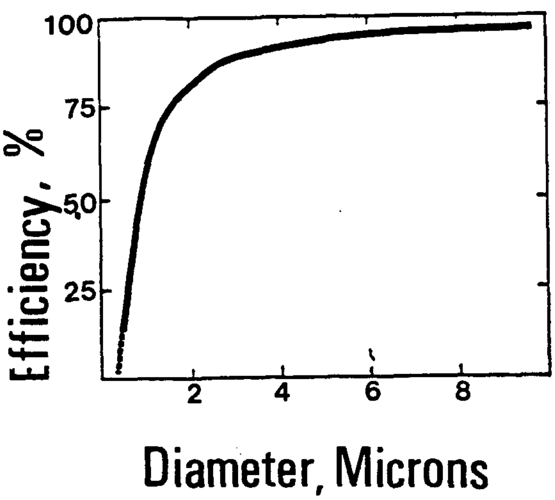
Very small particles can also be generated by the evaporation of droplets containing solids. This can occur in evaporative coolers or presaturators handling gas streams of high gas temperatures. The total quantity of solids put back into the gas stream can comprise a significant fraction of the total mass present in the small particle range.

SLIDE 7-9



One additional mechanism for the development of small particles is the shattering of agglomerates as illustrated here. The high gas velocities necessary to ensure good impaction can result in the shattering of the agglomerates as they move in the gas stream. The individual particles are more difficult to capture than the agglomerate since they have much lower inertia.

SLIDE 7-10



Due to the formation of very small particulate matter, it is possible to have a major fraction of the particulate mass in a size range which is beyond the capability of the scrubber.

Unfortunately, the fraction efficiency curve, as shown on the slide is rarely known for the specific scrubber being inspected. Also, the particle size data is never known during the period of the inspection. There are no instruments with which the inspector can take a quick sample and determine if there has been a shift in the particle size distribution.

Changes in the particle size distribution can be inferred from changes in the process operating conditions and from the visible emissions levels. It is apparant that the particle size of most concern in scrubber performance is also the size range in which liqht scattering is most effective. A sudden increase in the residual opacity without any other obvious changes in scrubber operating conditions may indicate a change in particle size distribution characteristics.

SLIDE 7-11

There is no question that the pressure drop is a very important operating parameter for most types of particulate wet scrubber systems. However, there are some very important limitations which must be considered when using this data. The next set of slides examines the uses and limitations of the static pressure data.

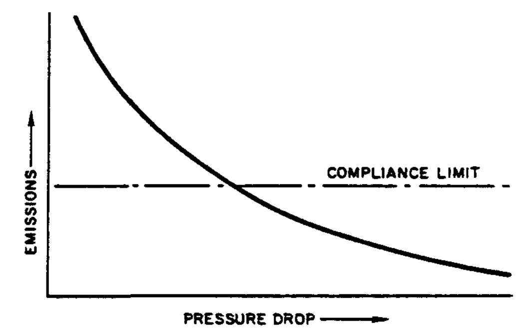
SLIDE 7-12

"When compared at the same power consumption, all scrubbers give substantially the same degree of collection of a given dispersed dust, regardless of the mechanism involved and regardless of whether the pressure drop is obtained by high gas flow rates or high water flow rates."

The use of static pressure drop data has been based primarily on the Contact Power Theory which is summarized in the two equations to the left. The first states that the penetration (which is a way of expressing emissions) is proportional to the energy consumed in the gas phase plus the energy consumed in the liquid phase.

The gas stream power input was always considered to be the dominant factor. In the late 70's EPA funded studies indicated that the liquid stream power input for certain types of scrubbers was less important than indicated by the equation. This reduced the Contact Power Theory to a simple proportionality between the emissions and the pressure drop.

SLIDE 7-13

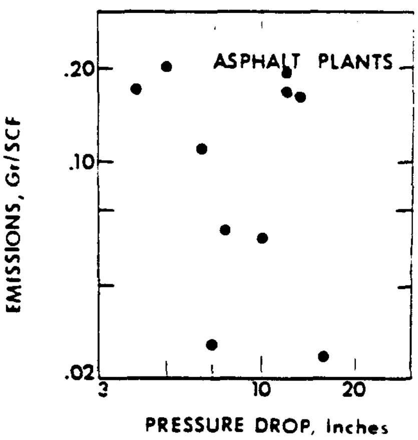


The generally assumed relationship between static pressure drop and overall scrubber performance based on the Contact Power Theory is shown in this slide. In some cases, curves have been compliled for "similar" scrubbers in a certain industry category. These correlations can suffer from large plant-to-plant particle size variations.

Other variables which contribute to the scatter in the data include variations in the surface characteristics of the particles, variations in the liquor characteristics, and variations in the degree of gas-liquor maldistribution.

The net result of the plant-to-plant differences and the variations over time at any given plant render these correlations almost meaningless for the purposes of the inspector. The scatter in the data is too great to draw meaningful conclusions from an industry wide pressure drop-emissions correlation.

SLIDE 7-14



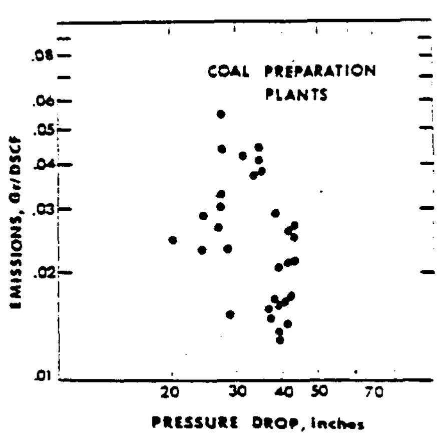
This is one extreme example of the degree of scatter which is possible when data from more than one scrubber system is used in a correlation. In this case, the correlation attempts to relate emissions from Hot Mix Asphaltic Concrete Plants using mechanically aided scrubbers.

This degree of scatter should not exist if the relationship between pressure drop and emissions is strong and if the particle sizes distributions are consistent.

Lecturer's Notes

This is the first of several examples intended to illustrate that the evaluation of particulate wet scrubber performance is more complex than simply recording the static pressure drop.

SLIDE 7-15

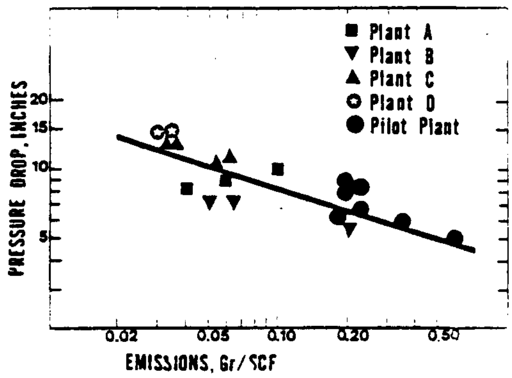


This is another example of an industry wide correlation of wet scrubber performance. It is for venturi scrubbers on coal preparation plant thermal driers. There is no obvious correlation between the pressure drop and particulate emissions rate.

Lecturer's Notes

One of the problems with these correlations is that the industries are not as homogeneous as they appear. In the case of coal preparation plants, there are four different types of coal dryers. Several different styles of venturi scrubbers are commonly used. In the case of asphalt plants there are a large number of variations in the operating conditions and plant designs.

SLIDE 7-16

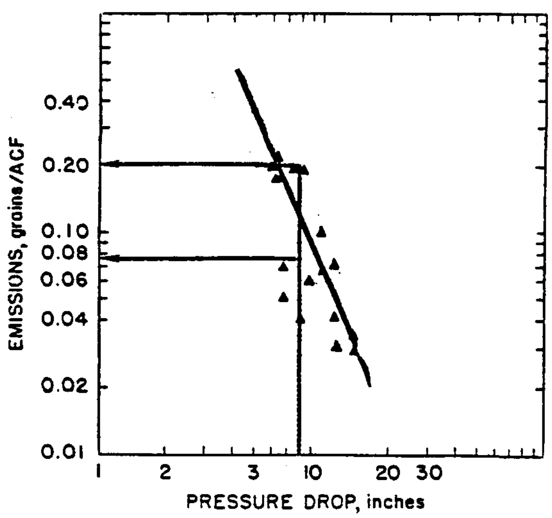


This is published data for venturi scrubbers serving 4 commercial lime kilns and one pilot scale lime kiln. There appears to be a relationship between the pressure drop and the particulate emissions. However, it should be noted that the data is plotted in log-log coordinates for the convenience of the authors. The degree of scatter may be much less than the previous two slides, but it is still too high for use by inspectors.

Lecturer's Notes

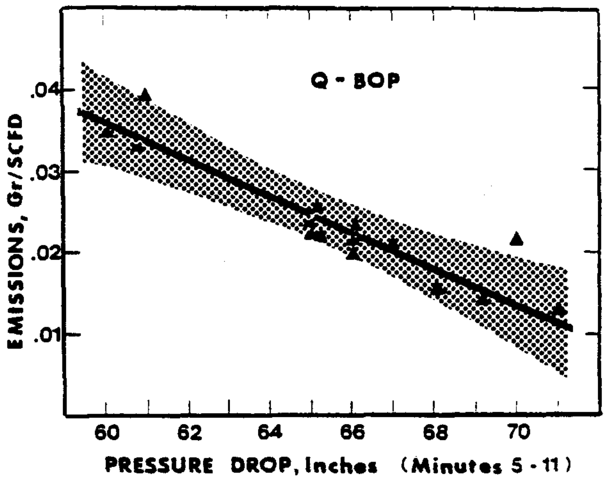
The main point of this slide is that there are a number of published correlations of the type shown in this graph. The authors were simply illustrating the general relationship between the pressure drop and the emissions. They were not advocating that the performance can be evaluated by use of the static pressure drop alone.

SLIDE 7-17



The data from the previous slide has been replotted here. A confidence interval has been superimposed on the line, using the calculation procedures presented in the Appendix (and discussed in Lecture #2). Using 9 inches of pressure drop as an example, it is apparent that the mass emissions could vary from 0.07 to 0.20 grains per ACF. There is too much scatter in the data.

SLIDE 7-18

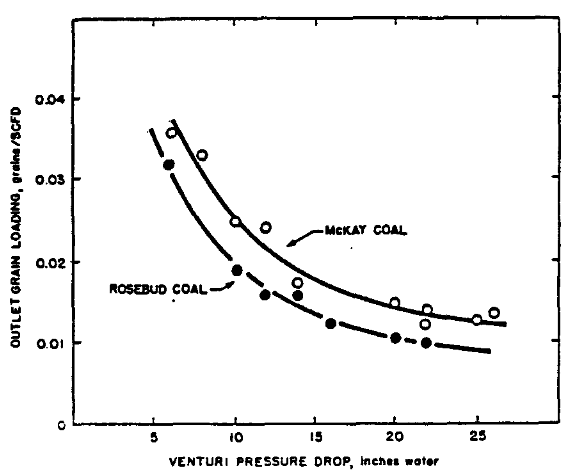


One way to minimize the scatter in the pressure drop - emissions correlations is to limit it to a specific plant. This slide presents a correlation for three venturi scrubbers on three Q-BOP units at the same plant. The reduced variability is probably due to the fact that the systems were identical and the liquor quality was very similar.

For single site correlations, the variability should be reduced to only those conditions which change with time at the site. This conceivably allows for the preparation of a meaningful correlation which could be used during an inspection.

There are never enough stack tests on a specific site to adequately define this correlation. Furthermore, there is always the possibility that there has been a sudden shift in the one or more of the particle generation mechanisms. The pressure drop data must be used carefully.

SLIDE 7-19



The consequences of a shift in process operating conditions is illustrated in this slide. The two curves relate the outlet particulate emissions to the pressure drop of a pilot scale venturi scrubber serving a coal-fired boiler.

The only major difference is the coal characteristics. The emissions are 10 to 20 % higher with the McKay coal supply. In other types of applications, there can be a much greater shift in the site specific performance.

SLIDE 7-20

$$P = 0.158\,\Delta P$$

$$P = \frac{\Delta P}{\rho}$$

Another potential source of error in the use of the Contact Power type correlations is the erroneous application of the original equation.

The author of the original paper derived the equation from Bernoulli's Law. The 0.158 constant which appears in slide 7-17 represents the inverse of the gas density at 70 °F and 14.7 psia. Although this was stated in the article, the importance of gas density was forgotten by some.

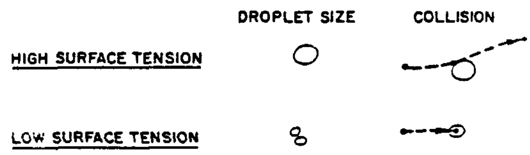
A rederivation of the Contact Power theory (see Wet Scrubber Performance Evaluation Manual, EPA 340/1-83-022) indicates that the relationship should be as shown in the above slide. The pressure drop divided by the average gas density should be correlated with the total energy consumed by the scrubber. The average gas density can vary substantially from scrubber to scrubber. It is a function of the gas temperature and the static pressure as indicated in the equation.

A check of the change in gas densities before and after some high pressure drop scrubbers also indicates that there can be more than a 10% change. This means that the incompressible flow assumption on which the Contact Power Theory was based is also in error.

Lecturer's Notes

The point regarding compressible flow is not very important for field inspectors. They do need to understand, however, that the gas density is an important variability. Gas temperature measurements are made during inspections to aid in estimating the densities before and after the unit.

SLIDE 7-21



Two other factors of importance to particulate scrubber performance are the surface tension of the liquid and the surface characteristics of the particle. As illustrated in this slide (see middle column), the liquids with high surface tension often yield large droplets when sprayed from nozzles. This decreases the number of impaction targets for particles passing through the scrubber. It is also more difficult for a particle to penetrate into the droplet when the liquid surface tension is high.

Particles composed primarily of hydrocarbons or coated with an organic material are less wettable. This also hinders the coalescence of the particle into the water drop. Unfortunately, the particles which result from the condensation of incompletely burned fuels and other hydrocarbon materials can be difficult to "wet" due to the surface characteristics and difficult to impact due to the very small size range.

The chemicals added to the system at the pond, the clarifier, or the recirculation tank can have a large influence on the surface tension of the liquor going to the scrubber. This can conceivably have an impact on the efficiency of the overall scrubber. Unfortunately, both the particle surface characteristics and the liquor surface tension are difficult to evaluate during the inspection.

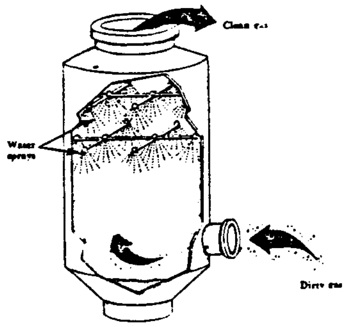
SLIDE 7-22

INSPECTION TECHNIQUES FOR MAJOR TYPES OF PARTICULATE WET SCRUBBERS

The remainder of the lecture will concern specific types of scrubbers. The focus of this material is on the relevant operating parameters for each type to order to identify common problems. The inspection procedure is "tailored" for each group.

Each of these categories is actually a group of different designs which share some basic similarities. The specific inspection procedures must be adjusted for these minor differences. It is the responsibility of each field inspector to make these changes in the inspection procedure and to perform the inspection in a safe manner.

SLIDE 7-23



Source: Air Pollution
Training Institute

This is a sketch of a spray tower scrubber. It is the simplest type of wet scrubber and it has the lowest overall particulate removal capability. This is partially due to the low relative velocities between the liquor droplets formed at the nozzles and the particles moving with the gas stream. Remember that impaction is proportional to the relative velocity of the particle to the droplet.

Due to the limited capability of the unit, it should not be used at sources for which a major fraction of the particulate matter is in the 0.1 to 5 micron range.

Another common version of a spray tower scrubber has the spray nozzles arranged on a vertical header near the center of the cylindrical shell. The gas enters tangentially so that there is some cyclonic action to aid particle removal.

Lecturer's Notes

Another particle capture mechanism that could contribute to particle removal in spray tower scrubbers is electrostatic attraction. Static charges could conceivably occur on droplets sprayed from high pressure nozzles.

SLIDE 7-24

SPRAY TOWER SCRUBBERS INSPECTION DATA

1. Average Opacity (Residual)
2. Minimum and Maximum Opacities
3. Droplet Reentrainment
4. Liquor Flow Rate
5. Nozzle Operating Pressures
6. Liquor pH
7. Liquor Turbidity
8. Nozzle Operating Condition
9. Shell Condition

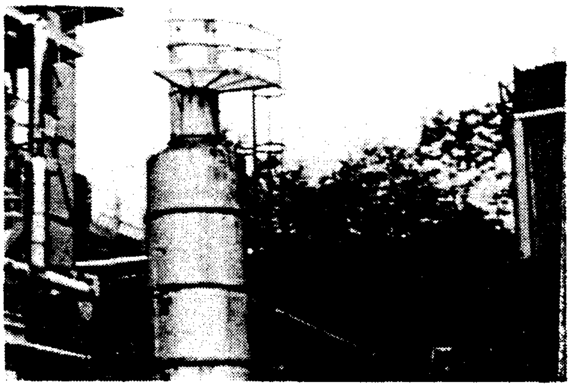
This is a list of the operating data and observations which should be made during routine inspections of spray tower scrubbers.

The emphasis is placed on nozzle performance problems such as pluggage, erosion, and corrosion. Since the nozzles can rarely be observed, indirect symptoms of these problems must be used. These include nozzle pressure, liquor pH, and liquor turbidity.

One parameter not listed here is the static pressure drop. Performance is not a strong function of the normally low static pressure drops in this type of scrubber. While the liquor flow rate is listed explicity, it is rarely measured by on-site instruments. In these cases, changes in the the liquor flow must be determined from pump performance conditions and/or changes in the nozzle operating conditions.

Evaluation of the ductwork and shell physical condition is especially important since many of these scrubbers are made with unlined carbon steel. Low pH excursions can lead to rapid and severe damage.

SLIDE 7-25



This is a photograph of a simple spray tower scrubber serving a Hot Mix Asphaltic Concrete plant drier. The fan is ahead of the scrubber vessel and not shown here. The stack discharge is directly above the frame of the picture.

One of the first steps in any scrubber system inspection is the evaluation of the visible emissions. The residual opacity should be observed, using the established reference methods. Any variations in the opacity are normally due to changes in process conditions. The timing of these cycles or spikes should be noted so that the process equipment performance can be checked later in the inspection.

The physical condition of the shell and the ductwork should be checked for signs of erosion and corrosion. Spray tower scrubbers are used on sources of large particulate which can be very erosive. The absorption of carbon dioxide and sulfur dioxide can reduce the liquor pH to the corrosive range. Some smaller systems do not have alkaline addition systems which add neutralizing materials on a continuous basis.

SLIDE 7-26

NOZZLE PLUGGAGE IN SPRAY TOWER SCRUBBERS

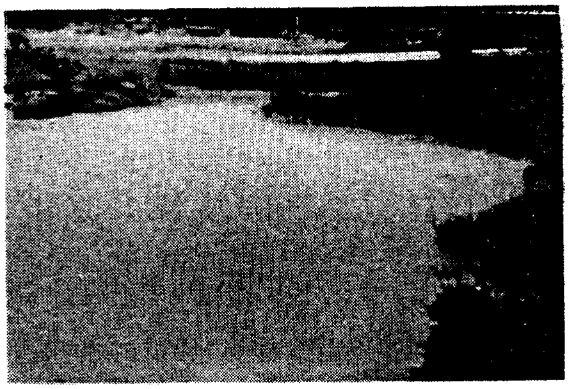
1. Increased Quality
2. Increased Nozzle Header Pressure
3. Unchanged Pump Motor Currents
4. Unchanged Pump Discharge Pressure
5. High Liquor Turbidity
6. Small Ponds
7. Low Pump Intake
8. Corroded Piping and Shell
9. Scaling Conditions in Scrubber Vessel

These are potential symptoms of nozzle pluggage. The increase in the nozzle header pressure from baseline levels occurs only when the flow rate is increased or the nozzles have plugged. If the pump motor currents have not changed since the baseline period and the pump discharge pressure is also similar, it is unlikely that the flow rate has increased.

The presence of high suspended solids in the recirculation liquor is often associated with nozzle pluggage. The turbidity of the recirculation liquor should be qualitatively evaluated. If it appears to be high, the sample can be taken for a suspended solids test.

For systems that are operating, the type of nozzle presently being used should be determined. This should be compared with the type used previously to see if the present nozzles are more susceptible to pluggage. The type of spray and the spray angle should also be noted on any data sheets concerning the nozzles.

SLIDE 7-27



Several of the items listed on the last slide concern settling pond related nozzle pluggage problems. This area should be part of the inspection whenever nozzle pluggage problems are suspected.

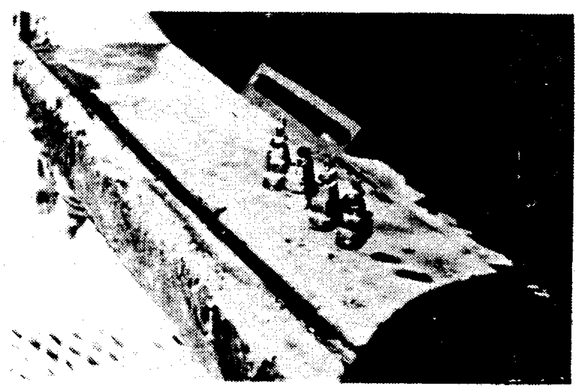
This is a photograph of a pond for a small spray tower scrubber. The turbidity of the pond water near the pump intake should be checked. The sample should be taken at a safe and convenient location in the last zone of the pond. If the turbidity is high, the settling characteristics are not satisfactory.

The position of the pump intake should be carefully checked. It must be deep enough to prevent cavitation of the pump, but not so deep that silt from the bottom of the pond is carried into the suction line.

Lecturer's Notes

The performance of settling ponds can often be improved by the construction of several distinct settling zones separated by overflow weirs. It may be necessary to occassionally remove the settled material in the first zone.

SLIDE 7-28

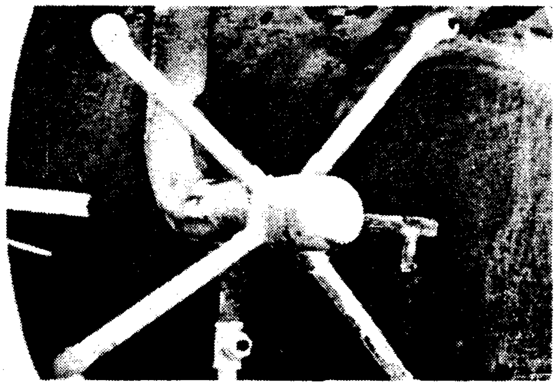


Whenever nozzles are removed for cleaning or replacement, the type of damage should be briefly described in the maintenance records.

The objective of the records is to prevent repeat failures. Either the fundamental cause of the nozzle problem should be rectified or a nozzle which is less vulnerable should be used.

The field inspector should plan to inspect the scrubber the first time that it comes out of service and the nozzles are being checked. In this way, a first hand opinion can be formed concerning the cause of the problem.

SLIDE 7-29



Pluggage of a small number of nozzles in the same general location within the scrubber system can lead to poor gas-liquor distribution. This may not have a major effect on the nozzle header pressure or the pump operating conditions. The only way to identify these problems is to observe nozzle performance at a time when the scrubber is out of service.

From a vantage point above the nozzle header, the spray angles of the nozzles are observed when the recirculation pump is turned on. Distorted spray angles and completely plugged nozzles can be seen with a bright flashlight.

Under no circumstances should an inspector enter the scrubber to check the conditions of the nozzles or lean through the hatch to see the spray angles. There can be oxygen deficient conditions and high concentrations of toxic pollutants trapped in a scrubber which is out-of-service.

This is an especially effective way to find nozzle problems which are causing excess emission conditions. However, it is rare to find a spray tower scrubber with a safe and convenient access hatch to view the nozzles. This should not be attempted unless the inspector can comply with all plant and agency safety policies.

SLIDE 7-30

LEAKAGE AND INFILTRATION IN SPRAY TOWER SCRUBBERS

Leakage from Positive Pressure Scrubbers
1. Reduced Gas Flow
2. Visible Leaks
3. Audible Leakage Points

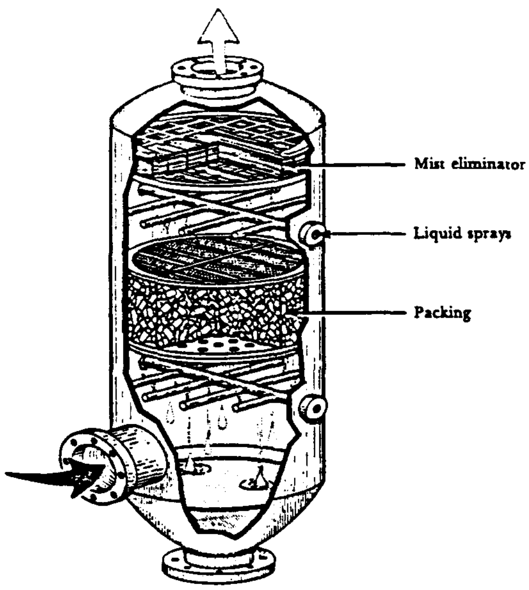
Infiltration Into Negative Pressure Scrubbers
1. Audible Infiltration Points
2. Reduced Hood Static
3. Fugitive Emissions

Gas leakage can occur due to corrosion of the ductwork and scrubber shell. These can be identified as visible leaks from the scrubber and as audible leaks from ductwork. The drop in gas flow through the scrubber can be quantified by conducting a pitot traverse at the stack.

Air infiltration into negative pressure spray tower scrubber systems is difficult to identify. There is little decrease in the fan inlet gas temperature since the temperature is normally 120 °F to 140 °F at this point.

There is also very little change in the scrubber outlet static pressure since the resistance to flow through these systems is normally low. A pitot traverse at the stack outlet is not useful for quantifying the leakage since gas flow rate does not change substantially. The best symptoms of air infiltration are increased fugitive emissions, reduced hood static pressure (see Lecture #5), and audible leakage sites.

SLIDE 7-31



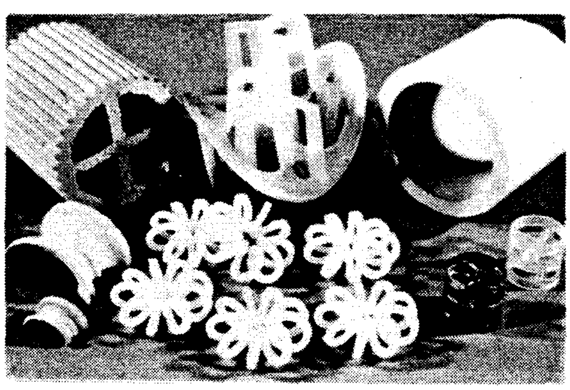
Source: Air Pollution Training Institute

This is a sketch of a packed bed scrubber. These are used primarily for gas absorption or for gas cooling, both of which are facilitated by the large liquid surface area on the packing. They have only a very limited capability for removal of particulate. However, there are applications where both gases and particulate must be removed.

Particle removal by impaction is limited due to the low velocities between the particles in the gas stream and the liquid on the packing. These scrubbers are rarely effective for particles less than 3 microns.

Another style of packed bed has horizontal gas flow through a vertical packed bed. The liquor is introduced at the top and from the front of the packing and flows in a cross current direction relative to the gas stream.

SLIDE 7-32



Source: Air Pollution Training Institute

This photograph shows some of the most common types of packing material used in packed bed scrubbers. The one in the upper left corner is a cross partition ring, the ones in the lower left are Intalox saddles. Tellerettes are in the lower center of the slide. Pall rings are in the lower right and a Raschig ring in the uppper right. Gravel is another material which is commonly used.

All of the packing materials are available in various sizes, ranging from 1/2 inch to 3 inches. The materials of construction include synthetic plastics, ceramics, porcelain, and metal. The packing size and configuration affects the overall pressure drop and liquid hold-up within the bed.

SLIDE 7-33

PACKED TOWER SCRUBBER INSPECTION DATA

1. Average Opacity (Residual)
2. Minimum and Maximum Opacities
3. Presence or Absence of Detached Plume
4. Droplet Reentrainment
5. Inlet and Outlet Gas Temperatures
6. Shell Condition
7. Liquor Flow Rate
8. Nozzle Operating Pressures
9. Liquor pH
10. Liquor Turbidity
11. Rate of Addition of Alkaline Material

This is a list of the inspection data and observations which should be made during a routine inspection of a packed tower scrubber. The primary emphasis is on any conditions which promote bed pluggage, bed channeling, and poor liquor distribution.

On level 3 inspections, it is necessary to have accessible measurement ports at the scrubber inlet and outlet. Ports between beds in series are also helpful.

As with the spray tower scrubbers, these systems are often small and lack any on-site instrumentation. In these cases, the liquor flow rate must be estimated from the pump operating characteristics.

Reentrainment is less common with this type of scrubber since the gas velocities up through the bed are low. The only opportunity for reentrainment is while the gas stream passes around the nozzles at the top of the scrubber. However, these nozzles should not be generating fine droplets which could be carried upwards with the gas stream. The function of the nozzles is simply to uniformly distribute the liquor on the top surface of the packing.

SLIDE 7-34

BED PLUGGAGE IN PACKED TOWER SCRUBBERS

1. High Static Pressure Drops Across Beds
2. High Liquor Turbidity
3. High Liquor pH
4. High Solids Content in Inlet Gas Stream

Packed beds are prone to pluggage since the liquid stream is not flowing rapidly enough to continually remove accumulated materials. The sources of the solids include: (1) suspended solids in the recirculation liquor, (2) precipitated dissolved solids from the recirculation liquor, and (3) impacted solids from the gas stream on the first bed.

The symptoms which may indicate the development of bed pluggage are listed on this slide. An increase in the static pressure drop across the entire scrubber or any individual bed must be due to either a gas flow increase or pluggage. The gas flow rate can be evaluated using the fan motor currents or a pitot traverse. In the case of severe pluggage, there could be a drop in gas flow rate and increased fugitive emissions.

The liquor turbidity should always be low at the inlet of a packed tower scrubber. An increase in the pH may suggest that some precipitated solids are scaling the packed bed.

SLIDE 7-35

CHANNELING IN PACKED TOWER SCRUBBERS

1. Reduced Liquor Flow Rate
2. High Turbidity Liquor
3. High Solids Content of Inlet Gas Stream

Channeling can occur whenever part of the packing material is incompletely wetted or when the gas stream flow up the bed(s) is very nonuniform. The latter can be caused by solids deposits withing the bed.

Channeling is especially difficult to avoid when the liquor flow rate is low. For this reason, attempts should be made to evaluate the liquor flow rate using either the on-site gauges or the pump operating conditions.

On large packed tower scrubbers with multiple beds,it is common practice to have liquid redistributors between the beds. For all packed tower scrubbers, the spray nozzles must have the proper spray angle and must be located at the appropriate distance from the top of the bed.

SLIDE 7-36

SYMPTOMS OF CHANNELING

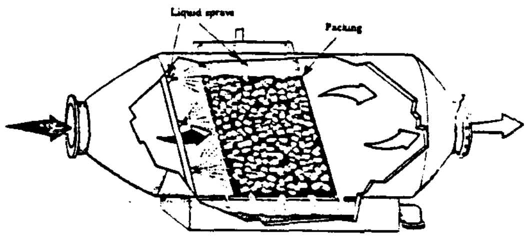
1. CHANGE IN NOZZLE HEADER PRESSURE
2. MODERATE LIQUOR TURBIDITY
3. REDUCED LIQUOR FLOW RATE

Channeling can be especially severe in the cross flow type of packed bed scrubbers. There is a natural tendency for the liquor to flow to the bottom of the bed. Under low flow conditions, a major fraction of the packing at the top remains unwetted. This reduces the amount of particulate captured and significantly reduces gas absorption.

On units which have worked well previously, the most useful symptoms of this problem include a decrease in the total liquor flow rate or a change in the nozzle header pressure (indicating a problem with the front spray nozzles).

For units which have suffered a chronic channeling problem, it may be possible to substitute large capacity nozzles for the top header and reduce flow to the lower header. The use of smaller diameter packing in the top portion of the bed can lead to greater flow resistance, thereby shifting some of the gas flow rate to the lower portion of the bed. The latter approach must be done carefully so that the gas absorption is not hindered by the shorter retention time in the bed.

SLIDE 7-37



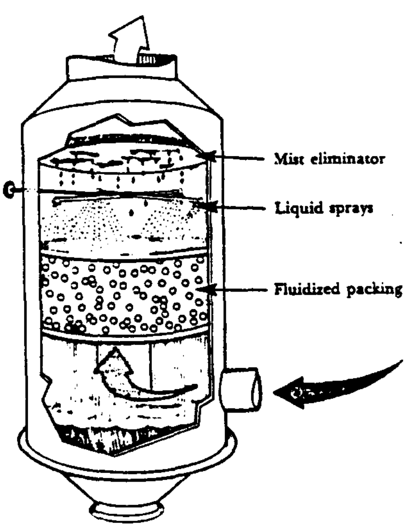
Sneakage can occur around the bottoms of the cross flow packed beds. This is normally prevented by internal weir seals which maintain a head of liquor greater than the static pressure of the gas stream. However, some of the gas stream will bypass the packed bed if the weirs are improperly sized or corroded.

This is not a problem with the counter-current flow (vertical flow) type packed bed. The packing extends from one side of the scrubber vessel to the other without any open areas which could permit sneakage.

Source: Air Pollution
Training Institute

Sneakage is identified by measuring the static pressure drop across the entire scrubber or the individual beds. A decrease in the pressure drop which is not accompanied by a gas flow rate decrease is a clear sign of sneakage. The gas flow rate can be measured using a pitot tube or estimated from the fan operating conditions.

SLIDE 7-38



This is a sketch of a single stage moving bed scrubber. This unit has hollow spheres as packing material which are entrained by the gas stream. Impaction of particulate occurs on the droplets which are formed within the turbulent bed. The liquor is introduced from the top using a set of nozzles similar to those used in packed bed scrubbers. There can be a number of beds in series.

These are used for both particulate control and gas absorption. They are especially effective for sources which have sticky materials which would clog a conventional packed bed scrubber.

Source: Air Pollution
Training Institute

SLIDE 7-39

MOVING BED SCRUBBER INSPECTION DATA

1. Average Opacity (Residual)
2. Minimum and Maximum Opacities
3. Droplet Reentrainment
4. Presence or Absence of Detached Plume
5. Pressure Drop Across Each Stage
6. Inlet and Outlet Gas Temperature
7. Condition of Shell
8. Liquor Flow Rate
9. Nozzle Operating Pressures
10. Liquor pH

The routine inspection observations and measurements for moving bed scrubbers are listed in this slide.

Reentrainment is more of a problem with these units than with the spray towers and packed beds discussed previously. This is due to the higher gas velocities through the beds and the possible formation of fine droplets within the turbulent bed.

Both the static pressure drop across the scrubber and the liquor flow rate are important operating parameters. Gas absorption and particulate removal are favored at high liquor-to-gas flow rates. Particulate removal is favored at high static pressure drops.

The liquor turbidity is not very important since the moving bed scrubber is inherently resistant to pluggage. The movement of the beds prevents the accumulation of solids and the spray nozzles generally have pluggage resistant large orifices. The liquor pH is important primarily when corrosion of the scrubber vessel or the recirculation pump is possible. At very high pH levels, scale deposits can occur in the scrubber sump and in portions of the screens which retain and support the packing.

SLIDE 7-40

SYMPTOMS OF GAS-LIQUOR MALDISTRIBUTION

1. REDUCED PRESSURE DROP
2. UNSATURATED GAS STREAM AT SCRUBBER OUTLET
3. CHANGE IN NOZZLE HEADER PRESSURE
4. LOW LIQUOR FLOW
5. HIGH LIQUOR TURBIDITY

Poor gas-liquor distribution can occur due to improper inlet duct configuration, low liquor flow rate, the presence of precipitated solids on the support screens or nozzle problems. One symptom of this condition is a reduction in the pressure drop across one of more of the stages. If this occurs without any obvious changes in the gas flow rate or the liquor flow rate, poor distribution is likely.

On those few units with observation windows (which remain partially transparent), it is possible to visually identify severe maldistribution. The hollow spheres will tend to rotate across the bed away from the area of highest gas velocity.

When the distribution is poor, the gas stream will not reach the adiabatic saturation temperature. The temperature probe discussed in Lecture #2 (developed by Shifftner) can be used in the outlet gas duct to evaluate the degree of saturation.

SLIDE 7-41

DECREASED GAS FLOW RATE IN MOVING BED SCRUBBERS

1. Reduced Static Pressure Drop
2. Lower Fan Motor Currents
3. Decreased Fan Speed
4. Decreased Production Rate
5. Audible Gas Leakage or Infiltration
6. Reduced Gas Flow Rate Measurements

The performance of the moving bed scrubber is partially dependent on the gas flow rate through the scrubber. These units have limited turndown capability since the area of gas flow can not be easily reduced. The droplet size population and size distribution are both dependent on the gas velocity.

Changes in the gas flow rate can occur due to: (1) gas leakage in positive pressure units, (2) infiltration in negative pressure units, and (3) reduced process operating rates in all types of units.

The preferred method for estimating the gas flow rate is to perform a pitot traverse at the outlet of the scrubber or at the stack. Alternatively, changes in the gas flow can be identified from changes in the corrected fan motor currents and fan speed (Lecture #5). Audible sites of gas leakage and infiltration should be noted during the inspection.

SLIDE 7-42

PACKING FAILURE ON MOVING BED SCRUBBERS

1. Gradual Absorption of Chemicals
2. Exposure to High Gas Temperatures
3. Exposure to Low Gas Pressure

Premature failure of the hollow sphere packing materials can reduce the overall performance of the scrubber and present a threat to the recirculation pump.

The absorption of chemicals into the packing material leads to gradual loss of the natural elasticity. Due to the turbulent motion of the packing, it is possible to shatter the brittle spheres. Exposure to moderately high gas temperatures due to temporary loss of liquor flow can have the same effect.

Spheres exposed to low gas pressures during shipment can be seriously weakened due to the difference between the internal pressure (basically sea level pressure) and the external air pressure. After a short period of use, they can have a high rate of failure.

The small fragments from the shattered spheres can be retained in the recirculation system if the settling rates in the recirculation tank are poor. These fragments can blind a strainer on the suction line or can accelerate abrasion of the pump impeller and lining.

SLIDE 7-43

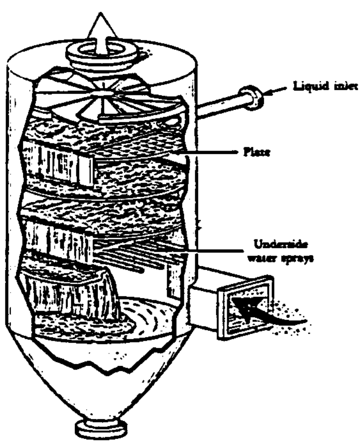
DEMISTER PROBLEMS IN MOVING BED SCRUBBERS

1. High Demister Static Static Pressure Drop
2. High Turbidity Demister Cleaning Water
3. Absence of Demister Cleaning System
4. Rainout from Stack
5. Mud "Lip" at Stack
6. I.D. Fan Vibration

The demisters can be troublesome for moving bed scrubbers when the liquor used for cleaning the demister is the same as the recirculated liquor. These types of scrubbers often use a liquor with moderate to high suspended solids levels. Another cause of problems is inadequate freeboard distance (see Lecture #5 for definition). The liquor carried from the top stage will drop back down if the freeboard distance is great enough.

The symptoms of demister problems are listed in this slide. The pressure drop across the cyclonic demisters or chevron demisters is usually in the range of 0.5 to 2.0 inches. Higher static pressures indicate partial pluggage.

SLIDE 7-44



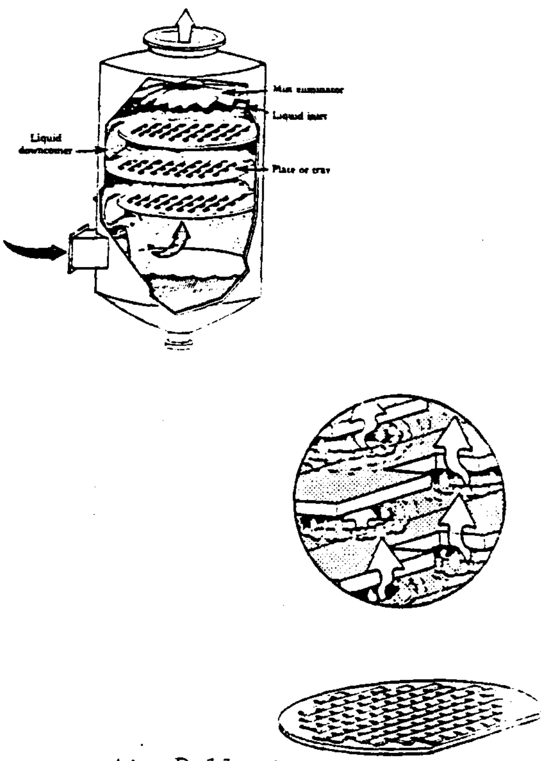
Source: Air Pollution Training Institute

This is a sketch of a sieve plate scrubber. As with all tray type scrubbers, it consists of one or more horizontal stages mounted in a vertical shell. The liquor is introduced at the top through a simple delivery pipe. The height of the liquor on the stage is controlled by the overflow weir on the opposite side of the tray. The liquor passes from tray to tray by means of downcomers.

The gas stream passes upward through the holes in the tray. Atomized droplets formed when the gas passes through the liquid layer serve as the impaction targets for capturing particles.

This type of scrubber is not as common as spray tower or venturi type scrubbers. Its efficiency is moderate to good for small particles. The main operating variables include the liquid flow rate, the gas flow rate, the height of liquor on each tray, the number of trays in series and the suspended solids content of the liquor. As with all scrubbers, the pH is also important.

SLIDE 7-45



Source: Air Pollution
Training Institute

The impingement plant scrubber shown in the sketch is similar to the sieve plate scrubber shown in the previous slide. The holes in the trays of impingement tray units are much smaller and more numerous. Due to the higher gas velocities through the holes, the particulate matter collection is more efficient than the sieve plate units. This advantage is gained at the expense of increase sensitivity to pluggage of the very small holes.

The operating parameters important to impingement scrubbers are identical to those which are important for the sieve plate scrubbers. The inspection procedures are also similar.

SLIDE 7-46

TRAY-TYPE SCRUBBER INSPECTION DATA

1. Average Opacity (Residual)
2. Minimum and Maximum Opacities
3. Droplet Reentrainment
4. Presence or Absence of Detached Plume
5. Pressure Drop Across Each Stage
6. Liquor Flow Rate
7. Liquor Turbidity
8. Liquor pH
9. Condition of Shell

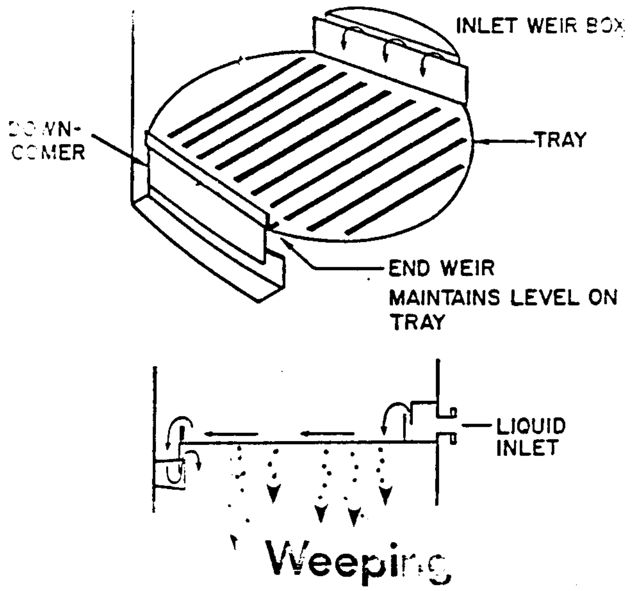
The inspection observations and mesurements for tray type scrubbers are summarized on the adjacent slide.

The liquor quality is extremely important due to the susceptibility to pluggage of the trays. A sample of the liquor should appear almost clear and have a total suspended solids content of less than 1% by weight.

The pressure drop across each stage can be used to evaluate a variety of problems which affect particulate control. Low pressure drop can be caused by low gas flow rate, low liquor flow rate, low liquor levels on the trays, or sneakage of the gas around the trays.

The outlet gas temperature is useful for identifying severe maldistribution or inadequate liquor flow rates. The pH is especially important since there are a number of wetted scrubber components which are vulnerable to corrosion. These include the trays, impingement targets (if used), inlet weir box, overflow weirs and downcomers.

SLIDE 7-47



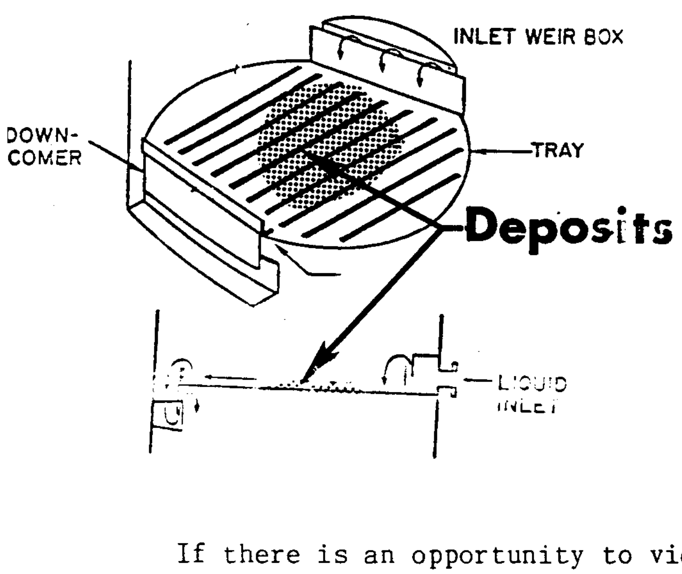
Reduced gas flow rate can lead to reduced particulate removal in several different ways. The lower velocity through the holes and the liquor layer reduces the effectiveness of impaction. In severe situations, the gas velocity can be so low that the liquor "weeps" through the holes. In this case, the gas-liquor distribution is very poor and there are few small droplets to serve as impaction targets.

Reduced gas velocity can be identified by using the static pressure drop across each of the stages. Decreases from the baseline values indicate reduced gas flow rate. Values less than 1.5 inches W.C. indicate potential "weeping".

When low static pressure drops are observed, it is useful to estimate changes in the gas flow rate since the baseline period. If possible, a pitot traverse should be conducted on the outlet of the scrubber or in the stack. The fan motor current and speed should also be noted.

Audible air infiltration points in the outlet duct or fan (negative pressure systems) should be noted. Gas leakage (positive pressure systems) ahead of the scrubber vessel should be noted.

SLIDE 7-48

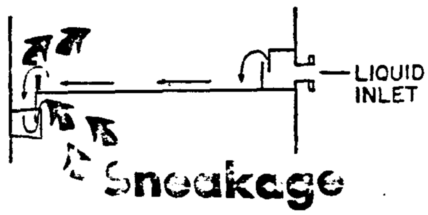


Pluggage of trays has the opposite effect of reduced gas flow rates. The observed static pressure drop across the trays increases. This increase may be most severe for the bottom tray since it handles the liquor with the highest solids content and since it is the tray exposed to the inlet gas stream.

Another symptom of pluggage problems is the liquor turbidity. A sample of the recirculation liquor should appear relatively clean.

If there is an opportunity to view the trays while the scrubber is out-of-service, the presence of solids on the trays can be confirmed. Under no circumstances should the inspector enter the scrubber vessel since there can be oxygen deficient or toxic gases contained inside. Also, the corrosion resistant liners can be easily damaged.

SLIDE 7-49



Sneakage around the trays can occur when the pressure drop across the trays exceed expected values. The downcomer weir shown in this sketch must be high enough so that the resistance to gas flow up through the downcomer is too high. If the designer did not anticipate the present high static pressure drops across the tray, this weir may be too short and gas may be sneaking around the tray. The static pressure drop across the tray will often exhibit rapid variations when sneakage up the downcomer is occurring.

Sneakage can also occur around the outer edges of each tray. These must be secured and sealed completely around the tray. Even moderately small gaps between the tray and the scrubber wall will allow significant gas sneakage and a permanently reduced pressure drop across the tray.

SLIDE 7-50

CAUSES OF GAS-LIQUOR MALDISTRIBUTION

1. SLOPED TRAY
2. PLUGGED HOLES
3. SOLIDS ACCUMULATION ON TRAYS
4. CORROSION OF WIRES
5. EXCESSIVE GAS VELOCITY

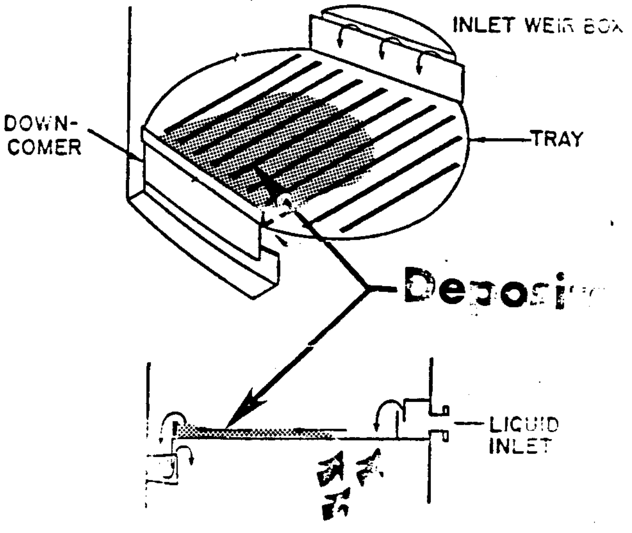
Nonuniform gas-liquor distribution can occur due to a number of tray related conditions. These are indicated on the adjacent slide.

The tray must be level to ensure a uniform layer of liquid across the top of each tray. The lower resistance in the areas with low liquid levels have increased gas flow rates which only aggravate the distribution problem. Unfortunately, it is difficult to identify the presence of non-level trays since the pressure drop does not decrease substantially.

Non-level trays can occur due to poor installation, failure of tray supports, or bowed trays. The cause of the problem can be determined only by an internal inspection by plant personnel.

Solids can accumulate adjacent to the tray overflow weir. This closes off a portion of the tray to gas flow and increase gas flow elsewhere on the tray.

SLIDE 7-51

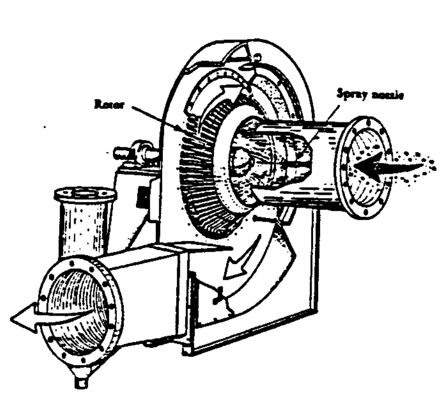


High gas flow rates can be another source of gas-liquor maldistribution problems. The high velocities can cause pluggage of the holes in the middle of the tray as shown in the sketch to the left. This forces the gas stream to pass up through the holes on the outer edge of the tray.

Pluggage in one portion of the tray due to either high gas flow rates or the build-up adjacent to the overflow weir will cause increased static pressure drop. This is due to the higher velocities necessary for the gas stream to pass through the few opèn holes.

During the inspection, an attempt should be made to assess the changes in the gas flow rate since the baseline period. The procedures used are identical to those discussed in slide 7-52 regarding low gas flow rates (see also Lecture #5).

SLIDE 7-52



Source: Air Pollution Training Institute

A mechanically aided scrubber operates quite differently from all other types of particulate scrubbers. Due to the shaft energy supplied to the gas stream, there is a static pressure increase rather than a pressure drop. The only other type of scrubber which operates in a similar manner is the ejector scrubber which is rarely used for removal of particulate.

The liquor quality is again critical with the mechanically aided scrubbers. High levels of suspended solids can lead to erosion of the fan blades or solids accumulation on the fan blades.

This type of unit is normally small, with gas flow rates in the range of 1,000 ACFM to 10,000 ACFM. Like most small systems, there are rarely measurement ports for static pressure and gas temperature. Few systems have liquor flow rate meters.

SLIDE 7-53

MECHANICALLY AIDED SCRUBBER INSPECTION DATA

1. Average Opacity (Residual)
2. Minimum and Maximum Opacities
3. Droplet Reentrainment
4. Scrubber Rotational Speed
5. Scrubber Static Pressure Rise
6. Liquor Flow Rate
7. Nozzle Operating Pressure
8. Liquor Turbidity
9. Liquor pH
10. Condition of Shell

This list summarizes the useful data and observations for mechanically aided scrubbers of the type depicted in the previous slide. The emphasis is on the static pressure increase across the scrubber, since this is related to the effectiveness of particle capture.

The liquor turbidity of the recirculation liquor should be checked as an indication of the total suspended solids content of the liquor. The nozzle operating pressures and the pump discharge pressures can be evaluated to determine changes in liquor flow rates and possible pluggage problems in the nozzle.

Decreased static pressure rise across the scrubber may indicate a change in the scrubber rotational speed. Data concerning the speed should be requested. During level 3 inspections, the speed can be measured if there is safe access to the main shaft. It is also helpful to measure the gas flow rate through the scrubber by means of a pitot traverse in the stack. Reduced gas flow rates are usually due to decreased scrubber speeds.

If there is reduced gas flow, there is some potential for fugitive emissions from the process equipment. The hood static pressure (if measured) should be checked and visible emission observations should be conducted.

SLIDE 7-54

TYPES OF GAS ATOMIZED SCRUBBERS

1. Fixed Throat Venturis
2. Variable Throat Venturis
3. Flooded Disc Scrubbers
4. Rod Decks Scrubbers
5. Orifice Scrubbers

A number of different gas-atomized scrubbers have been introduced in Lecture #2. Each of these has unique advantages and is susceptible to different operating problems. While the inspection procedure is basically the same for all types, it is necessary to "tailor" the inspection procedure to each specific type. Some ares of emphasis are presented in the next set of slides.

SLIDE 7-55

VENTURI SCRUBBER INSPECTION DATA

1. Average Opacity (Residual)
2. Minimum and Maximum Opacities
3. Presence or Absence of Detached Plumes
4. Droplet Reentrainment
5. Inlet and Outlet Static Pressures
6. Inlet and Outlet Gas Temperatures
7. Inlet Oxygen and Carbon Dioxide Levels
8. Recirculation Liquor Flow Rate
9. Nozzle Operating Pressures
10. Pipe Skin Temperature
11. Recirculation Liquor Turbidity
12. Recirculation Liquor pH
13. Evaporative Cooler or Presaturator Liquor Turbidity
14. Condition of Shell and Ductwork

This a fairly complete list of the inspection observations and measurements for gas-atomized scrubbers. Not all of these inspection points have to be performed on each inspection.

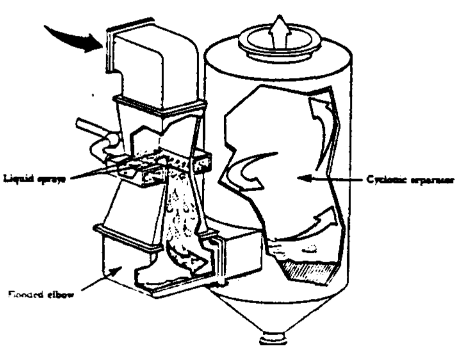
The static pressure drop divided by the average gas density is almost always important since this is related to the overall effectiveness of particulate removal in most cases (see earlier portion of Lecture #7).

The liquor suspended solids level is critical when the recirculation liquor is used for evaporative cooling ahead of the scrubber. It is also important for any units in which the liquor is sprayed into the gas stream

The outlet gas temperature is measured to provide an indication of severe gas-liquid maldistribution. These is an especially serious problem with gas-atomized scrubbers since there is only one very brief opportunity for particle capture. Poor distribution at the location of maximum gas velocity results in substantially reduced particulate removal. Most of the scrubbers discussed previously are less susceptible to this problem since there are several "collection zones" in series.

Gas-atomized scrubbers are more prone to erosion problems than other types of particulate scrubbers. This is the result of the high gas velocities in the restricted area (the "throat") and due to the sharp changes in flow direction common in most designs.

SLIDE 7-56



Source: Air Pollution Training Institute

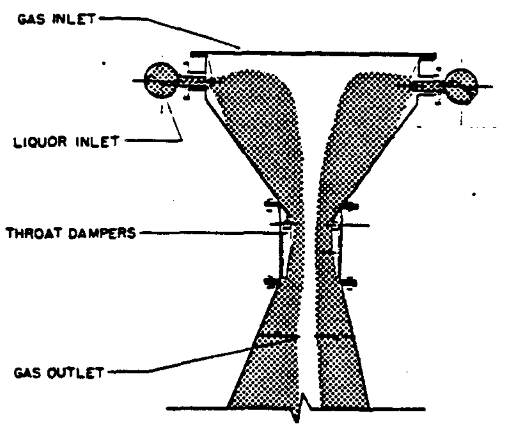
This is a sketch of a simple fixed throat venturi scrubber. A decrease in the corrected pressure drop can be due to a drop in the gas flow rate or a drop in the liquid-to-gas ratio. As indicated below, the pressure drop can be adequately represented by these two terms and a proportionality constant.

$$P = C \times V^2 \times \{Q_l / Q_g\}$$

Where: P = Static Pressure Drop
C = Proportionality Constant
V = Throat Velocity
Q_l / Q_g = Liquid-to-Gas Ratio

Changes in the gas flow rate can be evaluated directly by means of a pitot traverse or indirectly based on the fan operating conditions. The liquid flow rate can be evaluated directly using on-site gauges or estimated based on the pump operating conditions.

SLIDE 7-57

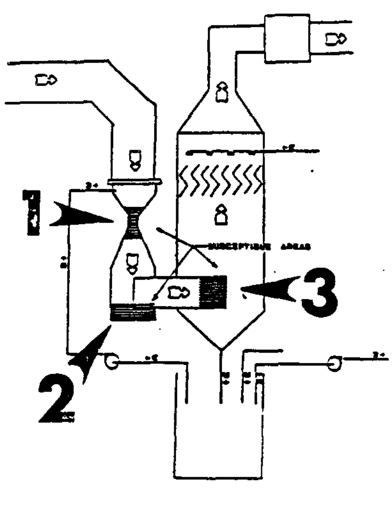


Maldistribution of the gas and liquid can result from improper nozzle placement, improper throat design, or partial pluggage of the nozzles. The problem stems from the difficulty of spraying liquid from the side wall into a gas stream moving between 20,000 to 40,000 feet per minute. This is equivalent to spraying liquid out of a car moving between 200 and 400 miles per hour! As one may expect, much of the liquor will be deflected and will not penetrate far into the throat. It is possible to incompletely irrigate the middle of the throat.

One symptom of this problem is outlet gas temperatures which are above the saturation temperature. This can be measured using the temperature probe discussed in Lecture #4. It is common practice to include manual rod out capability on all side mounted nozzles so that plugging is minimized. The loss of even one nozzle in some units can significantly reduce performance due to incomplete liquor distribuition across the gas stream.

The reason that distribution is so important in venturi scrubbers is that the point of maximum impaction is the entry to the throat. Here, the gas velocity is high and the liquor velocity is near zero.

SLIDE 7-58

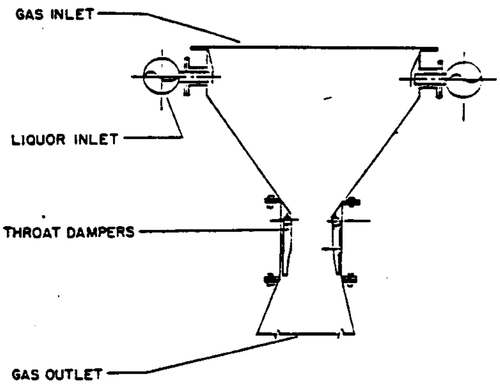


Erosion is common in the three areas shaded in the fixed throat venturi sketch. The high velocities within the throat (arrow #1) are responsible for the erosion in this area. The 90°turn near the bottom of the diverging section (arrow #2) are responsible for damage in this area. There can also be some erosion in the tangential entry to the cyclonic demister (arrow #3).

The damage to the elbow and the demister tangential entry can be easily seen during a walk around inspection of the unit. On negative pressure units, both areas are under high negative pressures and will have severe infiltration if there is damage.

The problems can be minimized by maintaining the pH in a noncorrosive range. In the case of the elbow, a shallow recession of 6 to 9 inches can be made directly below the diverging section of the throat. This "flooded elbow" blunts the abrasive action of the turning gas stream.

SLIDE 7-59

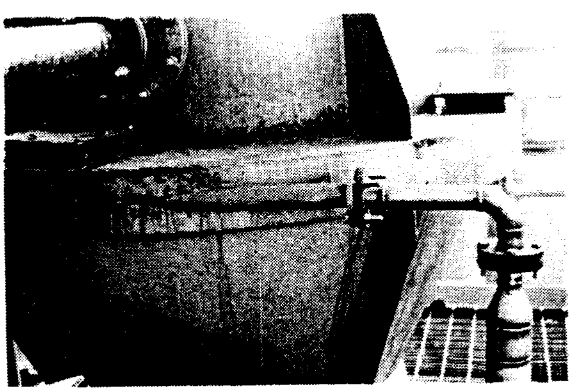


This is a side view of an adjustable throat mechanism for a venturi scrubber. A scrubber with these internal dampers would look similar to that shown in the previous slides. There is another common version which has a single damper mounted on one side of the inlet. In this case, the "throat" is often on the tangential inlet duct to a cyclonic demister.

Venturi scrubbers with these dampers can suffer severe abrasion of the dampers due to the high gas velocities in the restricted area. The symptom of this problem is reduced static pressure drop without any significant changes in the gas flow rate or the liquor flow rate. Due to the sensitivity of the pressure drop to throat velocities, even a little damper erosion can result in a static pressure decrease from baseline levels.

The liquor inlet configuration of this particular design is quite different from the array of side mounted nozzles depicted in the previous sketches. While it obviously does not have spray penetration problems, this design is also not immune to maldistribution problems. It is possible for the liquor to incompletely wet the sloped sides of the section which leads to the throat. This results in incomplete distribution of the liquor across the throat.

SLIDE 7-60

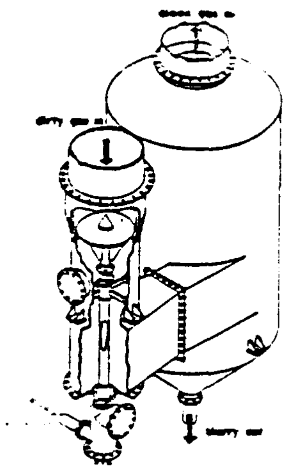


This is a photograph of the liquor inlet and converging section of a venturi scrubber. In this cases, the liquor swirls down to the throat in a manner which resembles a dentist bowl.

Maldistribution of the gas and liquor is possible if one or more of the pipes leading to the scrubber plugs. On systems in which a warm liquor (90 to 140 °F) is recirculated, it is often possible to identify these plugged lines. There is a difference in the pipe skin temperatures with the plugged line being several degrees colder than the others.

The pipe skin temperature can be measured using either a battery powered thermocouple or a thermister. The location for the measurement on each inlet pipe is shown by the arrows in the photograph. In some cases, it is possible to identify plugged lines simply by touch.

SLIDE 7-61



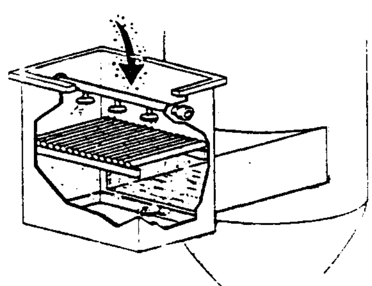
This is a cut-away sketch of a flooded disc gas-atomized scrubber. In this type of scrubber, the "throat" is the concentric area between the disc and the outer shell. The throat area is changed by moving the disc assembly up or down in the tapered section of the inlet column. The liquor comes up the center support of the disc and flows out over the top. The liquor is atomized on the outer edges by the high velocity gas stream.

For proper gas-liquor distribution, it is very important to maintain the disc level. If it is tipped slightly, the liquor will flow to one side and only partially irrigate the annular area. The maldistribution problem will be aggravated by the constricted passage on the side with liquor and the enlarged opening next to the high side of the disc.

Due to its position facing the inlet gas stream, the flooded disc must be very abrasion resistant. Linings should be checked regularily and replaced occassionally.

These scrubbers perform in basically the same manner as the venturi scrubbers discussed earlier. The inspection procedures for evaluating decreased pressure drop and materials of construction problems are identical. The flooded disc scrubbers are less susceptible to high suspended solids levels in the liquor since nozzles are not used.

SLIDE 7-62



Source: Air Pollution Training Institute

This is a sketch of a variable rod type venturi scrubber. The "throat" of this unit is the rectangular area between the rods. This area can be varied by moving the rods. Some versions of this design have several rod decks in series. The liquor is introduced through several large nozzles above the rod deck.

This unit is susceptible to erosion due to the high velocity particulate laden gas stream. The rods must be checked routinely and replaced whenever the erosion has progressed significantly. Rod erosion can often be identified as reduced pressure drop without a change in gas or liquor flow rates.

Gas-liquor maldistribution problems can result from improper nozzle selection, improper nozzle placement, and nozzle erosion. This can often be detected by evaluation of the outlet gas temperature.

LECTURE 7 - REVIEW PROBLEMS AND QUESTIONS

7-1. The best answers are "b" and "e". It is very possible that the asphalt plant is presently operating at higher mix temperatures and this is causing some additional volatilization of the components from the asphalt binder used in the drum mixer. It is also possible that the binder injection point has been moved forward toward the burner or that the binder recently received has a lower smoke point. Any of these process changes would result in large quantities of submicron organic particles which condense while passing through the scrubber. These particles would be difficult to capture and difficult to "wet". The possibility of these process related problems could be evaluted by observing the mix temperature monitored in the control room and by reviewing records on the grade of asphalt binder and its smoke point.

Answer "b" remains a possible explanation since there are normally only a few nozzles above the throat. Pluggage of one would leave a major portion of the throat without any water droplets and zero particle collection efficiency for this zone. The nozzle header pressure should have increased slightly if one nozzle plugged. However, these gauges are often not reliable due to solids accumulation in the inlet and due to severe vibration. To check out the gauge, the pump discharge pressure and the pump motor currents should be checked. Unfortunately, these are rarely available on small systems such as drum mixers. The point of this part of the question is that it is often wise to check the condition of the spray nozzles. This can usually be done when the asphalt plant is not operating.

Answer "a" is not correct since the decrease in pressure drop is not very large. It would be unlikely that a drop of this magnitude would result in an increase in opacity from 5% to 65%.

7-2. Only answers "c" and "d" are correct. The stem of the gauge has probably corroded away since the system is not operating at the time. The latter can be easily confirmed. Concerning answer "a", it is highly unlikely that the system would operate this far below normal saturation temperatures. It would require massive quantities of very cold liquor to depress the gas temperature to this level. Answer "b" is totally incorrect since liquor is not sprayed into a cyclonic demister.

LECTURE 7 - REVIEW PROBLEMS AND QUESTIONS

7-1. A venturi scrubber with an adjustable throat damper is being used to control the particulate emissions from a drum mix type asphaltic concrete plant. The residual opacity has increased from 5% to 70% since the last stack test. The pressure drop is now 17 inches W.C. and the baseline values ranged from 18 to 19%. There is no liquor flow meter. However, the nozzle header pressure has remained constant at 45 psig. The inlet gas temperature now is 283 °F compared with baseline values ranging from 276 to 294 °F. What are some of the possible explanations for the present high opacity?

a. Serious erosion of the throat damper has decreased the throat velocity, thereby reducing impaction.

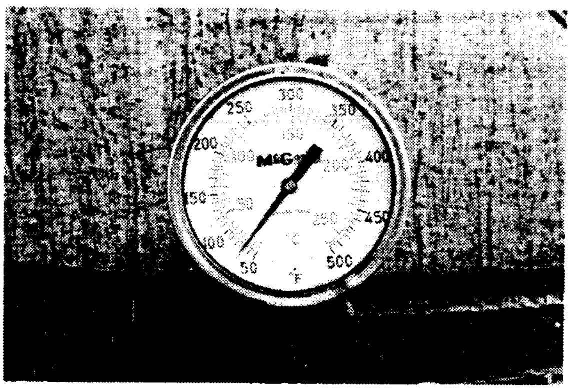
b. One or more of the liquor inlet nozzles is plugged.

c. The liquor flow rate has decreased substantially.

d. There is some oil scum on the surface of the settling pond.

e. The process operating conditions and/or raw materials have changed.

7-2.



This is a slide of a dial type thermometer in the upper section of a cyclonic demister. The indicated temperature is approximately 65 °F. What can be concluded from this data?

a. Since the gas stream is below normal saturation temperatures, the gas-liquor distribution is probably adequate.

b. The liquor sprayed into the cyclonic demister is too cold.

c. The gauge is not operating correctly.

d. The scrubber system is presently out-of-service

e. All of the Above

LECTURE 7 - REVIEW PROBLEMS AND QUESTIONS

7-3. Answer "f" is the best. The increase in pressure drop across a packed bed scrubber is usually due to either an increase in the gas flow rate or to the accumulation of solids within the bed. While the liquor flow rate has only a little impact on pressure drop, the decrease in liquor flow rate may indicate other developing problems. For this reason, the presence of audible pump cavitation should be checked. The process raw materials and operating conditions should also be checked to determine if the particulate loading in the inlet gas stream could have increased.

7-4. Answers "b" and "c" could be correct. The depressed temperature of line 3 suggests the potential for pluggage. Answer "c" has been included only to caution the attendees that the pipe skin temperature evaluation is not absolutely reliable. There is at least a slim possibility that all the lines are open and in good condition.

7-5. This is a repeat of a question used in Lecture #5. The only correct answers are "c" and "e". The consequences of fan disintegration should not be underestimated.

7-6. The pressure drop will increase due to the higher gas velocities through the throat. This question was included since venturi scrubbers with throat inserts are common. These were not discussed in the lecture portion since the inspection procedures are identical to those for fixed throat venturis.

LECTURE 7 - REVIEW PROBLEMS AND QUESTIONS

7-3. The pressure drop across a packed bed scrubber has increased from 6 inches of water to 11 inches of water. The liquor flow rate as indicated by an on-site gauge has dropped slightly. The inlet gas temperature has dropped from 164 °F to 145 °F. What are the logical follow-up inspection points?

a. The gas flow rate through the scrubber should be checked using a pitot traverse and using the fan operating conditions.

b. The inlet liquor turbidity should be qualitatively evaluated.

c. The potential for pump cavitation should be checked.

d. Changes in process raw materials and fuels should be checked.

e. Answers a,b,and c

f. Answers a,b,c, and d

7-4. A venturi scrubber being inspected has four tangential liquor inlets and one center flush line above the throat. A check of the pipe skin temperatures indicates the following: line 1 - 124 °F, line 2 - 123 °F, line 3 - 120 °F, line 4 - 124 °F, and line 5 - 125 °F. What are the possible explanations for these results?

a. Line 5 is partially or completely plugged.

b. Line 3 is partially or completely plugged.

c. All of the lines are open and in good condition.

7-5. A fan downstream of a cupola venturi scrubber is vibrating severly during the inspection. What should be done next?

a. A pitot traverse should be done to determine if this condition has adversely affected the gas flow rate.

b. The fan motor current and speed should be measured.

c. The inspection should be interrupted due to the potentially dangerous situation.

d. This is strictly a maintenance problem and should be ignored.

e. A responsible plant employee should be advised of the situation.

7-6. An operator of a fixed throat venturi scrubber has proposed adding a small plate across the throat to decrease the open throat area. If the gas flow rate remains constant, will this increase or decrease the static pressure drop?

a. Increase

b. Decrease

7-7. Answer "b" is correct. The hollow cone nozzles do not provide good gas-liquor distribution in spray tower scrubbers. Answer "a" is not correct even though hollow cone nozzles are, in fact, less prone to pluggage. In this case the operator is simply exchanging a maintenance problem for a performance problem (which leads to excess emissions). Answer "c" is logical. However, this may be expensive. In may be possible to eliminate the problem simply by finding nozzles which are not prone to pluggage at the prevailing solids levels at the plant.

7-8. Answer "c" is correct. It is possible it have a major fraction of the particulate in the submicron range and still have the quoted mass median particle size. Possible causes include vapor condensation and particle regeneration. The object of this question is to emphasize the importance of the size distribution.

7-9. The efficiency will decrease due to the lower gas velocities. Answer "a" is correct. The residence time is not important in particulate removal systems.

7-10. The only logical follow-up inspection point listed is the check for fugitive emissions from the process equipment (Answer "d"). The position of the adjustable throat dampers can not be determined externally. Also, it is more likely that the observed decrease in pressure drop is due to the downstream air infiltration problem than a change in the damper position. The pitot traverse in the stack will not be very helpful since in this position, both the gas and air flows will be measured together. To evaluate the quantity of infiltrated air it would be necessary to conduct a pitot traverse ahead of the scrubber in addition to the one in the stack.

LECTURE 7 - REVIEW PROBLEMS AND QUESTIONS

7-7. An operator of a spray tower scrubber has had chronic problems with full cone spray nozzles. To minimize the problem, it is proposed that all of these be replaced with hollow cone spray nozzles. Is this a logical approach?

a. Yes. Hollow cone nozzles are less prone to pluggage.

b. No. Hollow cone nozzles have spray patterns which do not provide good gas-liquor distribution in spray tower scrubbers.

c. No. The liquor suspended solids levels should also be reduced, if possible.

7-8. The mass median particle size in the inlet gas stream to a spray tower scrubber is 7.0 microns. Should it be possible to achieve an outlet particulate concentration of 0.10 grains/ACF if the scrubber is in good operating condition?

a. Yes. This is within the normal capability of spray tower scrubbers.

b. No. This is too small for spray tower scrubbers.

c. Maybe. It depends on the size distribution of the particulate matter.

7-9. The gas flow rate to an impingement plate scrubber has decreased 40% due to a permanent drop in the production rate. Will this have a beneficial or an adverse effect on the particulate removal efficiency of this unit?

a. Efficiency will decrease due to lower gas velocities through the holes in the tray.

b. Efficiency will increase due to higher gas residence times.

c. Efficiency will not be affected by this change.

7-10. The static pressure drop across a venturi scrubber has dropped from a baseline level of 28 inches W.C. to 21 inches W.C. The liquor flow rate has not changed. However, the gas temperature to the scrubber has dropped from a baseline level of 241 °F to 230 °F. Severe air infiltration is noted in the cyclonic demister of the scrubber. What are the logical follow-up inspection points?

a. The location of adjustable throat dampers should be checked.

b. The air infiltration rate should be quantified by means of a pitot traverse in the stack.

c. Process operating conditions should be checked to determine the reason for the inlet gas temperature drop.

d. The hood static pressure should be checked and equipment served by the scrubber should be checked for possible fugitive emissions.

LECTURE 7 - REVIEW PROBLEMS AND QUESTIONS

7-11. Answers "b" and "c" are both correct. Obviously, it is possible to climb the short stack and measure the static pressure (if conditions on the platform are safe). However, the static pressure here will be very close to ambient static pressure which is zero. Therefore, the static pressure can be calculated as the difference between +9.8 inches and either -1/2 or + 1/2 inches. The result is an estimated static pressure of 9.3 inches to 10.3 inches. This approach saves the effort of climbing the stack.

7-12. Answers "b", "c" and "d" could all be correct. The anti-foaming solution would obviously have some beneficial impact on foaming in the scrubber. It would also have some impact on the liquor surface tension which in turn affects the droplet size distribution and the effectiveness of impaction. It is difficult to determine without stack tests whether the anti-foaming solution will have a beneficial or adverse impact on performance. However, the inspector should note the quantities and types of anti-foaming solutions presently being used.

LECTURE 7 - REVIEW PROBLEMS AND QUESTIONS

7-11. During an inspection of a venturi scrubber, the static pressure ahead of the scrubber is measured as + 9.8 inches W.C. The only port downstream of the scrubber at which the static pressure could supposedly be measured is the stack sampling port on the platform 75 feet above the ground. The stack terminates approximately 4 feet above the sampling elevation. What should be done to determine the static pressure drop across the scrubber?

a. The pressure drop can not be determined since the fan is between the scrubber vessel and the stack.

b. Take a guess that the static pressure is between -1/2 inches to + 1/2 inches and calculate the pressure drop.

c. Go up and measure the static pressure at this port.

7-12. During an inspection of a scrubber system, the operator is observed dumping a gallon of anti-foaming solution each hour into the recirculation tank. What can happen to the system due to the addition of these chemicals?

a. Corrosion is dramatically accelerated.

b. There less foam flowing off the top of the recirculation tank and within the scrubber. Therefore, scrubber performance is improved.

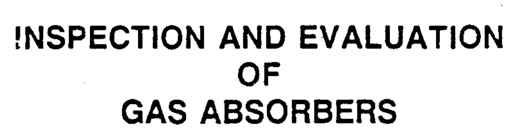
c. Particle impaction effectiveness is probably affected.

d. Droplet formation in the scrubber is affected.

LECTURE 8

INSPECTION AND EVALUATION
OF
GAS ABSORBERS

SLIDE 8-1



This lecture concerns wet scrubber systems used for the control of gaseous compounds, acid vapors and odor-causing organic vapors. It does not specifically address sulfur dioxide flue gas desulfurizations systems since this is covered in a separate U.S. EPA workshop program. However, the principles for gaseous scrubbers also apply to the SO2 control units.

The basic operating principles of this category of wet scrubbers are introduced. This is necessary to establish the most important parameters and to illustrate their differences from the particulate scrubbers discussed in Lecture 7.

The specific types of wet scrubber systems used for different applications are discussed. Inspection techniques for evaluating common modes of failure are presented. This incorporates much of the previous material from Lectures 3, 4, 5 and 6 into a complete inspection procedure.

SLIDE 8-2

GASES AND VAPORS ARE CAPTURED BY DIFFUSION

PARTICULATE MATTER IS CAPTURED MAINLY BY IMPACTION

There are numerous differences between gaseous absorbers and particulate wet scrubbers. One of the most important is listed in this slide.

Since most of the pollutants are captured by means of diffusion rather than impaction, certain parameters are important for absorbers which were not very important for particulate scrubbers. For example, the residence time in the scrubber becomes important in gaseous scrubbers since it takes time for the molecules to diffuse to the surface of the liquid and to transfer across the gas and liquid films.

The gas temperature becomes important in gaseous scrubbers since diffusion becomes more rapid as the temperature increases, while the solubility of most gases increases as the liquid temperature decreases. The scrubber pressure drop which is central to the performance of particulate scrubbers is less inmportant with the gaseous scrubbers. The liquor surface tension is also less important.

SLIDE 8-3

LIQUOR CHARACTERISTICS ARE CRITICAL TO PERFORMANCE

The characteristics of the liquor stream are critical to the performance of a gaseous scrubber. In the case of the particulate scrubber, the liquor characteristics are important only with regard to maintenance problems such as erosion, pluggage and corrosion.

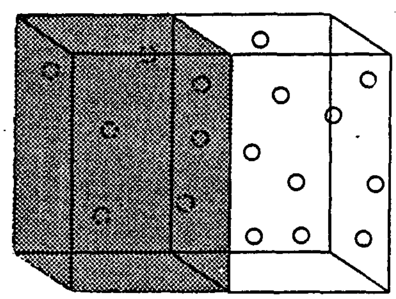
With gaseous absorbers, the liquor temperature, pH, and composition can all influence the performance of the air pollution control device.

SLIDE 8-4

LIQUID-TO-GAS-RATIOS ARE HIGHER FOR GASEOUS ABSORBERS

The quantity of liquor used in gaseous scrubbers is much larger than that used in particulate scrubbers. One of the reasons is that the maximum possible surface area for absorption is necessary. More liquor normally favors higher collection efficiencies. In the case of the particulate scrubbers, there is a broad range in which the liquid-to-gas ratio is not very important. That does not apply to the gaseous scrubbers.

SLIDE 8-5

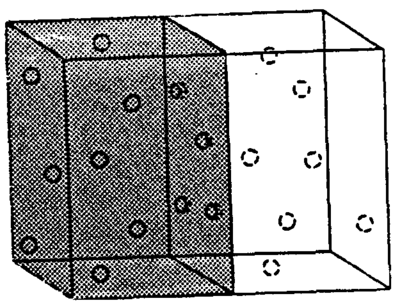


Source: Air Pollution Training Institute

The sketch shown in the circle on the right of this slide illustrates the microscopic process of absorption. Some of the gas molecules are diffusing across the interface between the gas and liquid streams. The overall rate of pollutant transfer from the gas stream to the liquid stream is dependent on the liquid surface area available and on the concentrations of the pollutant which exist in the liquid and gas phases. Turbulent mixing of both the gas and liquid streams favors absorption by decreasing the time required to cross the interface between the two phases.

Obviously, increased gas residence times favor the absorption of pollutants in a scrubber by allowing more time for diffusion to be completed. This is an especially important difference between absorbers and particulate wet scrubbers. With the latter, the impaction process occurs almost instanteously as a discrete event, while absorption is the collective process of mass transfer from the gas phase to the liquid phase. Absorption is time dependent. In Lecture 7 only the effectiveness of impaction is discussed, not the "rate of impaction." In this lecture both the rate and the effectiveness of diffusional mass transfer are important.

SLIDE 8-6

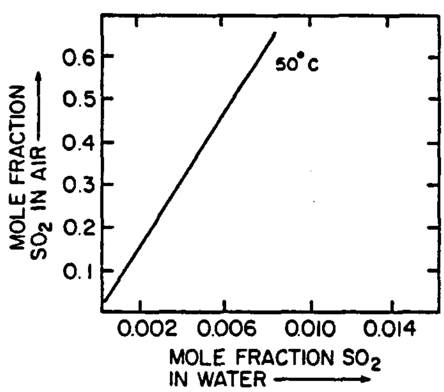


Source: Air Pollution
Training Institute

Mass transfer occurs in both directions until there are equilibrium concentrations of the specific compound in the liquid and gas streams. Once this equilibrium condition has been reached, there is no net transfer of pollutants into the liquid stream and the rate of pollutant collection is zero.

At this point, there are equal numbers of the specific molecules crossing the interface in each direction.

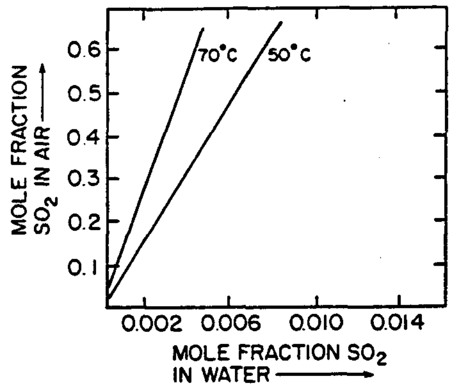
SLIDE 8-7



The equilibrium concentrations are an important operating limit for the wet scrubber systems. This slide shows one equilibrium relationship for sulfur dioxide in water at 50°C.

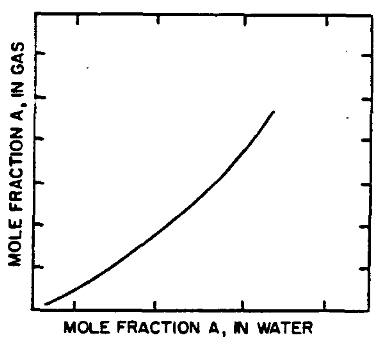
The units used in the graph are "mole fraction". This is simply a ratio of the number of molecules of the pollutant versus the number of molecules of the liquid. A 0.1 mole fraction SO2 concentration is equivalent to 100,000 ppm (or .1% by volume). A useful source for this data is the vapor pressures of the pollutant over the specific liquid of interest.

SLIDE 8-8



This is a repeat of the graph shown above. The equilibrium lines for 30°C and 70°C have been added to illustrate the strong temperture dependence of the equilibrium concentrations. Gases are much more soluble in cold liquids than in hot liquids.

SLIDE 8-9



Pollutants, which release large quantities of energy when dissolved, can have curved equilibrium lines. The graph shown earlier illustrates the strong effect that temperature has on the equilibrium levels. At high temperatures, gases are less soluble. When energy is released to the solution the temperature increases and the equilibrium levels decrease. This result is the curved line shown in this graph.

This type of curve can occur whenever gases such as HF and HCL result in a temperature gradiant across the scrubber. A portion of the unit may have very low rates of mass transfer under these conditions.

SLIDE 8-10

$$\bar{p}_a = H_a x_a$$

In some cases involving air pollution control systems, the pollutant concentrations are sufficiently low that the equilibrium data can be adequately represented by Henry's Law. This is shown in the adjacent slide.

It simply states that there is a straight line relationship between the gas stream and liquid stream concentrations of the specific compound. The slope of the equilibrium relationship is the Henry's Law Constant. In these cases, the equilibrium can be obtained from standard references.

Henry's Law is not followed whenever the molecule dissociates upon entering the liquid solution. Pollutants which dissociate include hydrochloric acid and hydrofluoric acid. For all molecules which do react once dissolved, the equilibrium relationship is normally curved, and it can only be obtained empirically.

SLIDE 8-11

FACTORS WHICH SHIFT THE EQUILIBRIUM CURVE

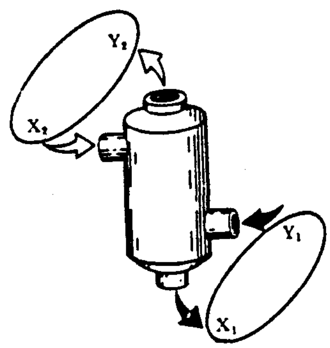
1. CHANGE IN GAS TEMPERATURE
2. HEAT RELEASE DURING ABSORBTION
3. CHEMICAL REACTIONS IN LIQUID

The primary objective of the last several slides has been to demonstrate that the equilibrium relationship in a wet scrubber can change. Any of the factors listed on this slide can cause a shift in these values.

The performance of an absorber is dependent on the operating temperature and the chemical reactions in the liquid stream. High concentrations of pollutants with high heats of dissolution can also cause an adverse shift in the equilibrium line.

Due to the number of variables which affect the equilibrium conditions, there is no one set of charts which can be universally applied to the wet scrubber systems.

SLIDE 8-12



lb mole in = lb mole out

$G_m(in) + L_m(in) = G_m(out) + L_m(out)$

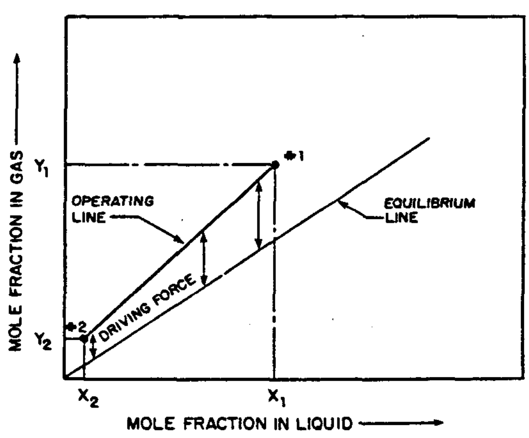
$$G_{m1}Y_1 + L_{m2}X_2 = G_{m2}Y_2 + L_{m1}X_1$$

$$Y_1 - Y_2 = \frac{L_m}{G_m}(X_2 - X_1)$$

The importance of the liquid to ga:
ratio is illustrated in the next
several set of slides. This slide
begins with a material balance aroı
the total system. The equation bel
the scrubber sketch states that wha
goes in also comes out!

The second equation is a material b
ance for the pollutant material. S
the concentrations of pollutants ar
small relative to the gas and liqui
streams, this equation reduces to t
third equation shown.

SLIDE 8-13



The third equation shown in the slid
above defines a line with the slope
equal to the liquid-to-gas ratio.

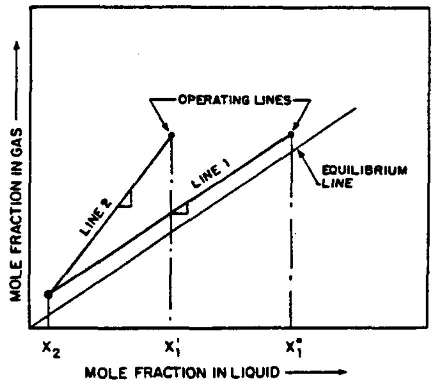
Point number one is determined by th
concentration of the pollutant in th
inlet gas stream and the outlet liqu
stream.

Point number two is determined by the
concentration of the pollutant going
the stack and by the inlet liquor
stream.

The straight line between these two
points is the operating line. This
defines the liquor and gas stream
concentrations of the pollutant at an
point in the scrubber.

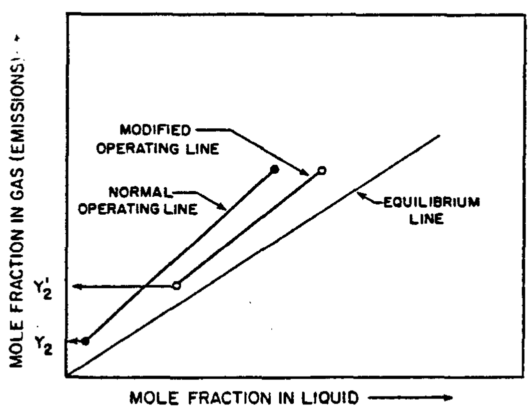
The difference between the equilibrium line and the operating line is th driving force for diffusion. The rate of mass transfer is proportional to this driving force.

SLIDE 8-14



As the liquid-to-gas ratio is increased, the concentration of the pollutant material in the effluent stream decreases. Line number two has a liquid-to-gas ratio which is approximately twice that of line one. The effluent liquid concentration is much lower with higher liquid-to-gas ratios.

SLIDE 8-15



The concentration of the pollutant in the incoming liquor, X2, controls the minimum stack concentration which can be achieved. If this is high, the emission rate will be high. This is illustrated in the graph. Line one represents normal operation, while line two represents conditions of high inlet liquor concentrations. Note that the stack concentration rises as the concentration in the incoming liquor rises.

This can happen in air pollution control systems in which the materials used to react with the dissolved pollutant material are temporarily stopped. As the inlet liquor concentration increases, so does the outlet concentration. Eventually the inlet and outlet liquor concentrations converge at a single point and the unit ceases any scrubbing action.

SLIDE 8-16

ABSORBER OPERATING VARIABLES

1. INLET GAS TEMPERATURE
2. INLET LIQUOR TEMPERATURE
3. LIQUOR FLOW RATE
4. LIQUOR TO GAS RATIO
5. INLET POLLUTANT CONCENTRATION
6. ABSORBENT CONCENTRATION
7. pH

Some of the major absorber operating parameters used during the inspection are listed in this slide.

The inlet gas temperature and the inlet liquor temperature are important since they will largely determine the operating temperature of the absorber. High temperatures adversely affect the total performance.

The characteristics of the inlet liquor stream are important since they define the minimum stack concentration of the pollutant. Factors such as the liquor pH and the hypochlorite concentration are important.

The liquid-to-gas ratio is important since it is a major factor in determing the rate of absorption. It also can affect the degree of liquor-gas maldistribution.

SLIDE 8-17

HCl SOURCES

1. High Concentration Effluent from Chlorination Reactors

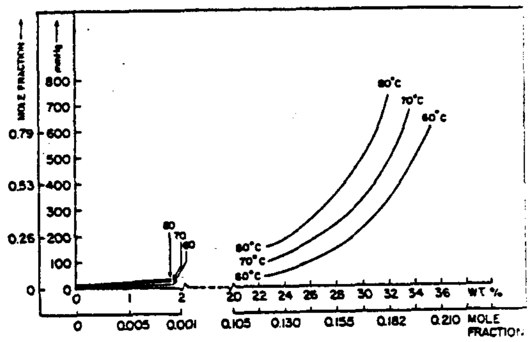
2. Low Concentration Effluent from Waste Incinerators

The principal sources of HCl include organic chlorination reactors and chlorinated waste incinerators. These two sources differ with respect to the concentration of the HCl vapor in the gas stream and with respect to the effluent gas stream temperature. The control system designs must be different to adquately handle these two different situations.

In the high HCl concentration applications, recovery of the HCl as a 30 to 38% weight percent solution is economically possible. In the low concentration applications, there is too little acid to justify recovery.

The heat of absorption must be taken into account for the high concentration HCl sources. It releases approximately 800 BTUs per pound of HCl upon absorption. As discussed earlier, this heat release to the solution has an adverse impact on the equilibrium concentrations.

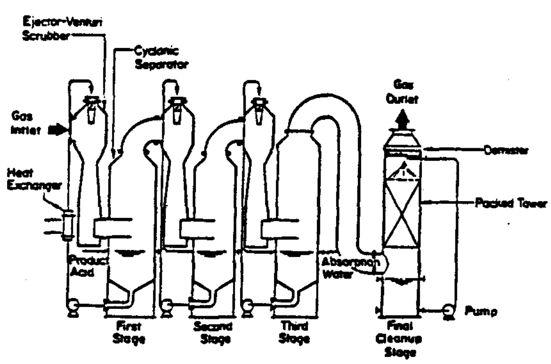
SLIDE 8-18



The equilibrium curves for HCl in water at several temperatures are shown in this slide. The right side of the graph shows the relationship at high concentrations of acid in water. The left side of the graph is an extrapolation to the origin. This was done to illustrate a Henry's Law type relationships at low HCl concentrations.

The strong effect of temperature is evident in the equilibrium data. Anything which increases the gas temperature will lead to reduced HCl removal.

SLIDE 8-19



A typical control system of a high concentration HCl scrubber is shown here. It consists of three ejector venturi scrubbers in series with a tail end packed tower scrubber.

Absorption water is brought to the last stage and moves forward through the system to the first stage. The heat of absorption is removed in the first two stages. The last ejector venturi and the packed tower operate at cold temperatures to maximize absorption. There is also a heat exchanger on the liquid stream inlet to the first scrubber to minimize the operating temperature in the first stage.

Due to the counter-current arrangement of the liquid and gas streams, the HCl concentration in the gas stream leaving the last ejector venturi is relatively low. Nevertheless, this would not satisfy most regulatory limitations. The packed tower is necessary as a polishing scrubber. This scrubber has relatively clean liquor at the inlet so that the stack levels of HCL can be minimized.

SLIDE 8-20

HCl SCRUBBER INSPECTION DATA

1. PACKED TOWER LIQUOR pH
2. PACKED TOWER PRESSURE DROP
3. PACKED TOWER LIQUOR FLOW RATE
4. PACKED TOWER OUTLET GAS TEMPERATURE
5. PACKED TOWER DEMISTER PRESSURE DROP
6. PACKED TOWER LIQUOR TURBIDITY
7. EJECTOR SCRUBBER STATIC PRESSURE RISES
8. EJECTOR SCRUBBER OUTLET GAS TEMPERATURES
9. EJECTOR SCRUBBER INLET LIQUOR PRESSURES

The important inspection points for the system shown in the last slide are listed here. The pH of the inlet liquor to the packed tower scrubber is of interest since this determines the minimum achievable outlet concentration of HCl. The pH should be relatively high, with normal conditions being in the 7 to 10 range. The temperature of this stream should also be kept to a minimum. The outlet gas temperature is the best indicator of an increase in the operating temperature of the scrubber. Increases from baseline levels suggest reduced removal efficiency.

The liquor recirculation rate to the packed tower scrubber is important since this partially determines the rate of absorption. This is rarely monitored directly. Indirect indications of flow include the pump discharge pressure and packed tower scrubber inlet line pressure.

The packed tower scrubber can be overwhelmed by HCl if the ejector scrubbers do not perform properly. The data which should be obtained is the static pressure rise across each ejector and the gas stream temperatures after each ejector scrubber. Reduced liquor flow rates can be identified by increases in the gas stream temperatures.

SLIDE 8-21

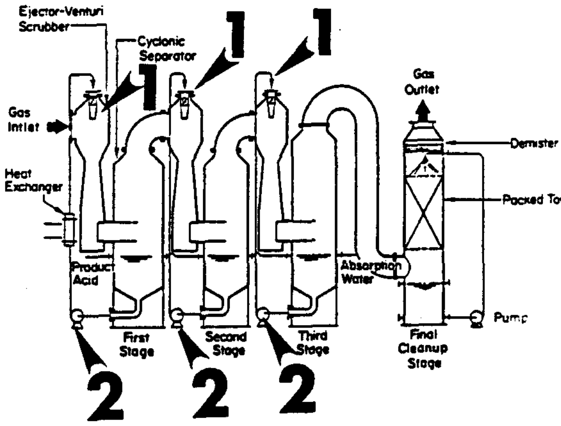
CAUSES OF REENTRAINMENT

1. PARTIAL PLUGGAGE OF DEMISTER
2. EXCESSIVE GAS VELOCITY
3. INADEQUATE DEMISTER CLEANING

Reentrainment from the packed tower is especially objectionable due to the potentially corrosive nature of the effluent liquor. The most common types of demisters are chevrons and mesh pads.

Any reentrainment which does occur is probably due to partial pluggage of the demister. Excessive design velocities are rare, due to the inherently low gas velocities necessary for the packed bed.

SLIDE 8-22

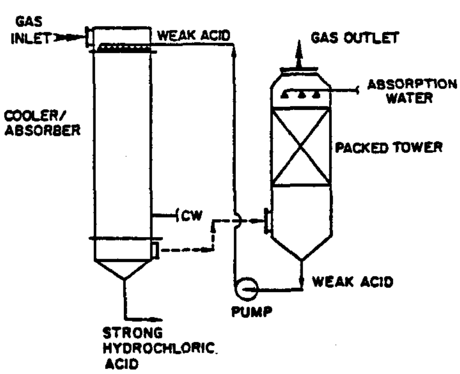


Low gas velocities through the scrubber system can result from a number of quite different problems. These are indicated on the modified sketch to the left.

Anything which reduces the liquid pressure at the ejector nozzle will reduce the gas flow rate. The operating condition of the recirculation pumps should be checked if the discharge pressures are low or if the static pressure increase across any of the ejector units is lower than the baseline levels.

Problems with the ejector scrubber nozzle can also reduce the gas flow rate. These high pressure nozzles are especially prone to pluggage and erosion. Obviously, the liquor quality is important in preserving these vulnerable nozzles.

SLIDE 8-23



This is a second type of high HCl concentration scrubber system. Absorption of HCl takes place on the inside tube surfaces of a vertical heat exchanger with graphite tubes. The absorbing water (with acid) flows downward as a film along with the gas. This is a co-current flow arrangement.

The heat of absorption is removed as quickly as it is released, thereby maintaining the equilibrium vapor pressure of HCl as low as possible. This system yields high strength acid (38% or greater), but the removal of HCL is incomplete in the cooler/absorber. This is due to the inherent limitations of a co-current scrubber.

To meet emission requirements, a packed bed tail gas scrubber is often used. The inlet liquor to this scrubber is relatively clean so that the stack concentration can be low. Automatic control of the entire system can be based on either the packed bed exit liquor temperature or the cooler/absorber exit liquor acid strength.

SLIDE 8-24

INSPECTION POINTS FOR FALLING FILM ABSORBERS

PACKED TOWER

1. Exit Gas Temperature
2. Exit Liquor Temperature
3. Inlet Liquor Temperature
4. Inlet Liquor pH
5. Inlet Liquor HC1 Content

COOLER/ABSORBER

1. Static Pressure Drop
2. Cooling Water Temperature
3. Product Acid Rate
4. Product Acid Strength

The inspection points for the falling film absorption system are very similar to those for the ejector-packed bed scrubber system discussed earlier. These are listed on the adjacent slide.

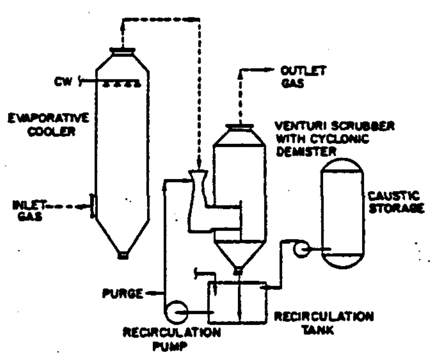
All of these parameters are related directly to the equilibrium concentations or to the rate of absorption in the scrubber system.

Note that there must be a fan with this system. Changes in the gas flow rate can be identified by the evaluation of the fan motor currents and the fan inlet gas temperatures.

The liquor flow rate to both the packed tower and the cooler/absorber are approximately the same since the exit liquor from the packed tower flows to the top of the cooler/absorber. While there may not be a flow monitor on this line, it is possible to approximate the liquor flow rate from the flow of the strong hydrochloric acid. It is necessary to account for the quantity of HCL absorbed and the quantity of cooling water added near the bottom of the cooler/absorber.

As with any scrubber, it is also necessary to check for apparent air infiltration due to problems with the scrubber shells or the ductwork. Also, the presence of reentrainment from the packed tower stack should be noted.

SLIDE 8-25



This is an example of a low HCl concentration wet scrubber system. It is used on sources such as waste incinerators where the concentration of HCl is less than 1000 ppm and the gas stream temperature is very high.

The evaporative cooler ahead of the scrubber is necessary to drop the gas temperature down to a range in which absorption is possible. HCl is removed in a venturi scrubber which also serves as a particulate removal device.

The pressure drop across the venturi throat is governed more by the particulate removal requirements than by the HCl removal requirements. The control of HCl is primarily dependent on the pH of the liquor. It is maintained at alkaline levels by the addition of caustic (normally 5 to 10% by weight). It takes 1.1 pounds of caustic for each pound of HCl absorbed.

SLIDE 8-26

$$F = C \times V^2 \times (L/G)$$

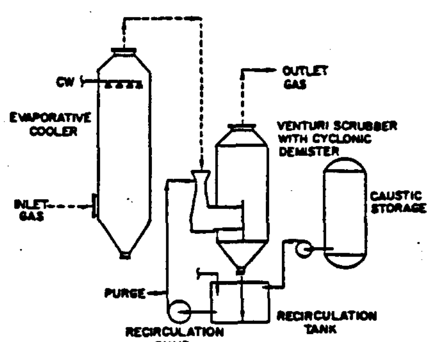
P = Static Pressure Drop
C = Constant
V = Gas Velocity in Throat
L = Liquid Flow Rate
G = Gas Flow Rate

The equation shown here is the formula which approximates the static pressure drop in venturi scrubbers (presented earlier in Lecture #7). It is possible to achieve the same pressure drop at numerous combinations of gas stream velocities and liquid-to-gas ratios.

With a scrubber intended for both gas and particulate removal, the correct combination of gas velocities and liquid-to-gas ratios are necessary. The pressure drop is not a reliable indicator of the performance of the unit with respect to HCl removal.

For this reason, the liquid flow rate should be obtained from plant gauges or estimated from pump performance data. The temperature of the recirculation liquor should also be determined. This can be measured directly at the recirculation tank or measured indirectly using the skin temperatures of the piping leading to the scrubber inlet.

SLIDE 8-27

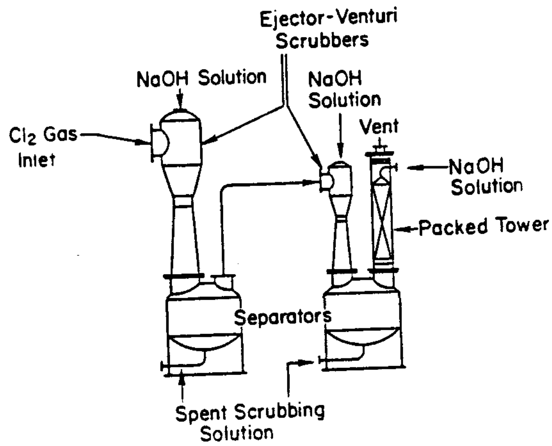


The pH of the liquor leaving the scrubber sump should be determined. In this co-current type of flow arrangement, it is this value which determines the minimum concentration of HCL which can exist in the stack (due to equilibrium considerations)

This pH also is important with regard to the rate of corrosion of the scrubber vessel. As discussed in Lecture #5, the rate of corrosion is governed by both the pH and the chloride content. At the high chloride levels which are inherently involved in HCl scrubbers, the pH must be relatively high at all points in the system.

The scrubber sample should not be taken at the pump discharge since at this point the recirculation liquor has been neutralized by the caustic added to the recirculation system.

SLIDE 8-28



A chlorine absorption system appropriate for control of emergency spills and appropriate for small continuous sources is shown in this slide. It consists of an initial ejector venturi followed by another ejector venturi and a packed bed combination scrubber. The ejectors are generally used since they are ideal scrubbers for applications requiring high liquid-to-gas conditions and there is no need for a separate fan to move the gas stream.

In the first ejector venturi, there is some liquid temperature rise due to the heat of absorption which is over 600 BTUs per pound of chlorine.

The solubility of chlorine in water is very small. Therefore, it is necessary to use caustic to react with any dissolved chlorine to yield the hypochlorite ion as indicated in the reaction shown below:

$$Cl \quad + \ 2\ NaOH \longrightarrow NaCl \ + NaOCl \ + H \ O$$

A once through liquor flow system is generally used due to the small scale of the equipment.

SLIDE 8-29

INSPECTION POINTS FOR SMALL CHLORINE SCRUBBER

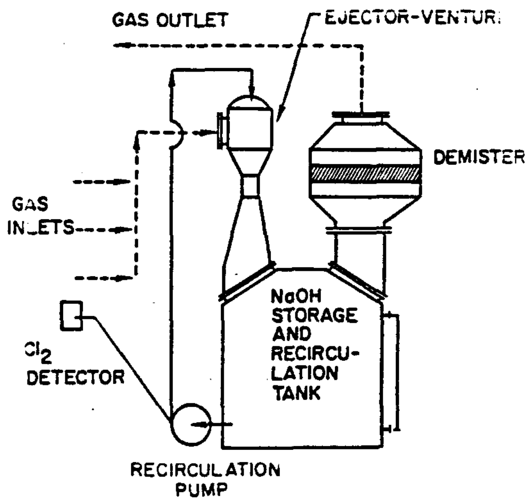
1. Flow Rates of All Inlet Liquor Streams
2. Gas Stream Exit Temperature
3. Gas Flow Rate to Scrubber
4. Static Pressure Rise Across Ejector
5. Pump Discharge Pressure and Motor Currents

The inspection of these scrubbers is similar to that for any other gaseous absorption system. The liquid-to-gas ratio is important since this affects the rate of absorption in all three of the scrubber vessels arranged in series.

The gas flow rate and the capture of the chlorine at the site of release are obviously important. This is evaluated by checking the static pressure rise across the ejector venturis. If this appears low, the ejector nozzle pressure or the pump discharge pressure should be checked.

Since these are once-through flow systems, the quality of the liquor coming into the last stage (the packed tower scrubber) is not usually a problem. The pH of the inlet NaOH solution should be sufficiently high to ensure very high efficiency chlorine removal. The temperature of the exit gas stream should be measured to indicate any conditions which have increased temperature and thereby reduced chlorine absorption.

SLIDE 8-30



This scrubber system is often used in water treatment and sewage treatment plants for the control of large releases of chlorine.

The large NaOH storage and recirculation tank contains sufficient caustic (5 to 10 weight percent solution) to neutralize one ton of chlorine. In the event of a spill, a chlorine detector activates a remote alarm system and starts the scrubber recirculation pump. At the same time, all openings and vents in the room where the spill occurred are closed. The ejector venturi draws in the gas, neutralizes the chlorine, and returns the scrubbed gas to the room.

A single stage system is adequate because the efficiency per pass is not an important consideration where there is no escape of gas to the surroundings. A typical system will neutralize the chlorine to a 1 ppm level in a matter of hours.

The wet chlorine environments are highly corrosive. The common materials of construction include titanium, PVC and special FRP fabrications. The integrity of the ductwork and scrubber vessel should be checked during all inspections.

SLIDE 8-31

EMERGENCY RELEASE CHLORINE SCRUBBER INSPECTION OBSERVATIONS

1. LEVEL OF CAUSTIC IN RECIRCULATION TANK
2. SYSTEM COMPONENTS SHOULD APPEAR IN GOOD CONDITION
3. RECORDS SHOULD INDICATE THAT DETECTOR IS CHECKED ON A REGULAR BASIS

It is unusual to find these scrubbers operating during any routinely scheduled inspection. Therefore, the inspection must be limited to an evaluation of the "capability to comply" rather than the operating conditions.

The level detector on the caustic storage and recirculation tank should indicate a normal level of caustic. The plant records should be checked to confirm that there is, in fact, caustic in the tank. The recirculation pump and piping should appear to be in good working order.

The system should be checked on a routine basis to ensure that the chlorine detector and the recirculation pump are operational. The ductwork should also be in good condition.

SLIDE 8-32

FLUORIDE CONTROL SYSTEMS

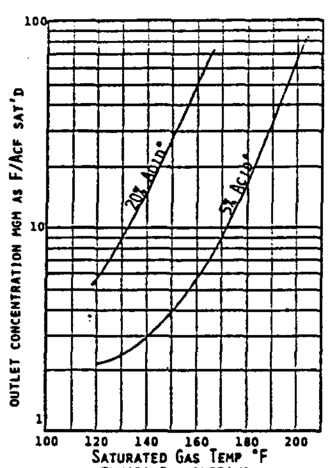
1. Gas Streams Often Contain Both Gases and Particulate Forms of Fluoride
2. Liquor is Often High in Fluoride Concentration and in Suspended Solids Levels
3. Liquor is Highly Corrosive
4. Control Requirements are Stringent

The principal sources of fluorine emissions are the phosphate fertilizer industry and the primary aluminum industry. The specific sources in these industries emit both gases and particulate matter which must be removed by the control system.

To avoid contamination of natural waters, fluoride systems usually involve recycle streams from a pond. The high flouride levels can present an equilibrium problem under extreme conditions and the quality of the recycle liquor can adversely affect pumps, nozzles and scrubber vessels.

The stringent regulatory requirements for fluorides means that it often necessary to have several scrubber units is series to achieve the necessary outlet gas stream concentration. As the system grows in complexity, the static pressure drop requirements can become large.

SLIDE 8-33



FLUORINE SCRUBBING
WITH
HYDROFLUOSILIC ACID
*% as H_2SiF_6

The problem with high fluoride content recycle liquor streams is illustrated in this graph. The lower line represents the conditions during a baseline period when the liquor temperature is low. An increase in the liquor temperature alters the equilibrium concentrations as shown in the higher line. With fluoride scrubbers, it is important to maintain proper operating temperatures to prevent low efficiency due to equilibrium conditions.

SLIDE 8-34

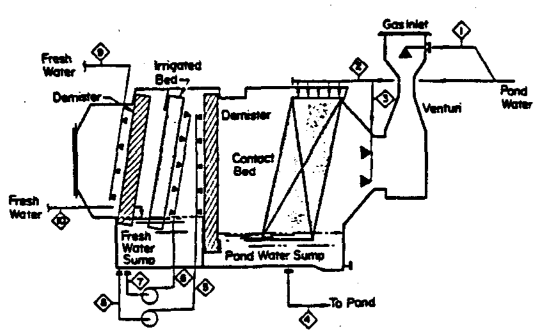
DESIGN PARAMETERS FOR FLUORIDE WET SCRUBBER SYSTEMS

1. Saturated Gas Temperature
2. Temperature of Scrubbing Liquor
3. Fluoride Concentration of Recycle Liquor
4. Inlet Fluoride Concentration and Physical Form
5. Allowable Fluoride Emissions
6. Scrubber Effectiveness
7. Demister Effectiveness

The design parameters for all types of fluoride scrubbers are listed in this slide. They become the inspection points for operating units.

This list starts with the saturated gas temperature for the reasons discussed in the previous slide. All of the other parameters are similar to those discussed with respect to other types of gas absorbers.

SLIDE 8-35



One type of scrubber used for the control of fluorides from wet process phosphoric acid plants is shown here. Due to the simultaneous presence of gases and particulate, there are a combination of control techniques within a single scrubber vessel.

The initial device is a venturi throat which is irrigated from a set of deluge nozzles above the converging section. The venturi is used for particulate removal. The next stage is a large cross flow packed bed for gas absorption. This is irrigated by front sprays, a distributor at the top, and the carry-over spray from the venturi. All of this liquor drains into the pond water sump.

A mist eliminator is used to prevent the transfer of the high fluorides liquor into the fresh water system downstream. A partition is used to keep the two liquor supplies separate. Within the fresh water portion of the scrubber, the absorption is completed using a liquor with low fluoride content and low liquor temperature. This fresh water section of the scrubber vessel, in a sense, serves as a separate "tail gas" scrubber.

SLIDE 8-36

FLUORIDE SCRUBBER INSPECTION DATA

1. VENTURI THROAT PRESSURE DROP
2. VENTURI THROAT LIQUOR FLOW RATE
3. CONTACT BED LIQUOR FLOW RATE
4. CONTACT BED LIQUOR TEMPERATURE
5. CONTACT BED LIQUOR TURBIDITY
6. CONTACT BED LIQUOR pH
7. POND WATER SUMP LEVEL
8. IRRIGATED BED LIQUOR FLOW RATE
9. IRRIGATED BED PRESSURE DROP
10. IRRIGATED BED LIQUOR TEMPERATURE
11. IRRIGATED BED LIQUOR TURBIDITY
12. IRRIGATED BED LIQUOR pH
13. OUTLET GAS TEMPERATURE

Inspection points for the fluoride scrubber shown in the previous slide are listed here.

The pressure drop across the venturi scrubber is important since this indicates the degree of particulate removal in the venturi. Carry-over of particulate into the contact bed could lead to partial pluggage and channeling. The total liquid flow in streams 5 and 8 are related to the absorption rate in the scrubber. The fluoride content of this liquor is important.

The temperature and fluoride content of the fresh water supply is important in determining the minimum fluoride concentration that can be present in the effluent gas stream. The outlet gas temperature also indicates the prevailing absorption temperature. The flow rate of stream 2 has a direct impact on the rate of absorption in the fresh water section of the scrubber.

SLIDE 8-37

FACTORS WHICH CONTRIBUTE TO MIXING OF POND AND FRESH LIQUOR SUPPLIES

1. SUMP PARTITION CORROSION
2. DEMISTER REENTRAINMENT
3. LEVEL CONTROLLER FAILURE

Anything which allows mixing of the pond water sump liquor and the fresh water sump liquor will reduce the collection efficiency of the scrubber system. The increase in the fluoride content will reduce the absorption of fluoride in the last stage.

This mixing of the two liquors can occur due to failure of the demister between the two compartments, due to failure of the liquid level controllers, or due to failure of the partition between the two sumps.

Due to the high fluoride levels often existing in the pond recycle liquor, it is necessary to neutralize with lime. If the pH becomes too high, some precipitation of calcium fluoride can occur in the contact bed and other portions of the scrubber system. This can have a very adverse effect on the contact bed and the first mist eliminator. For this reason, the pH of the liquor in line 1 (a portion of which becomes streams 5 and 8) should be checked during the inspection.

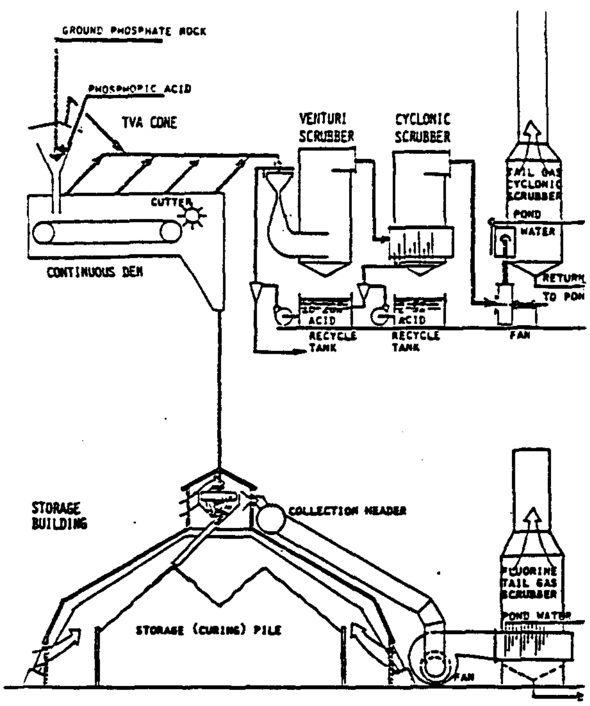
SLIDE 8-38

CORROSION IS A PROBLEM FOR FLUORIDE SCRUBBERS

Due to the severely corrosive nature of wet fluoride environments, the integrity of the materials of construction in the entire scrubber system should be visually checked. Areas of possible corrosion and air infiltration include the hoods, ductwork, fans, and pumps. The scrubber vessel is normally constructed of fluoride resistant materials.

Air infiltration into the scrubber system will obviously increase the quantity of untreated gas released to the atmosphere.

SLIDE 8-39



In the production of ROP Triple Superphosphate, there are several sources of silicon tetrafluoride. High concentrations of SiF_4 are evolved from the Acid/Rock Mixer, the Curing Den and the Cutter. These sources are often vented to a scrubber system similar to that shown in this slide. The principal purpose of the first two scrubber vessels is the concentration and recovery of the SiF_4. The last scrubber stage is necessary for compliance with environmental requirements.

The first stage of absorption is done with 16 to 20% by weight acid while the second is done with 2 to 5% by weight acid. The performance of both of these are of interest to the inspector only because problems here could overload the tail gas scrubber.

Recycled pond water is used for the final gas stream cleaning, since this has minimum fluoride levels and minimum temperatures. The unit illustrated here is a cyclonic spray tower scrubber.

SLIDE 8-40

FLUORIDE SCRUBBER INSPECTION DATA

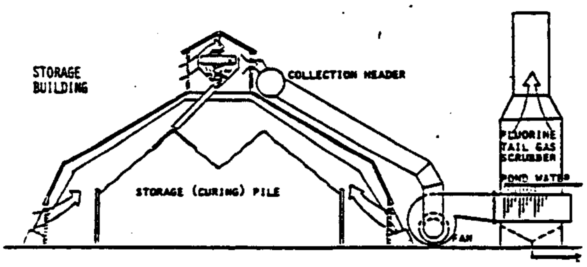
1. LIQUOR pH
2. RECIRCULATION LIQUOR FLOW RATE
3. FAN OPERATING CONDITIONS
4. STATIC PRESSURE DROP
5. OUTLET GAS TEMPERATURE
6. INLET GAS TEMPERATURE
7. INLET LIQUOR TEMPERATURE

Common inspection points for the tail gas scrubber shown in the previous slide include those listed here. The quality of the pond water is of central importance. The fluoride levels should be as low as possible and the liquor should be in the range of 7 to 10 pH.

The recycle liquor flow rate affects the removal efficiency of the scrubber. This flow rate should be obtained from on-site monitors or estimated from recirculation pump operating conditions.

The operating condition of the fan is important since this governs the gas flow rate from the various SiF_4 sources. This fan is vulnerable to fluoride attack and carry-over liquor droplets from the second stage scrubber.

SLIDE 8-41



SiF_4 continues to evolve in the curing pile. These emissions are collected in a building evacuation system and treated in a simple tail gas scrubber. The concentration is too low to economically recover the material. The type of scrubber illustrated here is a cyclonic spray tower similar to the one discussed in the previous two slides.

The inspection of this unit again emphasizes the recycle liquor quality and flow rate. Corrosion and reentrainment problems should also be evaluated.

SLIDE 8-42

CHARACTERISTICS OF ODOR CONTROL WET SCRUBBERS

1. Both Paritculate and Vapors Must be Removed.
2. Very Highly Removal Efficiency of Vapors Necessary
3. Numerous Compounds of Varying Solubilities Present

These are the primary problems which must be addressed in the design and operation of odor scrubbers.

Like many fluorine scrubbers, the effluent gas often containds both particulate matter and and vapors. Systems must have a combination of scrubbing techniques to handle both types of pollutants.

Very high removal efficiencies are necessary since odors can be detected by some individuals at very low concentrations. Scrubbers having an inlet concentration of 100,000 odor units often must reduce this to less than a 100 odor units in the effluent.

Unlike the previous scrubber systems, there is more than one compound which must be removed. In fact, it is highly probable that sources such as food product driers and rendering plants have 10 to 25 major components in the gas stream. The composition is rarely known. The various compounds all have different solubilities and this complicates the use of the equilibrium relationships discussed earlier.

SLIDE 8-43

COMMON ABSORBERS FOR ODOR SCRUBBER

1. HYPOCHLORITE
2. POTASSIUM PERMANGANATE

These are the most common absorbents used in odor scrubbers. The concentrations of the solutions generally vary between 0.5% to 5.0% by weight. The removal efficiency is not as highly dependent on the oxidant concentration as might be expected. Most field tests indicate that there is a certain minimum concentration necessary to react with the odorous compounds. Higher concentrations of oxidant yield only slightly additional odor removal.

The effectiveness of each of the compounds varies for different chemical species. However, there is very little test data to aid in the selection of the most effective oxidant for the compounds identified in the gas stream. The oxidant is selected based on vendor experience in similar sources.

There are certain odor causing materials which are essentially unreactive with these common oxidizing agents. The absorption of these unreactive materials (often termed "refractory" chemicals) is a function of the equilibrium concentrations and the effectiveness of the scrubber. Unfortunately, in some units the equilibrium concentrations can be quickly reached, thus limiting the performance of the system.

SLIDE 8-44

pH SHOULD BE HIGHER THAN 10

$HOC1 \rightleftharpoons OC1 \;+\; H$

In the case of hypochlorite scrubbers, optimum odor reduction occurs when the pH is above 10. Under these conditions the chemical equilibrium shown in this slide shifts to primarily hypochlorite ion (OCl). This is the species which reacts with the absorbed pollutant compounds. The hypochlorous acid is unreactive. The pH is adjusted using a caustic solution

SLIDE 8-45

OPTIMUM pH FOR PERMANGANATE SCRUBBERS 8 - 10

For permanganate scrubbers, the optimum liquor pH is between 8 and 10. In this range, the hydroxyl ion (OH) aids in the chemical attack of some absorbed pollutants.

SLIDE 8-46

INSPECITON POINTS FOR ODOR SCRUBBERS

1. Liquor pH
2. Liquor Oxidant Concentration
3. Liquor Flow Rate
4. Liquor Inlet Temperature
5. Gas Exit Temperature
6. Venturi Pressure Drop
7. Packed Bed Pressure Drop
8. Condition of Scrubber Shell, Fan and Ducts
9. Presence of Retrainment
10. Gas Flow Rate

These are the inspection points for odor scrubbers. The liquor oxidant concentration and pH are two of the most important variables. The oxidant concentration can not be measured during the inspection. The on-site conductivity monitor or oxidation-reduction monitor is used to determine if there has been a shift in the oxidant concentration.

As with all absorbers, the operating temperature and the liquid-to-gas ratio are important. The gas temperature leaving the scrubber provides a good indication of the operating temperature. The flow rate can be evaluated based on the recirculation pump discharge pressure and motor current.

The static pressure drop across the venturi provides a good indication of the particulate removal effectiveness. The static pressure drop across the packed tower is useful for identifying plugging problems within the bed.

The gas flow rate can be measured at the scrubber outlet using a pitot tube or estimated from the fan operating parameters. The fan rotational speed, inlet gas temperature and motor currents are necessary when evaluating gas flow rate changes.

The condition of the scrubber vessel shell, the ductwork and fans should be visually evaluated during the inspection. Any air infiltration can reduce the quantity of odorous gas pulled from the process equipment. The stack area should be checked for possible reentrainment from the packed tower stack. This is especially objectionable in the case of odor scrubbers due to the highly alkaline pH and the presence of the oxidant compounds.

LECTURE 8 - REVIEW PROBLEMS AND QUESTIONS

8-1. The correct answer is "c", the mole fraction is 0.097. The molecular weight of HCL is approximately 37.5. Therefore, 18 pounds is equivalent to 0.48 pound moles. The molecular weight of water is 18. Therefore 80 pounds of water is equivalent to 4.44 pound moles. The mole fraction of HCL is 0.48 divided by (0.48 + 4.44) or simply, 0.097.

8-2. Answers "a" and "c" are possible. At this pH, only a small fraction of the hypochlorite ion exists in solution. Most of it is tied up as hypochlorous acid. Since only a little hypochlorite ion is available to react with dissolved pollutants, it is possible that some of these pollutants are reaching the saturation concentration. After this is reached, there will be no more net transfer of the pollutant to the scrubber liquor. If the quantity of odorous material in the inlet gas stream is small, there may be sufficient reactants to adquately remove the odorous material. In this case, however, much of the hypochlorous acid solution will be wasted in the purge stream of the scrubber.

8-3. Answers "a", "b" and "c" are all possible. There has probably been a drop in the liquid-to-gas ratio of the scrubber. An increase in the inlet fluoride concentration is possible, but less likely.

8-4. Gases are more soluble at cold temperatures. Therefore, the observed increase in exit gas temperatures will have an adverse effect on the fluoride removal efficiency.

LECTURE 8 - REVIEW PROBLEMS AND QUESTIONS

8-1. What is the mole fraction of HCl if there are 18 pounds of HCl and 82 pounds of water? (0.095)

a. 18
b. 0.18
c. 0.097
d. 0.00457
e. It can not be determined from this data

8-2. An operator of a hypochlorite scrubber for a animal rendering plant is not presently adding caustic to the solution. The pH measured in the recirculation tank is 7.6. What statements could be true about the system at the present time?

a. The unit is operating satisfactorily, but a large quantity of the hypochlorite solution is being wasted.

b. Odor removal is not very effective since a pH in the range of 2 to 5 is necessary to initiate the oxidation reaction in the scrubber.

c. Some of the odorous materials are reaching equilibrium concentrations in the recirculated liquor and are no longer being removed effectively.

d. Plugging of the packed tower scrubber is probable under these conditions.

e. All of the above

8-3. The effluent liquor concentration of fluoride ion has increased by 46% since the baseline period. What does this possibly indicate?

a. The inlet concentration of HF has increased dramatically since the baseline period.

b. The liquid flow rate to the scrubber has dropped significantly since the baseline period.

c. The gas flow rate has increased substantially since the baseline period.

d. Severe air infiltration is occurring near the top of the scrubber vessel.

8-4. The exit gas temperature from a fluoride scrubber has increased 34 °F since the baseline period. Will this increase or decrease the fluoride removal efficiency?

a. Increase fluoride removal efficiency

b. Decrease fluoride removal efficiency

8-5. Answers "a", "c", "d", and "e" are all correct. In high concentration sources of HCl and HF, it is important to dissipate the heat of absorption in the first scrubber stage and then to complete the absorption in a tail gas scrubber. This is also necessary when recovering high concentration HCl. A particulate removal section is often used first to prevent pluggage of the packed tower absorption sections. The concept of transfer units was not discussed specifically.. This is related to the required control efficiency.

8-6. Answers "b" and "c" are possible. The ambient air passing through the unit will strip out fluoride compounds until the equilibrium concentration in the liquor is reached.

8-7. All of these favor absorption. Although not listed here, the liquid-to-gas ratio is equally important.

8-8. There is no indication that the gas flow rate has increased. However, the static pressure drop across the packed bed has increased substantially. Answer "c" is very probable.

LECTURE 8 - REVIEW PROBLEMS AND QUESTIONS

8-5. Why are several scrubbers often used in series on absorber systems?

a. To allow removal of the heat of absorption without adversely affecting absorption efficiency.

b. To allow removal of corrosive gases before the gas stream reaches the particulate removal section of the scrubber.

c. To allow for the concentration of a recoverable product

d. To allow removal of particulate before the gas stream reaches the gas removal section of the scrubber.

e. To increase the number of Transfer Units of the scrubbing system.

8-6. What would happen to a fluoride scrubber using recycled pond water of 3% by weight fluorides, if the inlet duct coming to the scrubber were handling only ambient air?

a. Absorption of fluorides would be high, due to the low gas temperature.

b. A small quantity of fluorides would be stripped from solution.

c. The stack concentration of fluorides would be higher than the inlet stream.

d. None of the above.

8-7. Which of the following conditions favor absorption

a. Turbulence

b. Time

c. Low temperature

d. High liquid surface areas

8-8. During an inspection of a packed tower absorber, it is noticed that the pH has dropped from 10.6 to 10.4 The static pressure drop across the bed has increased from 4 inches to 7 inches and the exit gas temperature has remained relatively constant. The fan rotational speed is constant, but the motor current is down slightly. What is probably occurring in this unit.

a. The gas flow rate has decreased.

b. The gas flow rate has increased.

c. The bed is partially plugged.

LECTURE 9

INSPECTION SAFETY

SLIDE 9-1

POTENTIAL INSPECTION HEALTH AND SAFETY HAZARDS

1. Inhalation of Toxic Gases
2. Inhalation of Toxic Particles
3. Inhalation of Asphyxiants
4. Burns on Hot Surfaces
5. Entrapment in Rotating Equipment
6. Falls off Ladders
7. Falls on Icy Surfaces
8. Falls from Weak Roofs and Platforms
9. Electrical Shock
10. Static Electrical Shock
11. Eye Injuries
12. Noise
13. Cold Stress
14. Fan Disintegration
15. Steam Burns
16. Contact with Pathogenic Organisms
17. Contact with Skin Absorbable Chemicals

Inspection safety is the most important topic in this workshop program. There are a number of potential health and safety hazards regardless of the level of inspection. A partial list of the types of hazards are provided in this slide. The inspector must be constantly alert so that these can be avoided.

The purpose of this lecture is to make everyone involved in field activities aware of the possible hazards near wet scrubber systems. Most of these are easily avoided as long as they are recognized.

The information presented here is not intended to replace or supersede any safety guidelines adopted by the agency of by the plant being inspected.

SLIDE 9-2

FACTORS CONTRIBUTING TO INSPECTION SAFETY PROBLEMS

1. Lack of Familiarity with Hazards at Specific Plant
2. Distractions Due to Conversations with Plant Personnel
3. Attempts by Plant Personnel to Hurry Inspector

There are a number of factors which make regulatory agency personnel potentially more at risk from these hazards than the plant personnel.

One of the most important of these is the lack of familiarity with the locations of the hazards at the specific plant. It is easy to overlook trip hazards such as valve stems and low support rods. High traffic areas may be in the same general area as the scrubber system. Also, some plants have high voltage cables and tracks. Even though these are marked, it is possible for the unwary inspector to contact the energized lines.

A contributing factor to the safety and health risk are the distractions inherent in conducting an inspection. The field inspector spends much of the time asking the plant representative questions about changes since the last visit. Also, it is not uncommon for the inspector to have to patiently listen to a long list of arguments and complaints from the plant personnel. Both the routine questions and the occassional arguments distract the person conducting the inspection.

An additional complicating factor is the tendency of a few plant representatives to "hurry" the inspector through the plant. The combined effect of a lack of familiarity and fairly rapid movement around the equipment creates favorable conditions for a serious accident.

SLIDE 9-3

FACTORS CONTRIBUTING TO INSPECTION SAFETY PROBLEMS

1. Hypersensitivity to Specific Pollutants
2. Lack of Acclimatization to Specific Pollutants
3. Synergistic Interactions

These are several other factors which can make a regulatory agency inspector especially at risk.

Due to the large number of different facilities, it is possible for an inspector to encounter low levels of a very large number of pollutants. There is a reasonable probability that an inspector who is hypersensitive to a certain chemical will encounter this material at some time during his or her career.

Unlike plant personnel, inspectors can rarely become acclimated to the materials which are sometimes encountered when inspecting wet scrubber systems and the associated process equipment. There is also the possibility for some synergistic interactions between pollutants inhaled in different plants and those retained in the lung. On plants with hot processes, it possible to have very hot and/or humid conditions around the scrubber. The inspector rarely spends the several days necessary to become acclimated to this heat stress.

SLIDE 9-4

FACTORS CONTRIBUTING TO INSPECTION SAFETY PROBLEMS

1. High Positive and Negative Static Pressures
2. Wet Walking and Climbing Surfaces
3. Icy Walking and Climbing Surfaces
4. Fan Disintegration Due to Solids Carry-over
5. Explosive Gases and Particulate in Gas Stream

The intrinsic nature of wet scrubber systems makes them especially prone to safety and health hazards!

They operate at higher pressure extremes (both positive and negative) than any other type of air pollution control device. This means that the potential for gas leakage out into the breathing zone can be high.

Leaks of water or entrained water from the stack can make all walking surfaces around the equipment hazardous, especially in cold weather. There are a number of sharp obstacles around the scrubber that would make any fall serious.

The wet and muddy conditions can also render fixed and portable ladders dangerous to climb. The foot rungs can be either muddy or icy. It is often difficult to secure portable ladders on the wet surfaces.

Wet scrubbers are often used on gas streams handling potentially explosive dusts and gases. It is the only type of collector which can not inherently ignite the mixture. However, the improper use of measurement probes and power tools ahead of the scrubber systems can create explosive conditions. Furthermore, there is potential for fan disintegration due to solids carry-over from the scrubber vessel.

SLIDE 9-5

BASIC FEATURES OF AN INSPECTION SAFETY PROGRAM

1. ROUTINE TRAINING
2. MEDICAL MONITORING
3. WRITTEN PROCEDURES

Due to the reasons presented in the previous set of slides, it is important that each agency have a routine safety training program for all individuals involved in wet scrubber system inspection (and all other field activities). This should address recognition of the problems and the agency policies regarding proper safety procedures.

There should be a medical monitoring program for all field personnel. This involves an initial physical to confirm that the individual is physically able to conduct the inspection. This exam then serves as the "baseline" for evaluating the health of the inspector in the future. This is important since some problems take time to develop.

There should be written safety procedures which contain all of the agency safety policies regarding personnel protective equipment and the performance of inspections. They should include any specific safety requirements at the plants to be inspected.

SLIDE 9-6

PERSONNEL PROTECTION EQUIPMENT USUALLY NECESSARY

1. Hard Hat
2. Gloves
3. Respirators
4. Safety Shoes
5. Hearing Protection
6. Eye Protection

The next set of slides presents the general safety principles which should be observed during the inspection of any air pollution control system.

The inspector should bring all the necessary personal protective equipment and be throughly trained in the proper use of the equipment. Sources have often distributed respirators and other protective equipment without realizing that the individuals did not know how to use them.

Hards hats are necessary primarily for protection against head blows against overhead obstacles. The safety shoes provide a slip resistant sole

Respirators are necessary for the various inhalation hazards potentially encountered at the specific plant. It should be remembered that each respirator is effective only for a small number of specific pollutants.

The need for gloves should not be underestimated. These are necessary for climbing ladders with rough foot rungs. Special gloves are also necesary when handling liquors with skin absorbable components or with pathogenic organisms.

SLIDE 9-7

NON-SPECIFIC SYMPTOMS OF EXPOSURE

1. Dizziness
2. Nausea
3. Lightheadedness
4. Drowsiness
5. Eye or Nose Irritation
6. Chest Pains

Whenever these non-specific symptoms are felt, the inspection should be interrupted. The inspector should proceed to an area with fresh air. The inspection should not be resumed until the cause of the ill feelings are identified. These are the initial symptoms of exposure to a large number of pollutants. Remaining in the area can quickly lead to serious health problems.

SLIDE 9-8

BASIC SAFETY PRINCIPLES

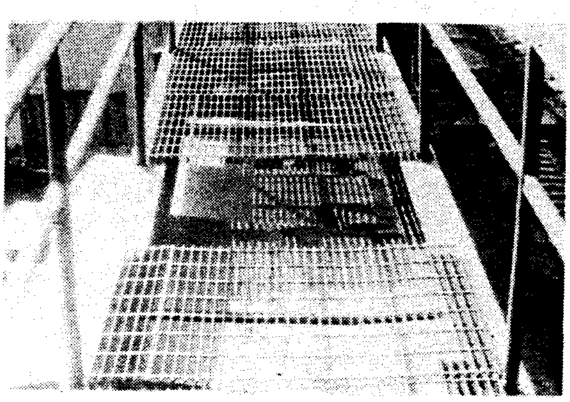
Work at Controlled Pace

Do Not Place Absolute Trust in Plant Personnel Regarding Inspection Safety

The last two basic safety principles are listed on this slide. The importance of conducting the inspection at a controlled pace can not be overemphasized. In this way, the common walking and climbing hazards can be avoided. There is also less chance or becoming trapped in areas with high pollutant concentrations.

Most field inspectors visit between 25 and 100 different facilities each year. While most plant personnel are safety conscious, it is inevitable that the inspector will encounter a few plants each year at which the personnel are either not concerned or are not aware of the potential problems. The inspector must never fall into the bad habit of abdicating judgment regarding inspection safety to the plant personnel. Sometimes they fail to realize that the inspector is not aware of potential safety hazards.

SLIDE 9-9



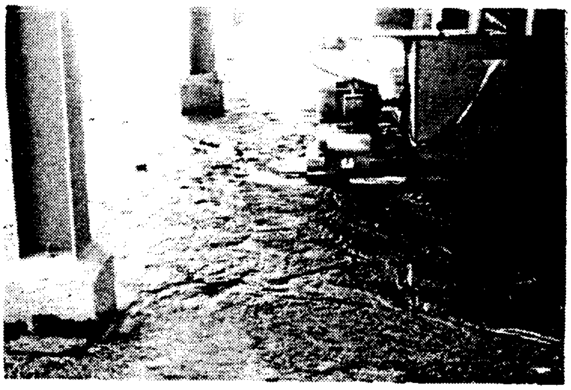
The next set of slides concerns the numerous walking and climbing hazards which can exist in the vicinity of wet scrubber systems.

Slippery areas are very common due to leakage of water from pump seals, rainout of scrubber liquor from the stack, and the occassional overflow of tanks. During cold weather periods these wet areas freeze.

The large number of pipes and electrical conduits provide a number of trip hazards.

Corrosion of the scrubber vessel walls and platform supports can make elevated platforms dangerous. The ladder leading to and from the platform can also present safety hazards.

SLIDE 9-10



This photograph shows the area around a centrifugal pump. The entire area is covered with water and wet pulp fibers. The water is due to the constant slight leakage of pump seal water. The wet pulp is due to an occassinonal overflow of foam from the recirculation tank. This makes the area around the pump very slippery. A fall here could result in a head injury on one of the footings shown in the slide.

During the inspection there is a natural tendency to look around or up at the various system components. Inspectors must be constantly aware of slip hazards around pumps.

SLIDE 9-11

This slide is similar to the one above. The only difference is that the wet area has frozen. Obviously, care is necessary when walking on the ice.

SLIDE 9-12

This is a view of a railroad siding next to a packed tower scrubber system. It is apparent that there is some ice approximately 15 feet ahead. What may not be apparent is that there is another patch of ice in the foreground. While this area looks like dirt, it is actually "black ice". It is simply frozen water with a high suspended solids content. This can form when the ambient temperature is very low.

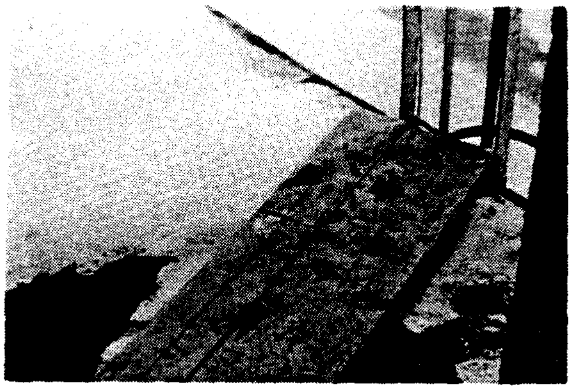
SLIDE 9-13

This is a view of a platform supporting a small rod deck scrubber. A small puddle of water has accumulated in a depression and frozen.

It would be easy to overlook this patch of ice since there are a number of overhead obstacles (out of view of the slide) which must be avoided while walking around the scrubber. A fall could result in a serious injury due to the sharp objects in the general area.

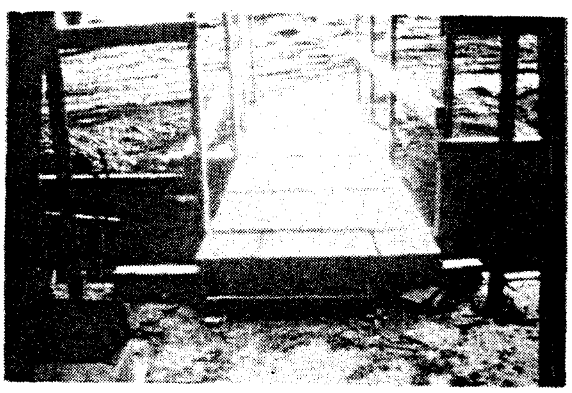
During cold weather periods, it should be assumed that almost all elevated platforms will have some frozen puddles or other slipper areas. Since some of them do not have hand rails, it is particularily important to avoid these slippery areas.

SLIDE 9-14



This board has been placed on a snow covered roof to improve the walking surface from a flooded disc scrubber to the access ladder (see in the upper right hand corner of the photograph). However, the board has become covered with a thin layer of ice due to water which has dripped off an adjacent roof and refrozen. A fall on this plank could result in a fall of 15 feet off the roof. Note that the roof does not have any railings to impede a fall.

SLIDE 9-15



This is a temporaty walkway over an excavated area. These should be used only when: (1) the ends are secured, (2) the wood appears to be in good condition, and (3) there are hand rails. Alternative routes are generally preferable to these temporary walkways.

Under no circumstances should inspectors use single boards as planks between two platforms, between two building roofs, or over open tanks. The support beams between two adjacent control systems or around a single scrubber should never be used for walking or climbing. Furthermore, ladders should not be used as planks.

It is not unusual for the field inspector to be ridiculed by plant personnel for refusing to walk across support beams or to use weak planks between high platforms. Inspectors must develop the self discipline to ignore this ridicule and to maintain safe inspection procedures at all time.

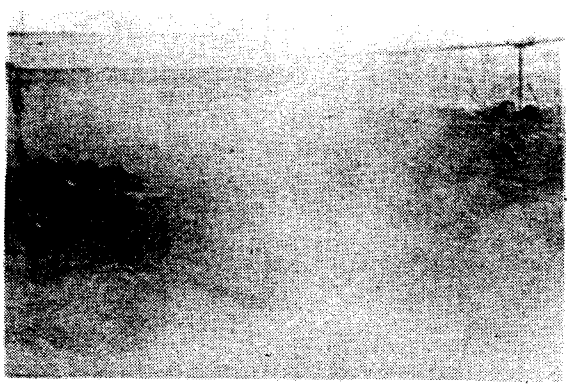
SLIDE 9-16

This is a view of the settling pond for a rod deck scrubber. It has a sloped ground level entry to permit a front end loader to occassionaly remove the solids from the first two zones. The walking area near the pond is very slippery. The unwary inspector could easy end up taking a swim in the pond. Due to the heavy winter clothes and the sloped side of the pond, this could result in a fatal accident. Also, the liquid temperature in the first zone can be as high as 140 °F and the pond can contain toxic suspended solids.

While access to activated sludge ponds is usually restricted, these can be especially dangerous. The specific gravity of the pond liquor can be so low that swimming and floating is impossible.

The areas immediately around basins and ponds should be avoided by the field inspector. Samples of the liquor should not be obtained at any location where it is easy to fall into the pond.

SLIDE 9-17

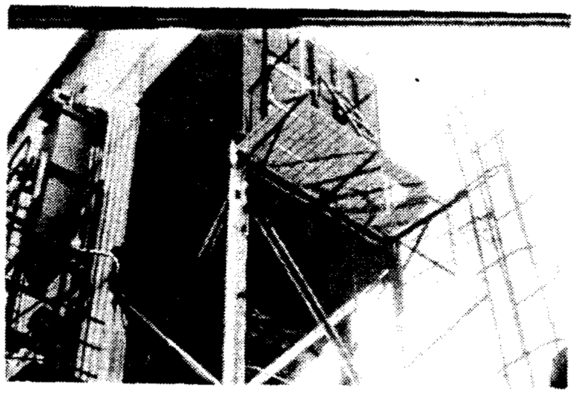


There are many locations around wet scrubber systems where steam clouds can suddenly envelop localized areas. This makes walking particularily hazardous.

This is a view of the same area shown in the previous slide. It was taken 15 seconds after the previous slide. The cloud is due to the contact of a cold breeze across the warm pond liquor. The inspector who fails to slow down as the cloud passes could easily get too close to the pond entry.

The inspector should not proceed until there is adequate visibility. Some make the assumption that they are completely familar with the plant. This can be a very bad assumption since plant personnel may have forgotten to replace a grating, or have left some obstacle in the walking path. Many changes can occur between inspections.

SLIDE 9-18



Several safety chechs should be made before climbing up to the elevated platforms around the wet scrubber vessels or the stack sampling areas.

The supports should be visually inspected for obvious corrosion. Also, the integrity of the ladder supports should be observed. Rotted wooden plants or gaps in the gratings should be checked.

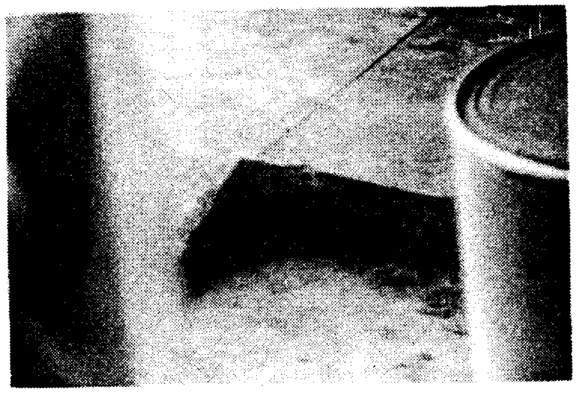
The potential for entrapment in a rising cloud of high temperature steam or a toxic cloud of fugitive emissions should be considered before going to the platform. If there are intermittant process operations which could create these highly dangerous conditions, the inspection should only be done when that portion of the plant is not running.

Inspectors should never underestimate the potential problems resulting from rising steam clouds and/or toxic clouds of pollutants. These can form suddenly due to process upsets or intermittant process operations. It is difficult to get off platforms when both visibility and breathing are impaired. Respirators should be taken when going to elevated platforms.

SLIDE 9-19

There are some elevated surfaces which may not be able to withstand any additional load. An inspector who walks across a roof, as shown in this slide, may fall through. It is important to stay within designated walking areas. It is also prudent to walk behind the plant personnel.

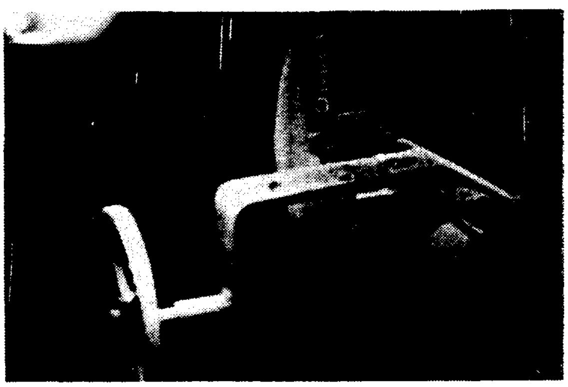
SLIDE 9-20



This is a picture of the floor around a packed bed wet scrubber. The entire system is in a very dimly lit building. While walking between the stockpiled materials near the scrubber, it is easy to miss the small raised portion of the floor. The severity of the accident depends on what is hit on the way down.

Whenever entering a building from the outside, it is necessary to wait briefly for the eyes to adjust to the low light conditions. Many scrubbers are placed in enclosed areas to protect piping from freezing during winter off-line periods.

SLIDE 9-21

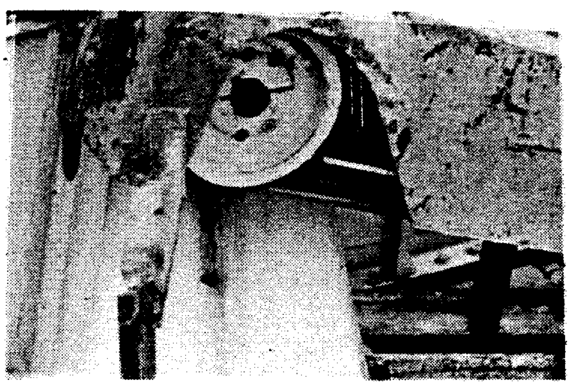


While walking around the scrubber system, it is easy to become preoccupied with inspection details. The valve stem shown in this slide sticks out far into the walkway at about the height of a knee. It is very hard to see due to the lack of light within the building (the photograph was shot with 1000 speed film and a 100 watt bulb approximately 2 feet away). This is just one example of the many trip hazards which can exist around the wet scrubber system.

SLIDE 9-22

This is a photograph of a small beam at about head height which is close to an access ladder. A painful and serious injury could occur to those who fail to wear a hard hat. It is surprising how many plants do not require these hats. It is also surprising how many overhead beams, conduits, valve stems, pipes, and other obstacles exist around a wet scrubber system.

SLIDE 9-23

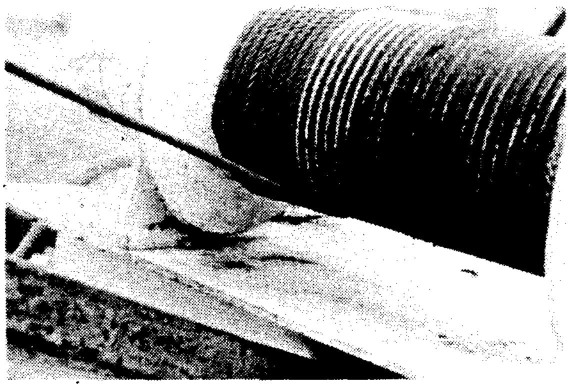


While walking around a wet scrubber system it is easy to forget about rotating equipment in the general area. This slide shows a partially covered fan sheave and drive belt. This was along a very narrow path to a rod deck scrubber. It is possible for loose clothing to get caught between the rapidly moving belt and sheave.

One way to minimize the risk of entrapment in rotating equipment is to avoid wearing loose clothing. Ties should not be worn during inspections.

The area immediately around the rotating equipment should be avoided to the extent possible. If there is only one path to the control system and there is a reasonalbe risk of entrapment even when caution is exercised, then the inspection should not be done!

SLIDE 9-24



This is a winch beside a narrow path to the same system discussed in the last slide. It is 4 feet above the walking surface and the cable cuts over the path that the inspector must take. The operation of the winch is controlled by plant personnel who can not see the scrubber from their work station. A serious injury could occur if an inspector placed a hand on the winch while trying to duck under the obstacles. It should be assumed that equipment which is designed to move will start suddenly!

SLIDE 9-25

Climbing ladders is a common part of wet scrubber system inspections. There are periods when these ladders can be very treacherous.

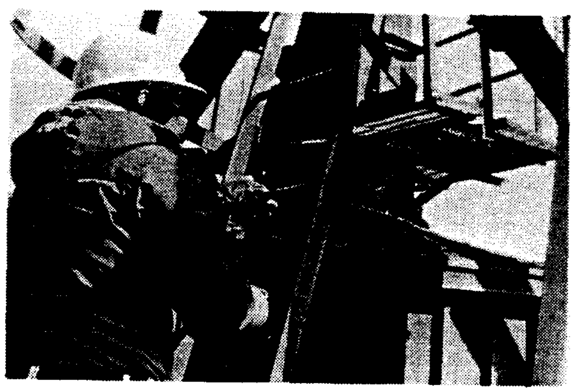
This slide illustrates a common problem with ladders around wet scrubber systems. The first person up the ladder (normally the plant representative) deposits a layer of mud or sludge on the foot rungs. This makes the ladder slippery

SLIDE 9-26

This slide illustrates one possible way to a ladder. There is a temptation to hold on to the side rails of the ladder to avoid the mud or sludge shown on the previous slide. However, it is easy for a foot to slip off the foot rungs under these conditions. With the hands on the side rails, an inspector may not be able to maintain a grasp on the ladder when the foot slips.

The inspector in this slide is making the mistake of trying to carry portable instruments while climbing. These significantly reduces the grip on the ladder.

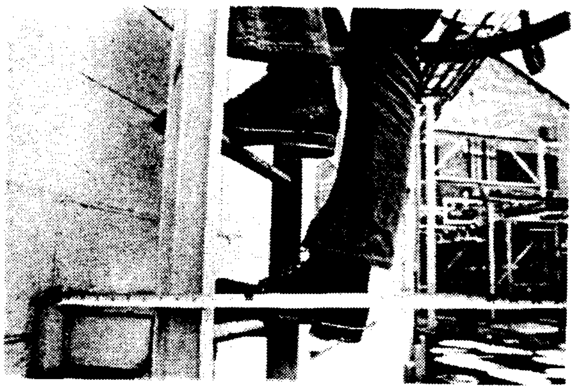
SLIDE 9-27



This slide illustrates another possible way to climb a ladder. The hands are placed on the foot rungs and the inspector is wearing gloves which improve his grip on the ladder. The portable instruments are being carried on a side pouch which does not impede the climbing motion.

Any large instruments should be transported to the platform or roof by means of a rope (with a bucket in some cases). Obviously, it is important that nothing falls during lifting and that the rope is not used near power lines. The wind speed should be low enough to prevent swinging of the rope.

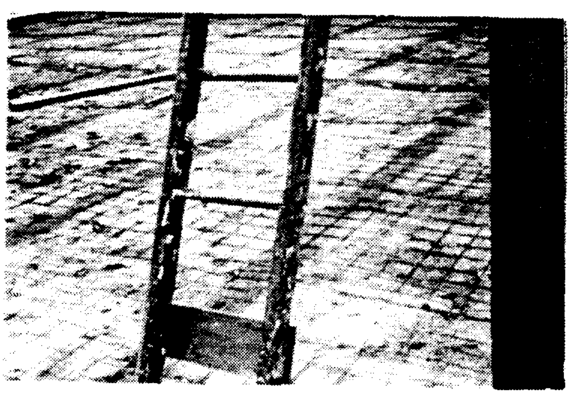
SLIDE 9-28



There should be at least 9 inches of clearance between the foot rungs and any obstacle behind the ladder. This is necessary to ensure that the foot rests securely and completely on the foot rung. The person shown in this slide should have been climbing by placing the back of the heel against the foot rung.

While the large majority of ladders on wet scrubbers have the necessary clearance, occassionally there are pipes, support beams or electrical conduits placed too close to the ladder.

SLIDE 9-29



Repaired portable ladders such as shown in this slide should not be used under any circumstances. If it has been necessary to fix one of the rungs, it is possible that some of the other rungs have also weakened.

All of the foot rungs should be inspected prior to use. The ladder should not be used if any of the rungs appear to be rotted or if a rung has separated from the side rail.

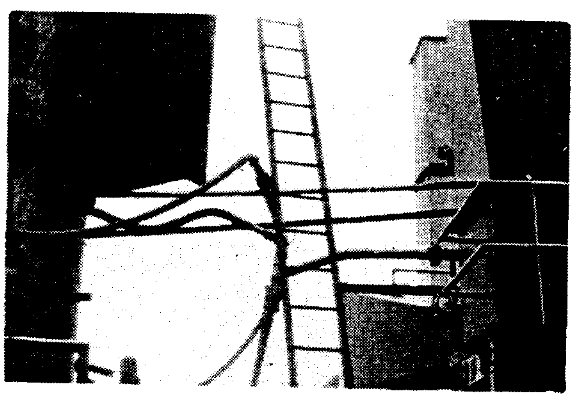
SLIDE 9-30

One of the basic requirements of a portable ladder is that it be secure at the bottom. It is often difficult to find a location near wet scrubber systems which is free of a coating of sludge or mud.

This slide shown a portable ladder sitting on a slippery layer of sludge next to a rod deck scrubber. There is a possibility that the ladder will slip at the bottom as an inspector climbs this ladder.

In addition to locating a dry spot for the ladder, it is necessary to have the right type of slip resistant protector on the bottom of the ladder. Two of the most common slip protectors are spurs and pads.

SLIDE 9-31



This is the same ladder shown in the previous slide. Another common problem with the portable ladders involves weak upper supports. Close examination of the slide illustrates that the small angle iron which is supporting this ladder has be cut approximately 80% of the way through. The load created on this beam as the inspector climbs will be enough to break the angle iron.

Ladders should not be resting on small support beams, pipes or electrical conduit. These were not constructed to withstand the 25 to 100 pounds of lateral force which can develop. Also the ladder should not be placed against a slippery wall.

The portable ladders should be inclined on an angle so that the ladder will not tip over and so that the base will not slip out. As a general rule the triangle defined by a sloped ladder should have a height which is 4 times the base. The ladder should never be near high voltage power lines.

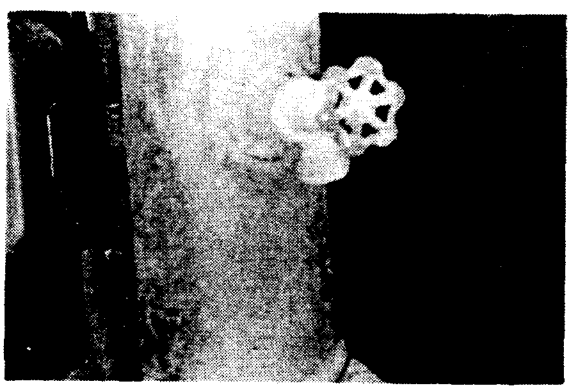
SLIDE 9-32

CATEGORIES OF EYE HAZARDS

- Physical
- Chemical
- Thermal Radiation
- Other Radiation

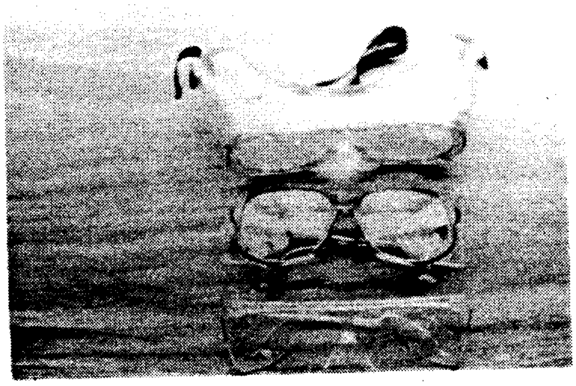
Potential eye injuries which can occur while inspecting wet scrubber systems are listed on this slide. The most common of these is chemical burn from fumes or splashes. It is important to wear eye protection while inspecting wet scrubber systems.

SLIDE 9-33



This is a photograph of a valve on the discharge line of a wet scrubber pump. The liquor is under approximately 90 psig pressure and the pH is quite high. If care is not taken in sampling the liquor, it can splash into the unprotected eye. This can result in a severe burn and/or blindness. The valve must be opened gradually and the receiving container must not facilitate splashing. The inspector should wear splash goggles while this is being opened. Plant personnel should take all liquor samples.

SLIDE 9-34



This slide shows three types of eye protection in general use for wet scrubber inspections. Most plants require eye protection and inspectors should be sure that theirs satisfies plant requirements. It is suggested that eye protection be used even if not specifically required. At the very least, it will prevent the introduction of chemicals and foreign materials into the eye by careless rubbing.

SLIDE 9-35

ON INDUSTRIAL JOBS . . .
DON'T
WEAR CONTACT LENSES

It is recommended that field inspectors avoid wearing contact lenses unless these are specifically allowed by plant and agency safety personnel. It is conceivable that hard contacts can increase the damage done to the eye by a foreigh body which gets trapped behind the lense. Soft contact lenses, particularily the gas permeable ones, may make the eye more susceptible to chemical damage.

Lecturer's Notes

There are differing opinions regarding the potential advantages and disadvantages of contact lenses during work in industrial facilities. Until this is settled satisfactorily, it is prudent to avoid the contact lenses. These are also not allowed during the use of any full face mask respirator.

SLIDE 9-36

Noise exposure related hearing loss is not a common problem in the inspection of wet scrubbers. The most probable sources of noise are the process equipment served by the scrubber system. The only significant source of noise on the scrubber system is the fan. Units which are operating a high tip speeds can have an appreciable noise level.

The best way to minimize noise related problems is to minimize the amount of time spent in the proximity to the noise source. Hearing protection should also be used whenever it is difficult to understand someone talking in a normal tone of voice from more than 2 feet away.

SLIDE 9-37

Some of the problems which seem the least likely on wet scrubber systems are the ones that can have the most serious consequences. These include explosions, burns, and electrical shock. The next set of slides briefly introduces ways to minimize the risk due to these problems.

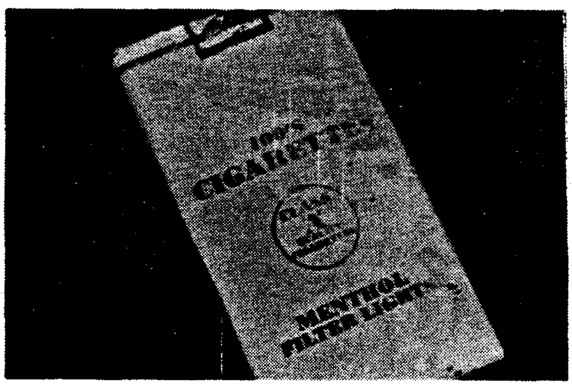
SLIDE 9-38

This slide shows flames engulfing an access ladder to a cupola wet scrubber system. This occurs when the plant is "dropping bottom". The inspector should not go near the scrubber system when this is about to occur.

Plant personnel are usually quite careful about advising inspectors about this operation. The problem occurs when the cupola operator is unaware of the presence of the inspector on the platform of the scrubber. The inspector must remain aware of plant operations and must not assume that the operators are always aware of his or her presence. After all, inspections occur only once or twice a year and it is easy for the operator to forget.

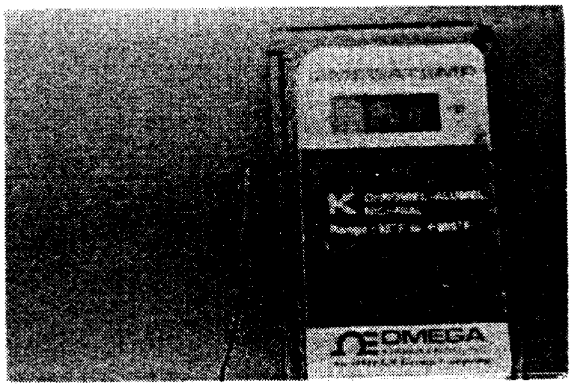
This is one of the many reasons why it is always advisable to perform the inspection in the company of a plant representative. This individual will know which operators must know about the inspector and will recognize when something is about to occur at the plant which could endanger the inspector.

SLIDE 9-39



Most plants have areas where explosions could be initiated by smoking. While the plant personnel are warned repeatedly about such areas, the inspector may not recognize the hazard. DO NOT TAKE SMOKING MATERIALS ON INSPECTIONS OF WET SCRUBBER SYSTEMS.

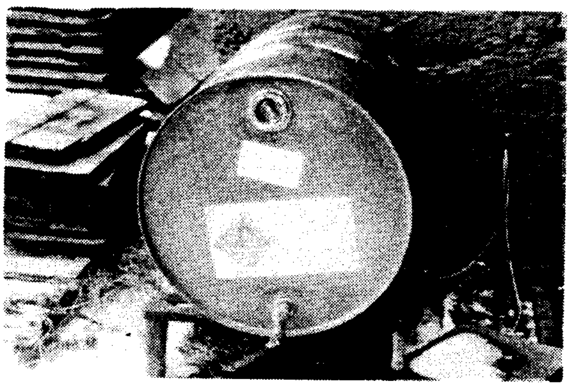
SLIDE 9-40



This is one type of portable thermocouple used for measuring gas, liquid, and pipe skin temperatures. It should not be taken into potentially explosive areas since most battery powered instruments can initiate explosions. All flashlights used should be explosion proof.

Potential safety problems with battery powered thermocouples, pH meters and flashlights should be discussed with plant personnel before use in the plant.

SLIDE 9-41

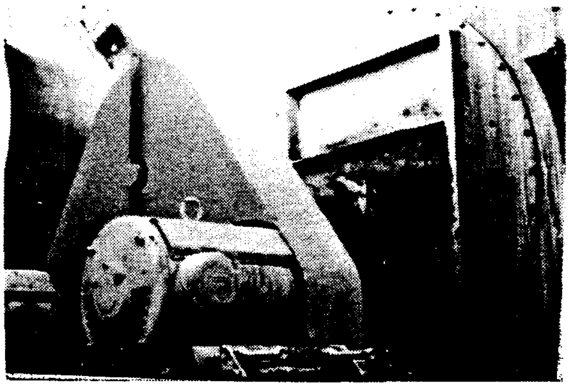


It is sometimes necessary to obtain a sample of fuel oil or other material stored in drums. When transferring the liquid from a storage drum to a sample bottle, is is possible to build up a high static charge on the sample bottle due to splashing. An explosion is possible if the drum and sample bottle are not properly grounded and bonded.

This slide shows a storage drum and a small clip which is part of the bonding line. This clip has so rusted that it would not provide a good contact. Also, the grounding line to the drum has been disconnected.

Samples should not be taken under the circumstances shown in the slide. A metallic sample bottle should be used and a grounding/bonding cable in good condition should be connected between the bottle and the drum. Another cable in good condition should connect the drum to the grounding rod. Plastic and glass bottles should not be used since it is impossible to ground these properly. Unfortunately, agency lab quality assurance personnel often are not aware of the significant explosion hazards and that often request field inspectors use plastic or glass bottles to prevent contamination.

SLIDE 9-42

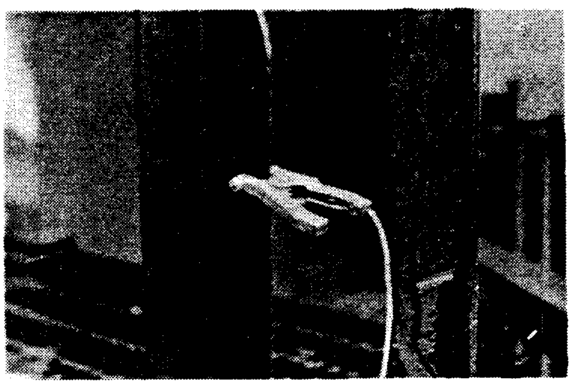


Several times during the previous lectures the potential dangers of fan disintegration have been mentioned. This can occur on wet scrubber systems due to the carry-over of liquor and solids from the demister. The erosion or solids accumulation on the fan blades lead to unbalanced conditions. Due to the high rotational speed the lack of balance can ultimately lead to the disintegration of the fan wheel and fan housing.

Other causes of fan disintegration include bearing failure and aerodynamic forces (fan operating in unstable region of fan curve).

The area around the scrubber should be left immediately if the vibration appears to be excessive. A responsible plant representative should be notified about the situation.

SLIDE 9-43



Static grounding/bonding cables should be used whenever making measurements at the inlet ducts of evaporative coolers and scrubber vessels. Static electrical charge accumulation can occur whenever the relative humidity is low (high gas temperatures) and the particulate mass concentration is high. It is conceivable that the charge will reach a sufficient voltage to arc within the duct and cause an explosion.

It should be noted that this problem has not been reported or discussed in the literature. However, the author has been able to develop high voltages on a pitot system which resembles the inlet to a wet scrubber system.

The gas streams in the inlet duct usually have more than enough particulate to sustain an explosion and many of these have the necessary oxygen levels. Scrubbers are often used specifically becuase of the potentially explosive nature of the inlet gas stream. For all of these reason, the probes should be bonded to a grounded portion of the plant using the grounding/bonding cables.

SLIDE 9-44

COMMON AREAS WITH INHALATION HAZARDS

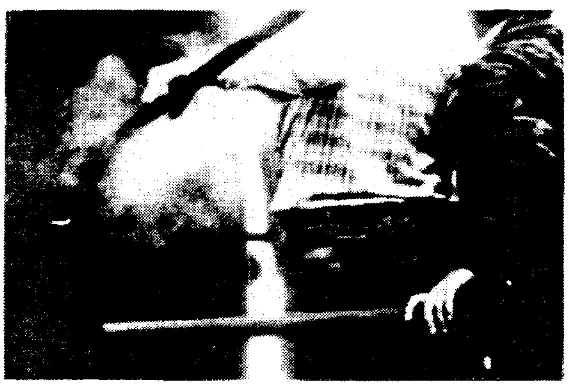
- Elevated Sampling Platforms
- Areas Adjacent to Process Vents and Discharge Points
- Partially Confined Areas
- Fugitive Process Emissions
- Fugitive Emissions from Solids Discharge Equipment

The next set of slides concerns the large number of inhalation hazards which can be encountered during inspection of wet scrubber systems. One of the fundamental principles of industrial hygiene is that inhalation exposures should be minimized or eliminated through the application of engineering controls. In the case of the field inspector, this is not a realistic possibility. Most exposures occur because of fugitive leaks of the pollutant-laden gas stream out into the area immediately surrounding the wet scrubber system.

These conditions occur by accident and often are not identified by plant personnel. Other sources of exposure are contact with the downdraft from nearby stacks or rising clouds of toxic pollutants released from intermittant process operations. Both types of exposure can result when inspectors are present on elevated platforms around the scrubber or on stack sampling platforms.

Since the exposures can not be easily limited by engineering controls, the inspector must substitute awareness of the potential problem areas and awareness of the warning properties of all chemicals present in the general area. The inspector must know when certain areas should be avoided and what respirators and other protective clothing to use in the areas which must be visited. The choice of respirators is complicated by the lack of monitoring data for the types of materials present. The conditions are highly variable and this makes monitoring data subject to error. Furthermore, there is rarely any monitoring data in the specific locations where the inspector may experience the most significant exposures.

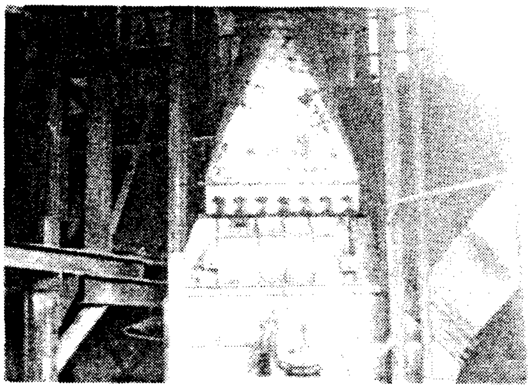
SLIDE 9-45



One common source of fugitive emissions are the open 4 inch stack sampling ports sometimes used when measuring scrubber operating conditions. This is a photograph of several inspectors attempting to use an oxygen analyzer at a 4 inch port having less than 1 inch W.C. positive pressure. Even at this low pressure, a substantial quantity of the gas can escape through the port into the breathing zone of the inspector.

These large diameter ports should be avoided whenever possible. The ports should be between 1/4 inch and 1 inch diameter. Only ports in areas with good natural ventilation should be used.

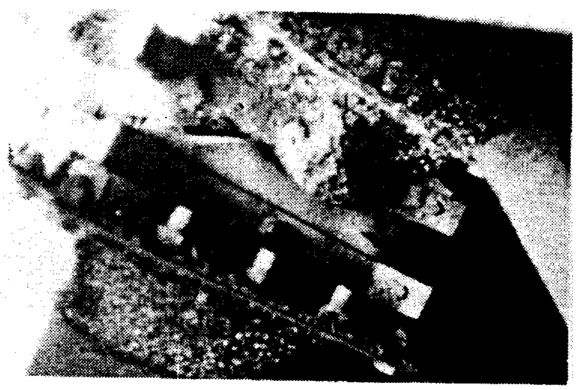
SLIDE 9-46



There can be areas around scrubber systems which have poor ventilation. Any fugitive leaks which occur in these area result in high localized pollutant concentrations. These can exceed the capabilities of some respirators.

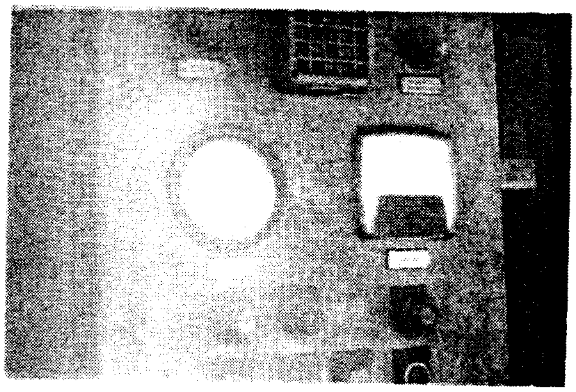
This photograph shows a fan serving a large venturi scrubber. The fan and scrubber are enclosed on three sides by building walls. A gap in the isolation sleeve on the fan or corroded ductwork could lead to very high concentrations near the fan. All fan housings or partially enclosed areas surrounding fans must be approached carefully.

SLIDE 9-47



This is a close-up photograph of the isolation sleeve on the discharge side of the fan shown in the slide above. There are a number of gaps which are leaking pollutant laden gas into the area around the scrubber.

SLIDE 9-48

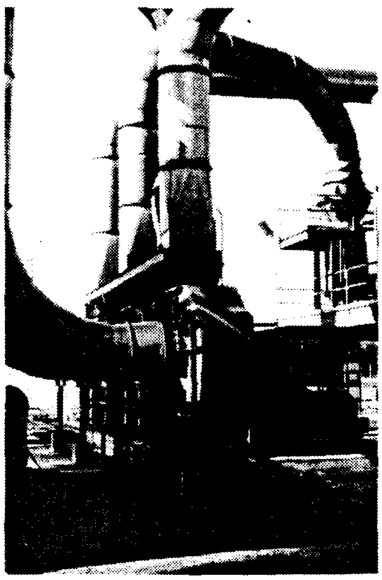


This is the scrubber control cabinet which is located less than 3 feet from the cracked isolation sleeve (see last two photographs). An inspector trying to determine the operating conditions of the scrubber system could be fumigated with toxic or oxygen deficient gases.

SLIDE 9-49

This is a view of a pump house. High concentrations of vaporous material can accumulate in this area. These must be approached cautiously since ventilation in pump houses can be limited.

SLIDE 9-50



High concentrations of pollutants can occur almost anywhere in wet scrubber systems which operate at positive pressures (fan ahead of the scrubber vessel). This slide illustrates a scrubber system under positive pressure. Wet scrubber systems operate at higher static pressures than all other types of air pollution control devices.

All partially confined areas around areas of possible fugitive leaks should be avoided. The inspector must remain constantly alert for symptoms of possible exposure.

SLIDE 9-51

MOST CONTAMINANTS HAVE POOR WARNING PROPERTIES

Avoiding hazards is the best way to minimize risk. Many of the materials inhaled during the inspection have poor warning properties. In other words, the person may have no physical sensation that there are high levels of pollutants in the air.

The inhalation of dust and fume rarely causes any immediate physical discomfort or impairment. For this reason, it is possible for undesirable quantities of toxic materials such as lead, arsenic and asbestos to reach the lungs where they can be slowly absorbed by the blood.

The chemical and physical asphyxiants are another group of chemicals with very poor warning properties. Chemical asphyxiants, such as carbon monoxide and hydrogen sulfide, can occur at life threatening levels without any odor or taste preception. The most common physical asphyxiant, carbon dioxide, also does not have any odor.

Most organic compounds and nitrogen dioxide are not very soluble and can penetrate into the deep lung. The initial symptoms of exposure are non-specific and may not be recognized by the inspector who is preoccupied with conversations with plant personnel. These symptoms include dizziness, headache, light-headedness, and nausea. Acute exposure can result in pulmonary edema hours after the exposure. It should also be remembered that non-soluble chemicals are not removed effectively in wet scrubbers. That means that high concentrations can exist in both the inlet and outlet gas streams.

SLIDE 9-52

The next three slides illustrate the differing characteristics of common air pollutants which can be encounted while inspecting wet scrubber systems.

At low concentrations, hydrogen sulfide is an eye irritant and it has a very disagreeable rotten eggs odor. If these symptoms are noted, the inspector should leave the area immediately. Exposure to higher concentrations of hydrogen sulfide can occur in areas close to the point where these symptoms were first noted. At moderate to high concentrations, hydrogen sulfide is an very deadly chemical and there is no odor at all! High concentrations of hydrogen sulfide immediately overcome the olefactory senses.

It is possible to walk into a confined or partially confined area with toxic concentrations of hydrogen sulfide and not be aware of its presence at all. Brief exposure to such conditions can lead to pulmonary edema and other serious respiratory problems in 6 to 12 hours after the exposure. In other words there is a delayed response during which the victim feels only slightly ill. The exposure can also result in immediate death.

Due to the almost total lack of warning properties, respirators do not provide an adequate defense. There are no commercially available respirators rated for hydrogen sulfide.

SLIDE 9-53

During the exposure to nitrogen oxides only mild bronchial irritation may be experienced. Concentrations of 100 to 150 ppm are dangerous for periods of 30 to 60 minutes.

Nitrogen oxides are generated in almost all combustion processes. While they do not have a distinctive odor, it is sometimes possible to see the orange color of nitrogen oxides.

These gases are examples of the non-soluble chemicals which can be treated in wet scrubber systems. They are often accompanied by other combustion related pollutants such as sulfur dioxide, ozone, carbon monoxide and particulate matter. Any respirator used in areas of fugitive gas leakage must be capable of handling all of these potentially dangerous gases.

SLIDE 9-54

CHLORINE

Route of Entry — Inhalation of Fibers

Symptoms — Intense Irritation of Eyes, Nose, and Throat

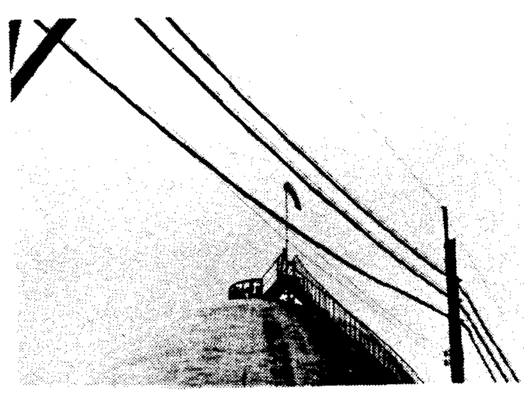
Consequences — Respiratory Problems

Chlorine is one of a number of chemicals which are partially soluble in mucous membranes. The initial site of attack includes the eyes, nose, and throat. It has relatively good warning properties.

Exposure can occur due to an accidental release from process equipment. Inspectors must be aware of plant warning sirens and know what to do if a cloud of chlorine is approaching their location.

Chlorine is often stored for use in odor scrubbers. It is also a common process chemical. Inspectors in areas vulnerable to sudden chlorine releases should be equipped with emergency respirators.

SLIDE 9-55



The wind socks and pennants on high places in the plants provide a good indication of prevailing wind direction. These should be observed whenever an inspection is being performed in a plant which could conceivably suffer an accidental spill or process release. As soon as the warning siren sounds or it is apparent that a gas cloud is approaching, all personnel should move to a safe position. It is also helpful to call in to a central location to report that everyone has reached a safe location. This call may prevent others from getting hurt while attempting a "rescue" of the inspection group.

SLIDE 9-56

SELECTION CRITERIA

- Concentration of Contaminants
- Forms of Contaminants
- Oxygen Levels
- Size and Shape of Head

The selection of the appropriate respirator for each inspection is a very important and complicated task. This provides a very brief overview of some important points. The readers are strongly advised to get expert assistance in the selection, fitting, maintenance and use of respirators.

The respirators must be selected based on a number of factors, some of which are listed on this slide.

One of the most important factors is the concentration of the material. The respirator must satisfactorily perform at these concentrations. It is also important to know if the concentration is in the range that is considered to be Immediately Dangerous to Life and Health (IDLH) and if the concentration is in the explosive range. These areas should not be entered by regulatory agency field inspectors.

Unfortunately, the concentrations of the contaminants are rarely known because the exposures are due to accidential and/or intermittant conditions. Also, the inspector visits many different localized sites around the control system and there is rarely any monitoring data available for all of these locations.

It is very important to know what the oxygen level is at the various areas to be visited. Many wet scrubber systems handle gas streams with very low oxygen levels of 3 to 6%. Even some small leaks can lead to localized oxygen concentrations below 19.5%, the point at which oxygen deficiency becomes a problem.

The warning properties of the materials must be known. This is best done by the file review before starting the inspection. If some of the chemicals are irritants, a full face piece unit may be required, regardless of the concentration. If the chemical(s) can be absorbed through the skin, protective clothing may be necessary in addition to a respirator.

The physical form of the material (gas, vapor, fume, dust) must be known to the extent possible. This is not as obvious as it would seem since the form of the contaminant can change in the wet scrubber or after release from the stack. There can be condensation of vaporous material to form submicron particles. There can also be stripping of dissolved compounds to form gases. The moist conditions can also promote atmospheric reactions between several pollutants.

The size and shape of the individual's head should be considered in the selection of respirators. There are usually several models of each type available, and the unit chosen must be comfortable and fit tightly.

SLIDE 9-57

There are a number of requirements concerning the the use of respirators. The material which follows has been excerpted from OSHA Standard 1910.134. The full text of the OSHA Standard and other material concerning the safe use of respirators should be read.

The user should be instructed and trained in the proper use and limitations of the specific respirators.

Whenever practicable, the respirators should be assigned to individual workers for their exclusive use.

Respirators should be regularly cleaned and disinfected. Those issued for the exclusinve use of one worker should be cleaned after each day's use, or more often if necessary. Those used by more than one worker should be thorougly cleaned and disinfected after each use.

Respirators should be stored in a convenient, clean, and sanitary location between uses. The trunk of a car is not adequate.

Respirator should be routinely inspected during cleaning. Worn or deteriorated parts should be replaced. Respirators for emergency use such as self-contained devices should be thorougly inspected at least once a month and after each use.

Appropriate surveillance of work area conditions and the degree of exposure or stress should be maintained.

Persons should not be assigned to tasks requiring use of respirators unless it has been determined that they are physically able to perform the work and to use the equipment. A local physician should determine what health and physical conditions are pertinent. The respirator user's medical status should be reviewed periodically.

Written standard operating procedures governing the selection and use of respirators should be established.

SLIDE 9-58

SOURCES WITH POTENTIAL BIOLOGICAL HAZARDS

- Municipal Incinerators
- Pathological Incinerators
- Foodstuff Processors
- Genetic Engineering Firms

The adjacent slide is a partial list of the possible sources of biological hazards. It is obviously important to avoid direct contact with contaminated materials. The appropriate respirators should be selected based on agency and plant industrial hygiene guidelines. Eye protection should be worn in situations where splashing or contaminated water is possible. It is important to avoid any rubbing of the eyes at any time since this is an easy entry route for pathogenic organisms. After the inspection the work cloths should be washed and the inspector should shower.

SLIDE 9-59

Here is one example of a commonly encountered potential biological hazard. This inspector is attempting to obtain a scrubber liquor sample. Since it is possible that the liquor contains pathogenic organisms, the inspector should avoid contamination of his skin and clothing. THIS IS THE WRONG WAY TO TAKE THE SAMPLE.

It is far better to sample in a area where there is no direct contact with the liquor and no possibility for splashing of the liquor.

SLIDE 9-60

This is the most important safety precaution that should be taken during the inspection of wet scrubber systems.

UNDER NO CIRCUMSTANCES SHOULD AN AGENCY INSPECTOR ENTER ANY PORTION OF THE WET SCRUBBER SYSTEM. Oxygen deficiency and/or high concentrations of highly toxic pollutants can be trapped in scrubber vessels, tanks, ductwork, and other areas. The conditions can persist even after the system has been off-line for a period of time. It is often difficult to detect the dangerous conditions.

It takes special training and personal protective equipment to make safe internal inspections of air pollution control systems. Regulatory agency personnel do not have either this training or equipment. Furthermore, there are certain safety procedures that must be observed at each plant.

Regardless of the possible encouragement by plant personnel or the natural curiosity of the inspector, entry inside the equipment should not be done. Everthing thing that must be done by an inspector can be done satisfactorily and safely outside the equipment.

LECTURE 9 - REVIEW PROBLEMS AND QUESTIONS

9-1. All of these are potential areas of high pollutant concentrations. They should all be approached very carefully.

9-2. The correct answer is "d". It is important to use the grounding/bonding cables whenever there is any possibility for static electricity. This is most likely at the inlets to wet scrubber systems.

9-3. Answers "b", "c", and "d" are correct. Often the plant personnel are not using hard hats, safety shoes, hearing protection and respirators. The inspector should not abdicate his or her judgement to plant personnel since there are a few who are not safety conscious and a few who are totally oblivious to health and safety risks.

9-4. The correct answer if "e". The inspector should always be accompanied by a plant representative who: (1) knows the warning siren codes and plant evacuation procedures, (2) notifies process operators of the inspection activities, and (3) knows the safe routes around process and scrubber equipment.

9-5. The correct answer is obviously "b", most pollutants have very poor or nonexistent warning properties.

9-6. The correct answer is "h", all of these are possible symptoms of exposure. The inspector should proceed immediately to a well ventilated area.

LECTURE 9 - REVIEW PROBLEMS AND QUESTIONS

9-1. Areas around wet scrubber systems which have often have poor ventilation and high pollutant concentrations include the following:

a. Fan houses
b. Walkways between adjacent scrubbers
c. Walkways adjacent to duct expansion joints
d. Pump houses

9-2. Before inserting a probe into a gas stream it is important to check which of the following items:

a. The grounding/bonding cable is in good condition
b. The ground clamp does not interfere with the probe
c. The clamp has penetrated any paint or corrosion layer
d. All of the Above

9-3. When selecting personal safety equipment necessary for an inspection, the inspector should be guided by which of the following:

a. What the plant representative and other plant personnel are using
b. Plant policies
c. Agency policies
d. Common sense

9-4. An inspector should not work alone during an inspection, unless the following conditions exist:

a. Plant personnel are too busy to accompany the inspector.
b. The inspector is very familiar with the plant.
c. No entry into pratially confined or confined areas are anticipated.
d. The inspector has all of the necessary personal protection equipment.
e. None of the above

9-5. Most gaseous contaminants have good "warning properties". Therefore the inspector is usually aware they are present.

a. True
b. False

9-6. Which of following symptoms may indicate exposure to air contaminants?

a. Headache
b. Drowsiness
c. Shortness of breath
d. Nausea
e. Loss of coordination
f. Eye irritation
g. Answers a,b,c,d,f
h. All of the above

LECTURE 9 - REVIEW PROBLEMS AND QUESTIONS

9-7. Hydrogen sulfide is especially dangerous since it has no odor at high concentrations. Answer "d" is correct.

9-8. Answer "c" is correct. The equipment should not be entered even though the plant personnel seem to be feeling fine insidé the unit. It is always possible that they will develop serious respiratory problems in the next several hours due to high concentrations of pollutants having no warning properties. Everything can usually be seen from an access hatch. If it can not be seen just take their word for it.

LECTURE 9 - REVIEW PROBLEMS AND QUESTIONS

9-7. At high concentrations what best describes the odor of hydrogen sulfide?

a. Fragrant
b. Sewer
c. Rotten Eggs
d. No Odor

9-8. During the inspection of a rod deck scrubber, the operator states that a chronic gas-liquor distribution problem has been solved by movement of both the spray headers and the rod deck. He suggests that you follow him into the scrubber to confirm that this has been done properly. What should the inspector do to complete this inspection?

a. Review the drawings and do not waste time on the equipment inspection.
b. Make sure the plant personnel enter first, and then follow them inside to confirm the modifications have been completed.
c. Limit the inspection to what can been seen through an access hatch without going inside.

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APPENDIX B - WORKSHOP FORMS

Sample Critique Form

Wet Scrubber Inspection Techniques
Location
Date

I. For each statement circle the one response that is the closest to your opinion.

1. Overall, I think this program was:
   a. excellent
   b. good
   c. fair
   d. poor

2. The program content was geared to a level that was generally:
   a. appropriate for my background
   b. too elementary
   c. too difficult
   d. inappropriate for my background

3. I think the organization of the program material was:
   a. completely clear and useful; excellent
   b. for the most part, clear and useful; good
   c. some topics were organized in a clear and useful manner, while others were not; fair
   d. there was little apparent organization in this course; poor

4. After reading the progarm handouts, I think they are:
   a. well written and useful documents
   b. fairly well written documents, but nevertheless useful
   c. poorly written documents that are of limited utility
   d. neither well written nor useful documents
   e. I have not been able to read the manuals yet

5. The amount of time allotted for this program was:
   a. sufficient
   b. too long
   c. too short
   d. this program should last ____________ number of days

6. For future programs, there should be:
   a. no substantive changes
   b. more practical application of the program material
   c. more theory presented as a basis for the material taught
   d. more of a "balance" provided between theory and practical application

Sample Critique - Wet Scrubber Inspection Techniques
Location
Date

II. Please check the statement that represents the extent of your agreement with each of the following statements. READ EACH ITEM CAREFULLY.

	Strongly Agree	Agree	Disagree	Strongly Disagree	No Opinion
11. The program content was useful for my professional growth.	_____	_____	_____	_____	_____
12. The program content was what I had expected.	_____	_____	_____	_____	_____
13. The program content was too complex.	_____	_____	_____	_____	_____
14. The program content was too simple.	_____	_____	_____	_____	_____
15. The program content was up to date.	_____	_____	_____	_____	_____
16. During the program I felt challenged to learn.	_____	_____	_____	_____	_____
17. Generally, the program materials were presented in an interesting manner.	_____	_____	_____	_____	_____
18. The program content was well coordinated among the speakers	_____	_____	_____	_____	_____
19. The speakers were well prepared for most class sessions.	_____	_____	_____	_____	_____
20. The speakers were quite knowledgeable about their subject areas.	_____	_____	_____	_____	_____

Sample Critique - Wet Scrubber Inspection Techniques
Location
Date

	Strongly Agree	Agree	Disagree	Strongly Disagree	No Opinion
21. The questions raised during the lectures were usually answered to my satisfaction.	_____	_____	_____	_____	_____
22. The production quality of the audio-visual materials was technically adequate.	_____	_____	_____	_____	_____
23. The audio-visual materials aided my understanding of the topics presented.	_____	_____	_____	_____	_____
24. Overall, I was pleased with this program.	_____	_____	_____	_____	_____
25. I think my technical skills and/or knowledge have been strengthened was a result of this program	_____	_____	_____	_____	_____
26. I think I will be able to use what I have learned from this program in my current position.	_____	_____	_____	_____	_____

III. Additional comments

27. The "best" part of this program was: ______________________________

____

____

____

28. The "worst" part of this program was: ______________________________

____

____

____

Sample Critique - Wet Scrubber Inspection Techniques
Location
Date

29. I consider the most needed improvements in this program to be: ________

____

____

____

30. Other Comments: ____

____

____

V. General Information:

31. Years of air pollution experience:
    a. less than 2 years
    b. between 2 and 5 years
    c. between 5 and 10 years
    d. more than 10 years

32. Present responsibilities (circle all which apply):
    a. field inspection
    b. permit review
    c. stack sampling
    d. management and supervision
    e. ambient air monitoring
    f. other________________________

Sample Registration Form

United States
Environmental Protection
Agency

Office of Air and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

If your address is incorrect, please change on the above label; tear off; and return to the above address.
If you do not desire to continue receiving this technical report series, CHECK HERE ☐; tear off label; and return it to the above address.