SECTION 9.0

WET SCRUBBERS

This section provides the reader with guidance on proper operation and maintenance of wet scrubber systems used as air pollution control devices. Wet scrubber systems include spray chambers, venturis, packed bed and tray towers, absorbers and water assisted mechanical collectors (e.g., Roto-Clones). Water assisted mechanical collectors are discussed in Section 3.

9.1 General Description

Wet scrubbers can be used to separate particulate and gases from other gas streams. They are used in situations where:[1]

1. Soluble gases are present.
2. The contaminant cannot be removed easily in a dry form.
3. Soluble or wettable particulates are present.
4. The contaminant will undergo some subsequent wet process (such as recovery, wet separation or settling, or neutralization).
5. The pollution control system must be compact.
6. The contaminants are most safely handled wet rather than dry (where the dry particulate may ignite or explode).

There are many different types of scrubbers. The type of scrubber selected is based on factors such as the gas temperature, pollutants to be removed, space available, and desired efficiency. Some types of scrubbers are mainly designed to remove particulate pollutants (e.g., venturi scrubbers) and others are designed to mostly remove gaseous pollutants or soluble particulates (e.g., packed towers and tray towers). Spray chambers are often added ahead of other scrubbers to condition the gas by saturating the gas stream, by cooling the gas stream via evaporative cooling, or by removing larger particulates. Examples of various categories of scrubbers and related types of scrubbers are presented in Table 9-1. Figures 9-1 through 9-4 show representative schematics of a spray chamber, fixed and variable throat venturi scrubbers, and packed tower, respectively.

Wet scrubbing is a two-step process, the first step being the capture of the gas stream contaminants in the liquid and the second step being separation of the scrubbing liquid droplets from the gas stream after it leaves the scrubber. This step is important in the ultimate collection of pollutants because poor liquid separation will cause reentrainment of the droplets containing the pollutant.

There are four basic types of liquid entrainment separators or "demisters": mesh-pad, chevron, centrifugal, and cyclonic. The mesh-pad and chevron types utilize inertial impaction of the liquid droplets to cause their agglomeration and removal. The centrifugal and cyclonic types utilize centrifugal inertia to collect the liquid droplets. Figure 9-5 shows schematics of the generic types of entrainment separators.

A wet scrubber system could contain more than one different type of scrubber. A typical air pollution control system for a hazardous waste incinerator, for example, might contain a spray chamber or quench chamber to cool and saturate the exhaust gases as they leave the incinerator. A venturi scrubber would follow the spray chamber to remove most of the particulate before the gas stream enters a packed column for gaseous contaminant removal (e.g., hydrogen chloride or chlorine gas). Liquid entrainment separators would follow both the venturi and packed column to remove the water droplets and their contained pollutants before going to the next air pollution control stage. In most of these type of systems, an induced draft fan follows the air pollution controls to pull the gases through the control system and force the cleaned exhaust gases through the stack. This type of scrubber control system is shown schematically in Figure 9-6.

9.1.1 Pollutant Collection

Pollution collection mechanisms are briefly discussed in this section. More detailed discussions of wet scrubber collection mechanisms and system design are readily available in most textbooks on air pollution control.

TABLE 9-1. MAJOR TYPES OF WET SCRUBBERS[a,b]

General Category of Scrubbers	Particle Capture Mechanism[c]	Liquid Collection Mechanism	Specific Types of Scrubbers
Preformed-spray	Impaction	Droplets	Spray towers Cyclonic spray towers Vane-type cyclonic towers Multiple-tube cyclones
Packed-bed scrubbers	Impaction	Sheets, droplets (moving bed scrubbers)	Standard packed-bed scrubbers Fiber-bed scrubbers Moving-bed scrubbers Cross-flow scrubbers Grid-packed scrubbers
Tray-type scrubbers	Impaction Brownian diffusion	Droplets, jets, and sheets	Perforated-plate Impingement-plate scrubbers Horizontal impingement-plate (baffle) scrubbers
Mechanically aided scrubbers	Impaction	Droplets and sheets	Wet fans
Venturi and orifice scrubbers (gas atomized scrubbers)	Inertial impaction Brownian diffusion	Droplets	Standard venturi scrubbers Variable-throat venturi scrubbers: flooded disc, plumb bob, movable blade, radial flow, variable rod Orifice scrubbers

[a] List not intended to be all inclusive.
[b] Reference 2.
[c] Absorption is the capture mechanism for gaseous pollutants.

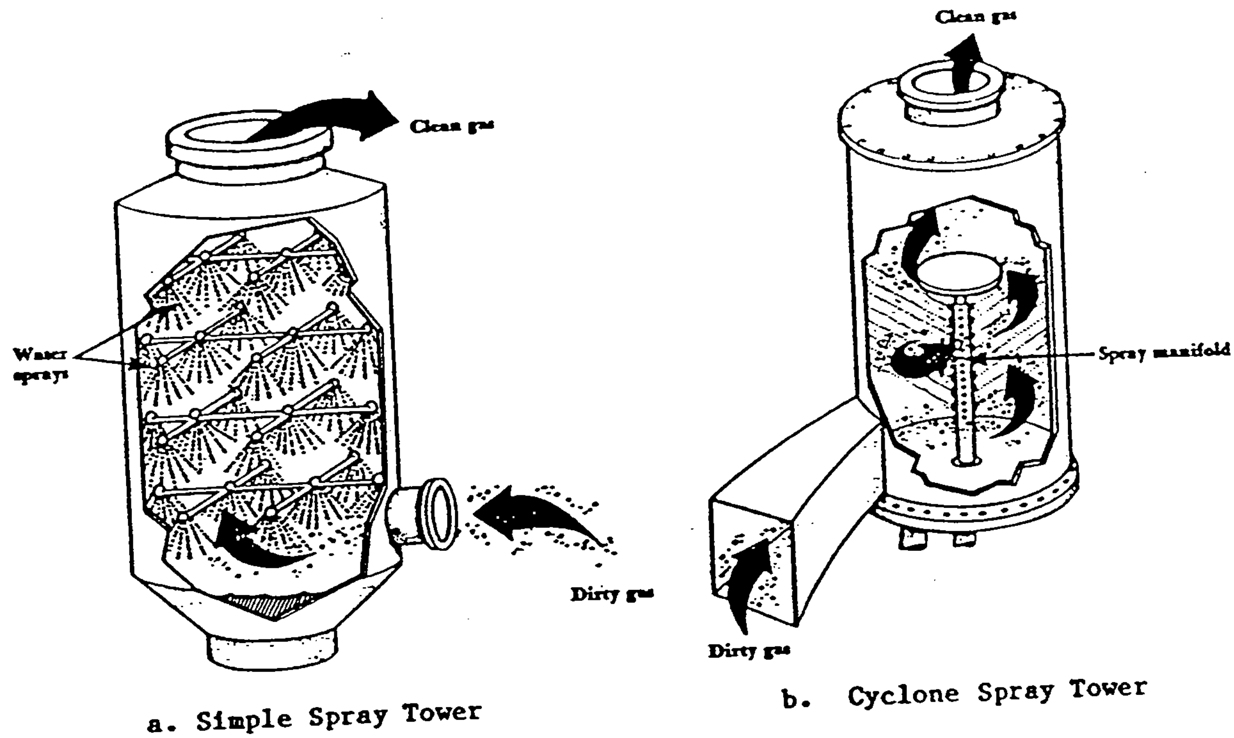

Figure 9-1. Preformed spray scrubbers[3].

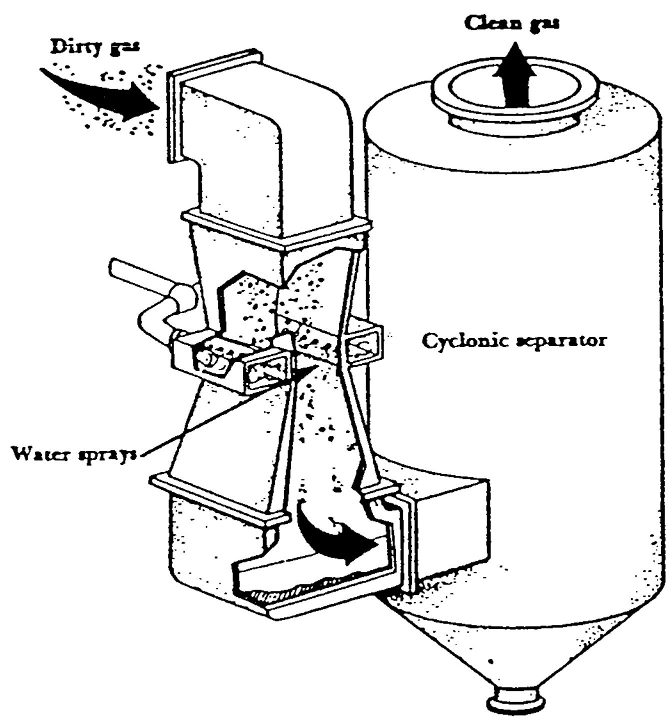

Figure 9-2. Fixed throat venturi scrubber[3].

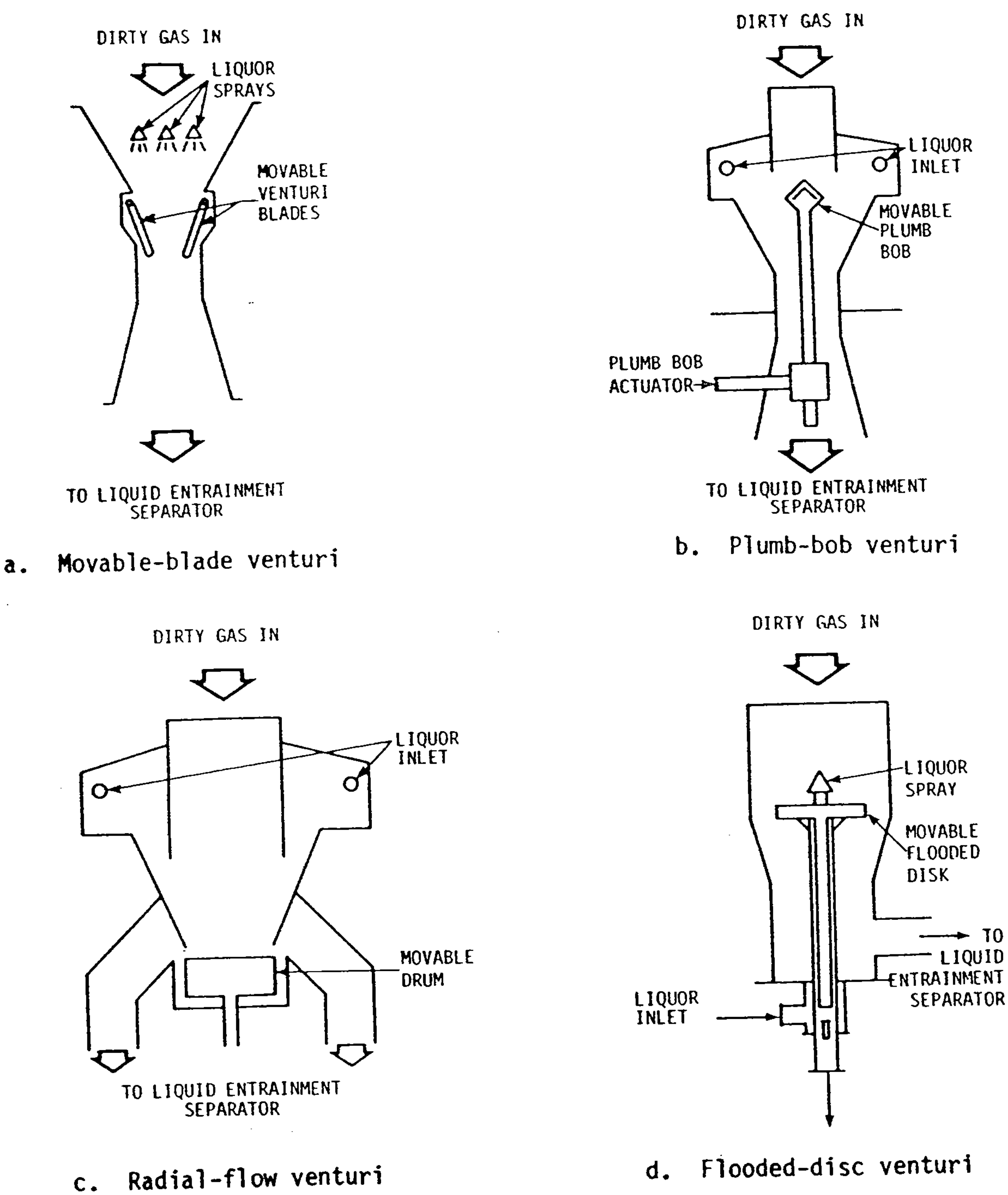

Figure 9-3. Throat sections of variable throat venturi scrubbers (Industrial Gas Cleaning Institute, Inc.).

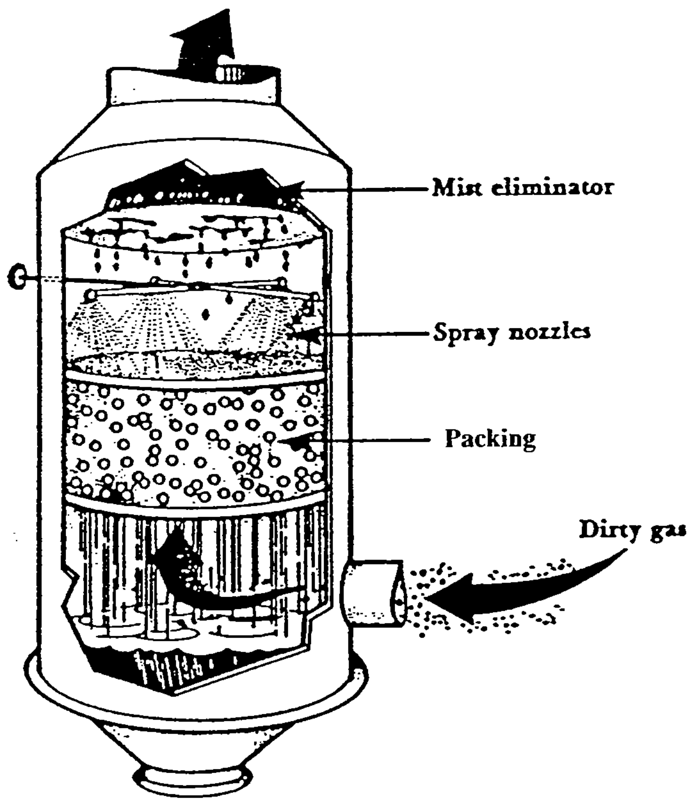

Figure 9-4. Packed bed scrubber[3].

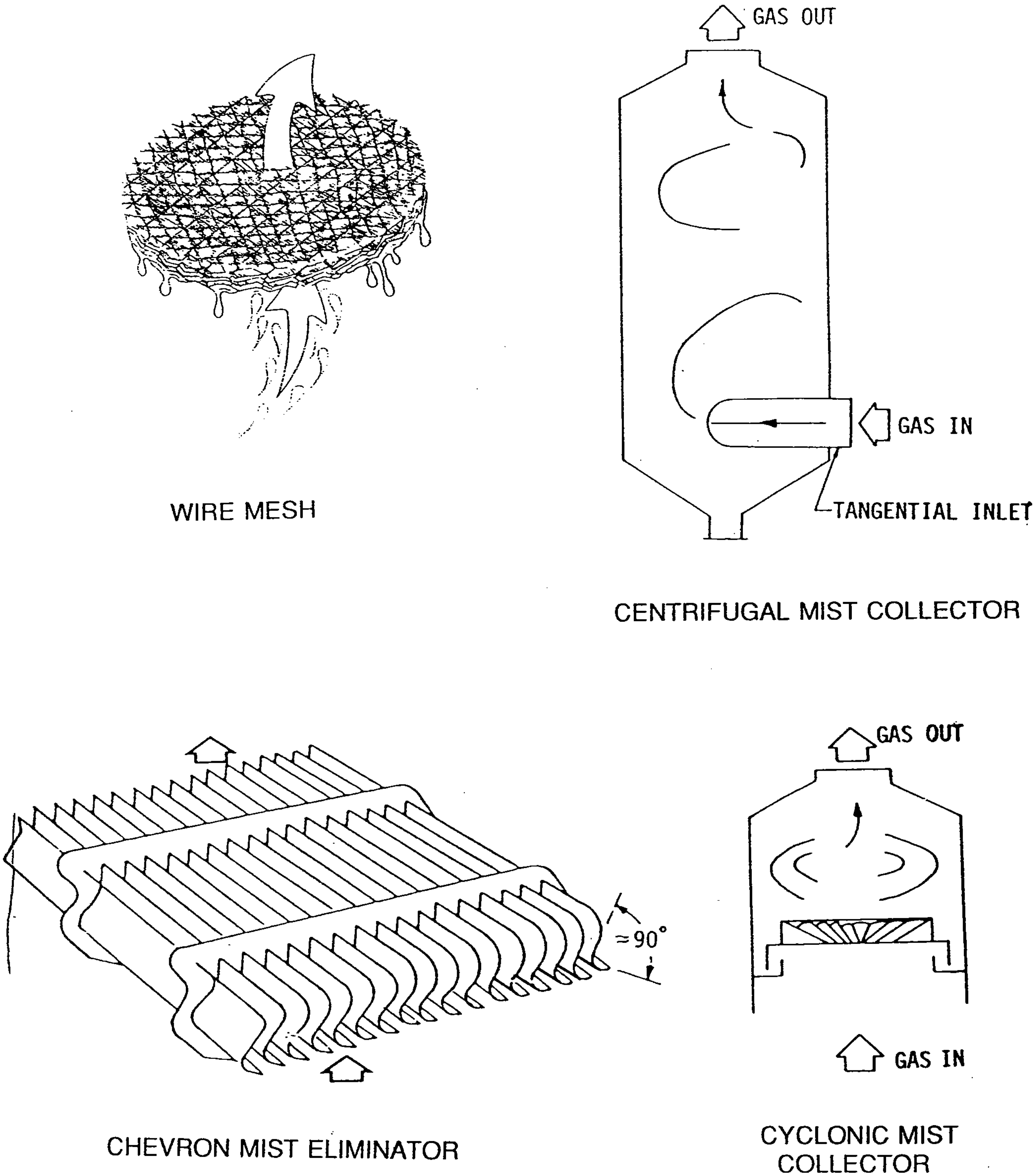

Figure 9-5. Liquid entrainment separators (Industrial Gas Cleaning Institute, Inc.).

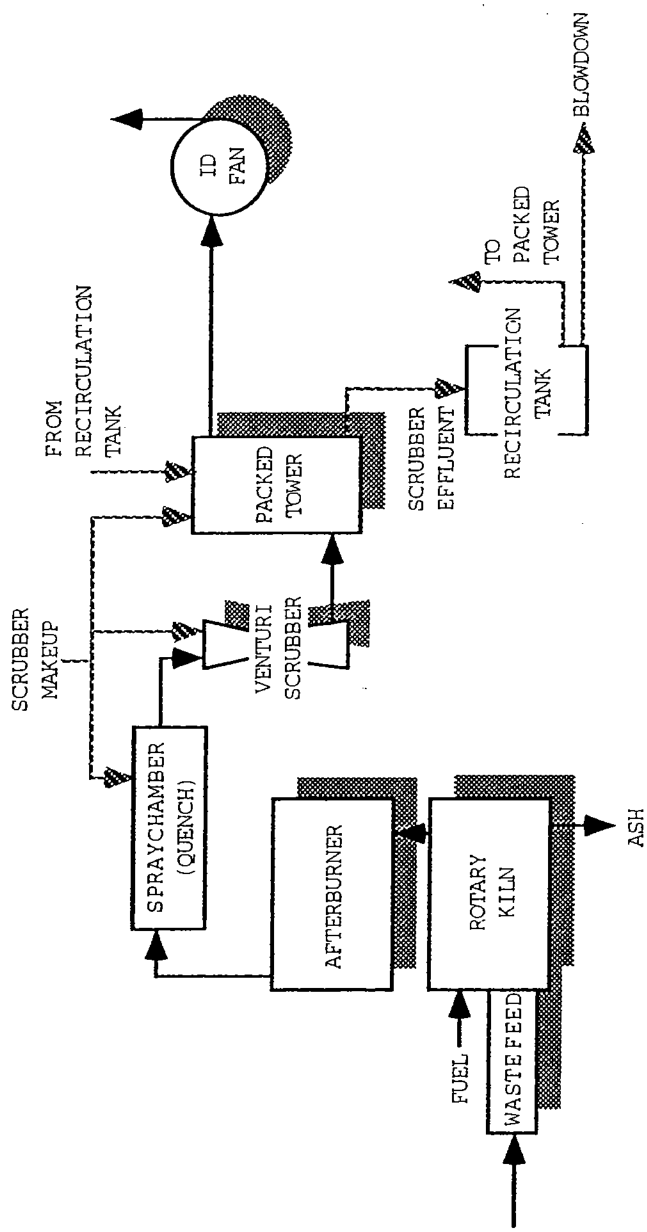

Figure 9-6. Schematic diagram of a wet scrubber air pollution control system controlling a hazardous waste incinerator.

Particulate--

All of the fundamental mechanisms employed to collect particulate in wet scrubbers are very particle size dependent. The two most commonly used mechanisms are impaction and Brownian diffusion. Impaction is a very effective means of capture for particles larger than 0.5 microns and Brownian diffusion is the primary capture mechanism for the very small particles in the less than 0.1 micron range. In the 0.1 to 0.5 micron range, both collection mechanisms can be active, but neither is especially effective.

Impaction occurs as a particle laden gas stream flows around an obstacle (e.g., a water droplet) and the particles remain on a straight trajectory and collide with the obstacle due to their inertia. Impaction is highly dependent on the particle diameter and is directly proportional to the differences in the relative velocities of the particle and the target.

The trajectories of very small particles are affected by the impacts of gas molecules. The random movement due to these collisions is termed Brownian diffusion. During this random movement, the particle may get close enough to a water droplet to be captured. The rate of Brownian diffusion is inversely proportional to the particle size diameter. As particle size decreases, Brownian diffusion increases. It also increases as the gas temperature increases due to the increased kinetic energy of the gas molecule striking the small particles.

Due to the combined action of impaction and Brownian diffusion, penetration of particulate matter in gas atomized scrubbers is low for particles greater than 1.0 microns and less than 0.10 microns.[4] However, there is a peak in the penetration curve (penetration = 1 - collection efficiency/100) at approximately 0.2 to 0.5 microns. Gas atomized scrubbers and other air pollution control devices using impaction and Brownian diffusion are least effective in the 0.2 to 0.5 micron size range.

Scrubbing systems for installations requiring very high particulate removal efficiencies in the submicron particle size range can utilize flux force/condensation mechanisms to aid capture.[4] These are inherently simultaneous mechanisms which facilitate both impaction and Brownian diffusion. Flux force/condensation conditions are initiated by removing the sensible heat from the gas stream downstream of a quench (i.e., supersaturating the gas stream using water sprays) so that a portion of the gas stream water vapor condenses on the particles to be removed, and creates a bigger particle that is easier to remove from the gas stream.

Gases and Vapors--

Gas and vapor collection in wet scrubber air pollution control devices is achieved by absorption. The process of absorption refers to the contacting of a mixture of gases with a liquid so that part of one or more of the constituents of the gas will dissolve in the liquid.

The gaseous air contaminants most commonly controlled by absorption include sulfur dioxide, hydrogen sulfide, hydrogen chloride, chlorine, ammonia, oxides of nitrogen, and light hydrocarbons.[5] The necessary condition for absorption is the solubility of these pollutants in the absorbing liquid. The rate of transfer of the soluble constituents from the gas to the liquid phase is determined by diffusional processes occurring on each side of the gas-liquid interface. Consider, for example, the process taking place when a mixture of air and gaseous hydrogen chloride (HCl) is brought into contact with water. The HCl is soluble in water, and those molecules that come into contact with the water surface dissolve immediately. However, the HCl molecules are initially dispersed throughout the gas phase, and they can only reach the water surface by diffusion through the air, which is substantially insoluble in the water. When the HCl at the water surface has dissolved, it is distributed throughout the water phase by a second diffusional process. Consequently, the rate of absorption is determined by the rates of diffusion in both the gas and liquid phases.[1]

Equilibrium is another important factor to be considered in controlling the operation of absorption systems.[1] The rate at which the pollutant will diffuse into an absorbent liquid will depend on the departure from equilibrium that is maintained. The rate at which equilibrium is established is then essentially dependent on the rate of diffusion of the pollutant through the nonabsorbed gas and through the absorbing liquid. The rate at which the pollutant mass is transferred from one phase to another depends also on a socalled mass transfer, or rate coefficient, which equates the quantity of mass being transferred with the driving force. As can be expected, this transfer process ceases upon the attainment of equilibrium.

In gas absorption operations the equilibrium of interest is that between a nonvolatile absorbing liquid (solvent) and a solute gas (usually the pollutant). The solute is ordinarily removed from its mixture in a relatively large amount of a carrier gas (air) that does not dissolve in the absorbing liquid. Temperature, pressure, and the concentration of solute in one phase are independently variable.

9.1.2 Key Operating Parameters

The scrubbing system is composed of exhaust hoods and ducts handling airborne contaminants. Gas pretreatment equipment may be required for coarse particulate removal and for cooling before the contaminants enter the scrubber vessel. The contaminant-laden droplets are removed by the entrainment separators. The clean gas is then passed through an induced-draft fan and up the stack. Forced-draft fans upstream of the scrubber are also used. The key operating parameters affecting the pollutant collection are:[3]

Velocity/gas flow rate
Liquid-to-gas ratio
Pressure drop
Temperature
Particle size distribution (particulate)

Velocity/Gas Flow Rate--

The collection efficiency of most scrubbers depends on the velocity of the gas stream through the liquid-contacting section of the scrubber vessel. For particulates, the relative velocity between washing liquids (droplets) and particulates is critical to contaminant collection. In the case of high-energy venturi scrubbers, a velocity of 40,000 ft/min can be delivered.[3] Fine droplet size and high density lead to increased removal efficiency.

When a high-temperature gas stream enters the scrubber, the volumetric flow rate diminishes accordingly (based on the temperature of the scrubber liquid) because the gas is being cooled by the scrubber liquors. When the system flow rate decreases, the resulting relative velocity may not be sufficient to collect the desired amount of particulate and emissions will increase.

For a packed tower or tray tower, low or no gas flow might indicate plugged packing in the absorber, fan problems, duct leaks, or an increase in liquid flow to the tower. Increased gas flow might indicate a low liquid flow rate, packing failure, or a sudden opening of a system damper.

Liquid-to-Gas Ratio--

The liquid-to-gas flow rate (L/G) is a calculated value, reflecting the liquid recycling rate (gal/min) for every 1000 ft^3 of gas cleaned. Typical values range from 2 to 40 gallons of liquid per 1,000 ft of inlet gas; and are a function of inlet gas temperature, inlet solids content, and method of water introduction. High L/G ratios are used for high-temperature gas streams and high-grain loadings. Should the L/G ratio fall below the design value, collection efficiency will diminish. Table 9-2 presents typical liquid-to-gas ratios for various types of wet scrubbers.

High L/G ratios are required for high temperature gas streams to prevent pollutant reentrainment. When the L/G ratio is not sufficient to saturate the gas stream, pollutant laden droplets reentering the scrubber from recycled liquors will evaporate (evaporative cooling) and leave the previously captured particulate reentrained in the gas stream. Should this occur, pretreatment with clean liquor (for quenching) may be required. The quenching stage saturates the gas stream to minimize evaporation in the scrubbing stage.

Pressure Drop--

The pressure drop across a scrubber includes the energy loss across the liquid gas contacting section and entrainment separator, with the former accounting for most of the pressure loss. A low pressure drop scrubber ranges from 2 to 10 in. H_2O; medium, from 10 to 30 in. H_2O; and high, 30 and above. The higher the pressure drop, the greater the particulate collection efficiency for both particle size and concentration. Table 9-3 presents typical pressure drops for various types of wet scrubbers.

TABLE 9-2. TYPICAL LIQUID-TO-GAS RATIOS FOR WET SCRUBBERS[2]

Scrubber Type	Liquid-to-Gas Ratio, gal/1000 ft^3
Venturi	5 - 8
Cyclonic spray tower	5 - 10
Spray tower	10 - 20
Impingement plate	3 - 5
Packed bed	1 - 4

TABLE 9-3. TYPICAL SCRUBBER PRESSURE DROPS[2]

Scrubber Type	Pressure Drop, inches water
Venturi	10 - 70
Centrifugal (cyclonic) spray	1 - 3
Spray tower	1 - 2
Impingement plate	1 - 10
Packed bed	1 - 10
Wet fan	4 - 10
Self-induced spray (orifice)	2 - 20
Irrigated filter (filter bed scrubber)	0.2 - 3

For tray and packed towers, an increase in pressure drop might indicate plugging or an increase in gas or liquid flow rates. A decrease in pressure drop might indicate a decrease in gas or liquid flow, channeling through the scrubber due to poor liquid distribution or partial plugging, or a damaged packing support plate allowing the packing to fall to the bottom of the scrubber.

Temperature--

Wet scrubber inlet and outlet temperatures are key parameters that should be monitored when controlling gas streams with elevated temperatures.

An increase in temperature could indicate a failure of the cooling equipment (e.g., quench chamber, dilution air) which would result in decreased pollutant collection efficiency and perhaps damage to the scrubber.

Particle Size Distribution--

Performance of a scrubber controlling particulate emissions depends on the gas stream particle size distribution. Efficient collection of submicron contaminants challenges the application of any type of control equipment. High-energy venturi scrubbers are designed for submicron contaminant collection. Changes in process equipment or operation can change the particle size distribution and, in turn, impact collection efficiency.

9.2 Monitoring Wet Scrubber Operation

Proper instrumentation is vital to the monitoring of scrubber performance. Many installations require instrumentation with associated alarms and interlocks to protect valuable components from malfunctions such as loss of water pressure or a process temperature runaway.

9.2.1 Pressure Drop

Every major scrubber system should include a continuous monitor to measure static pressure drop across the scrubber. Static pressure drop can be measured with a differential pressure gauge or manometer. Care must be taken in the design of the tubing and fittings to prevent plugging and to allow easy cleaning, and tubing materials should be selected to withstand the service expected. For example, certain plastics can melt when exposed to high temperatures; some plastics become excessively brittle at low temperatures; and polypropylene tubing is degraded under continuous exposure to sunlight.

9.2.2 Temperature

For sources that generate hot gases, the gas temperatures must be monitored if the scrubber contains materials that cannot withstand high temperatures. A high-temperature alarm and/or an interlock system is usually installed to shut down the process or to bypass the scrubber system. Where gas temperatures vary widely, it is sometimes necessary to install temperature feedback instrumentation that controls the water flow rates to the presaturator.

9.2.3 Liquid Flow Rate

Liquid flow rates are important because the liquid-to-gas ratio has a direct impact on the driving forces for particulate collection and absorption in wet scrubbers. Also, very low liquid flowrates could aggravate problems with poor liquid distribution in plate tower absorbers. Low liquid flowrates in packed towers could cause some packing wetting problems.

Water flow rates can be measured by in-line flow meters or doppler type indirect flow meters. A less expensive and less accurate method of flow measurement is the use of a pump pressure gauge calibrated to indicate flow rates. Open-channel type flow-measuring devices such as the Parshall flume are sometimes useful, although the preferred measuring point for liquor flow is between the pump outlet and the scrubber spray nozzles. The recirculation pump discharge pressure can be used as an indirect indication of liquid flow.

Alarm systems can also be included to indicate low water levels in orifice-type scrubbers. In systems that include presaturators, water flow through the scrubber and the presaturator should be measured individually.

9.2.4 Other Monitoring Equipment

Scrubber instrumentation often includes liquor pH indicators, fan ammeters, and fan vibration sensors. The pH meters are needed when pH of the scrubbing liquor must be closely controlled. Maintaining clean, accurately calibrated probes, although often difficult, is essential to the success of pH control. Fan ammeters and tachometers can be used in conjunction with the manufacturer's fan performance curves to provide an estimate of gas flow through the scrubber system, or these instruments can be used to provide a quick comparison of the system's performance with previous performance. It is helpful in all scrubber systems to provide small ports in the ducting before and after the fans, the scrubber vessels, and the presaturators. These ports should be 1/4" to 1" O.D. ports which can be used to periodically measure static pressure, gas temperature, gas flow rate, and/or gas oxygen concentration. Liquor sampling taps should also be included so that the pH and liquor solids levels can be routinely checked.

9.3 Inspection and Maintenance Procedures for Wet Scrubbers

9.3.1 Inspections

Inspection guidelines are given below, including guideline procedures for routine startup, inspection and maintenance during operation, and routine shutdown.

Pre-Startup Inspection--

Whether the scrubber has recently been installed or has undergone internal service and maintenance, before it is started up it must be thoroughly inspected. A checklist for preoperation inspection is provided in Figure 9-7. This checklist is to be used as a guideline only, and should be tailored for each specific system. The inspection survey during shutdown should include internal and external observations from the ducts up through the stack. If possible, as part of the pre-startup inspection before the unit is put into service, it is advisable to operate pumps and other components to observe their performance.

Routine Startup--

Proper startup procedures are critical to assure all components and instruments are operational and to prevent damage to the control system. After the scrubber has been thoroughly inspected, the following general startup procedure should be followed:[6]

PRE-STARTUP SCRUBBER INSPECTION CHECKLIST			
Facility Name:			Date of Inspection:
Facility Location:			Time of Inspection:
Process:			Name of Inspector (Print):
Scrubber ID:			Signature of Inspector:
	CHECKED		
INSPECTION ITEM	YES	NO	COMMENTS/CORRECTIVE ACTIONS
Ducts			
Warpage	___	___	
Corrosion	___	___	
Abrasion	___	___	
Gasketing	___	___	
Slip Joint	___	___	
Solids Buildup	___	___	
Gas Pretreatment Equipment			
Nozzles	___	___	
Solids Buildup	___	___	
Gasketing	___	___	
Corrosion	___	___	
Valve Operation	___	___	
Sump Sludge	___	___	
Scrubber			
Nozzles	___	___	
- Clogging	___	___	
- Wearing	___	___	
- Abrasion	___	___	
Abrasion	___	___	
Buildup	___	___	
Corrosion	___	___	
Piping	___	___	
- Scaling	___	___	
- Rusting	___	___	
- Riggings	___	___	
- Leakage	___	___	
Sump Sludge	___	___	

Figure 9-7. Preoperation inspection checklist for scrubbers.

INSPECTION ITEM	CHECKED YES	CHECKED NO	COMMENTS/CORRECTIVE ACTIONS
Mist Eliminator			
Nozzles	___	___	
- Clogging	___	___	
- Wearing	___	___	
- Abrasion	___	___	
Piping	___	___	
- Rusting	___	___	
- Pitting	___	___	
- Leakage	___	___	
Valve Operation	___	___	
Corrosion	___	___	
	___	___	
Mist Eliminator Media			
Buildup	___	___	
Cleaned	___	___	
Replaced	___	___	
Liquor Treatment			
pH Control	___	___	
- Calibration Check	___	___	
- Probe Buildup	___	___	
Caustic Hold Tank	___	___	
Sludge Buildup	___	___	
Valve Operation	___	___	
Piping Leakage	___	___	

Figure 9-7. Preoperation inspection checklist for scrubbers (continued).

1. Close all drain valves.
2. Fill vessels to normal level.
3. Activate circuit breakers for all controls and components.
4. Open pump suction valves.
5. Start pumps.
6. Open discharge valves slowly.
7. Open isolation dampers.
8. Start fan (if fan has an inlet control damper, it should normally be closed until fan reaches speed).
9. Record data from monitoring instrumentation.
10. Note changes in monitoring data as gases pass through system.

Routine Inspection and Maintenance During Operation--

During normal operation, the scrubber should be inspected on a daily and monthly basis. Example daily and monthly inspection forms for an operational scrubber are presented in Figure 9-8 and 9-9, respectively. A tailormade operational checklist should be prepared for each specific type of equipment based on the manufacturer's recommendation, knowledge of the controlled process, and internal administrative requirements. Figure 9-10 presents an example maintenance report form.

Routine Shutdown--

Proper shutdown procedures should be followed to avoid equipment damage and release of process pollutants to the atmosphere. A general procedure for scheduled shutdown is outlined below:

1. Stop blower.
2. Isolate scrubber vessel by closing dampers.
3. Shut down makeup water.

DAILY SCRUBBER INSPECTION FORM	
Facility Name:	Date of Inspection:
Facility Location:	Time of Inspection:
Process:	Name of Inspector (Print):
Scrubber ID:	Signature of Inspector:
INSPECTION ITEM	COMMENTS/CORRECTIVE ACTIONS
1) Gas pretreatment equipment (if applicable) - Leaks - Abnormal sounds - Pressure drop normal?	
2) Scrubber and mist eliminator - Leaks - Abnormal sounds - Pressure drop normal?	
3) Liquor treatment - Leaks - Abnormal sounds	
Pressures: Pressure drop across scrubber _____ in. WG Scrubbing liquid pressure _____ psi	
Scrubber liquid flow _____ gpm	Quench liquid flow _____ gpm (if applicable)
Temperatures: Gas into system _____ °F Liquid from scrubber _____ °F	Gas into scrubber _____ °F Gas from scrubber _____ °F
Fan amps _____ Pump amps _____ Opacity _____ %	

Figure 9-8. Example daily inspection form.

MONTHLY SCRUBBER INSPECTION FORM	
Facility Name:	Date of Inspection:
Facility Location:	Time of Inspection:
Process:	Name of Inspector (Print):
Scrubber ID:	Signature of Inspector:
INSPECTION ITEM	COMMENTS/CORRECTIVE ACTIONS
1) Gas Pretreatment Equipment Piping Leakage Valve Operation Pump/Lub.	
2) Scrubber Piping Leakage Valve Operation Level Control Pump/Lub.	
3) Mist Eliminator Piping Leakage Valve Operation Pump/Lub.	
4) Liquor Treatment Piping Leakage Valve Operation Level Control Pump/Lub.	
5) Fans, Ducts, Pipes - Abrasion - Corrosion - Solids Buildup	
6) Check sensors, alarm systems, and bypass devices for proper operation	

Figure 9-9. Example monthly inspection form.

MAINTENANCE REPORT FORM

Department	Unit	System	Subsystem	Component	Subcomponent

Originator: ______________________ Date: __________ Time: ____________

Assigned To:

1	Mechanical
2	Electrical
3	Instrumentation

Priority:

1	Emergency
2	Same Day
3	Routine

Unit Status:

1	Normal
2	Derated
3	Down

Problem Description: ____

____

____

____

Foreman: ______________________ Date: __________

Job Status:

1	Repairable
	Hold for:
2	Tools
3	Parts
4	Outage

Cause of Problem: ______________________________

____

____

Work Done: ____

____

____

Supervisor: ______________________ Completion Date: ____________

Materials Used: ____

____

____

Labor Requirements: ____

____

Figure 9-10. Example maintenance report form.

4. Allow system to cool.

5. Continue to blow down at normal rate until liquid levels reach pump inlet, and then shut pumps off.

6. Stop all other pumps.

7. Deactivate all circuit breakers.

8. Open access door and use necessary safety procedures for inspection.

9.3.2 Preventive Maintenance

Preventive maintenance is an important tool in assuring the continuous operation of scrubber systems. Preventive maintenance programs for scrubbers should include periodic inspection of equipment, replacement of worn parts, periodic cleaning of components prone to plugging, maintenance of an adequate spare parts inventory, and recording of all maintenance performed on scrubber equipment.

All instrumentation such as differential pressure gauges, scrubbing liquor flow meters, pump pressure gauges, and fan ammeters should be observed at least once per work shift. All equipment should be inspected regularly at regular intervals, determined by the severity of service and the likelihood of component failure. Failure-prone items include nozzles and pumps handling slurries, forced-draft fans handling particulate-laden gases, induced-draft fans downstream of inadequate liquid entrainment separators, wear plates, pH probes, and bearings. These items should be inspected as often as once per shift depending on the likelihood of failure. Such components as ductwork and induced-draft fans handling clean, dry gases should be inspected monthly.

All worn parts and malfunctioning equipment should be serviced as they are discovered to prevent deterioration of system performance and to prevent damage to equipment. An inventory of spare parts must be maintained in stock for replacement of nozzles, bearings, pump seals, liners for pumps with replaceable liners, pump impellers, wear plates for fan wheels with wear plates, pH probes, and valve parts. Records should be made of all maintenance performed and all parts replaced. This information is useful in planning subsequent preventive maintenance schedules and in determining the type and number of replacement parts needed.

9.3.3 Spare Parts

Scrubber manufacturers supply a list of recommended spare parts. Spare parts for auxiliary equipment, such as pumps, fans, piping, dampers, valves, and instrumentation, are also required. Table 9-4 shows the spare parts inventory guidelines.

TABLE 9-4. REPLACEMENT PARTS FOR SCRUBBERS

Motor (fan, pump, seals, bearings, impeller)
Mist eliminator media (full set)
Gauges (temperature, pressure)
pH probe and required reagent
Piping and valves
Nozzles
Packing
Wear plates

9.4 Common Problems or Malfunctions of Scrubbers

Wet scrubbers can provide continuous reliable service when they are operated properly and maintained regularly. Poor operation and maintenance leads to component failure. Most scrubber failures result from abrasion, corrosion, solids buildup, and wear of rotating parts.

The troubleshooting chart present in Table 9-5 gives guidelines for causes and remedies of symptoms noted during inspections. Although there is some discussion of pumps in this chart, it is by no means exhaustive. Fans are not mentioned because of the extensive scope of troubleshooting guides from manufacturers. The probable cause of fan noise, low or high flow rates, and static pressure are too numerous to itemize.Common failure modes for individual components are further discussed below.

TABLE 9-5. TYPICAL TROUBLESHOOTING CHART FOR SCRUBBERS[3]

Symptom	Cause	Remedy
Low pressure drop (scrubber section)	Low airflow rate	Check blower
	Low liquid flow rate	Check pump/nozzles
	Eroded cleaning section	Inspect/repair
	Meters plugged	Clean lines
High pressure drop (scrubber section)	High airflow rate	Check blower
	Plugging in ducts or scrubber	Inspect/clean ducts
Low pressure drop (mist eliminator)	Low airflow rate	Check blower
	Low liquid flow rate	Check pump/nozzles
	Media dislocated	Inspect/repair
High pressure drop (mist eliminator)	High airflow rate	Check blower
	High liquid flow rate	Check pump/nozzles
	Clogging	Inspect/clean
	Flooding	Inspect/drain
High temperature in stack	Insufficient wash liquor	Check pump/nozzle
	Liquid temperature too hot	Check sump temperature
Pump leaks Pump pressure increase	Worn packing or seals	Replace
	Nozzle plugging	Reduce nozzles
	Valves closed	Open valves
Pump flow rate/pressure diminished	Impeller wear	Replace
	Nozzle abraded	Replace
	Speed too low	Check motor
	Defective packing	Replace
	Obstruction in piping	Check pipes, strainer, and impeller
Pump noise/heat	Misalignment	Check/repair
	Bearing damage	Replace
	Cavitation	Check/repair
Corrosion	Inadequate neutralization	Check pH control
Erosion	Incompatible materials	Replace materials
	High recycled solids content	Wastewater system
Scaling	Improper chemical treatment	Change treatment
Pipe plugging	High solids content	Cleaning
	Abrupt expansion/contraction/ bends	Change pipe fittings

9.4.1 *Nozzle Plugging*

Nozzle plugging is one of the most common malfunctions in scrubbers. Plugged nozzles reduce the liquid-to-gas ratio or cause maldistribution of the liquid. Nozzle plugging results from improper nozzle selection, excessive solids in scrubbing liquors, poor pump operation, and poor sump design. Remedies for nozzle plugging include replacement with nozzles of a different type, frequent cleaning, and reduction of liquor solids content by increasing liquor blowdown and makeup water rates. Because presaturator nozzles are especially prone to plugging, the quench water should be limited to fresh water or very dilute liquors. Many quench nozzles cannot tolerate greater than 2 percent solids in the liquid.[7] Nozzle plugging can be detected by observing the liquid spray pattern the nozzles produce. If the nozzles are not accessible while the pumps are operating, they should be checked during scrubber shutdowns for evidence of caking over the nozzle openings. A decrease in water flow rate during scrubber operation is an additional symptom of nozzle plugging.

9.4.2 *Solids Buildup*

Solids buildup is another problem common to wet scrubbers and one that is often difficult to control. The two types of solids buildup are sedimentation and chemical scaling. Sedimentation occurs when a layer of particles becomes attached to a surface or settles in areas of low turbulence. Sedimentation can lead to plugging of pipes and ducts or buildup on internal parts. Chemical scaling results from a chemical reaction of two or more species to form a precipitate on the surfaces of scrubber components.

Solids buildup may occur in piping, sumps, scrubber packing, instrumentation lines, or ductwork, and may lead to reduced scrubber efficiency and major equipment failure. Most scrubbers using open pipes cannot reliably tolerate liquor slurries of over 15 percent solids by weight. It is usually best to maintain solids content at less than 6 to 8 percent.[7] Techniques to control scaling include increasing the liquid-to-gas ratio, controlling pH, providing greater residence time in the holding tank, and adding other chemical agents such as dispersants. Solids buildup can be detected by inspection of accessible components and by inspection of the inner surfaces of piping, tubing, and ductwork at removable fittings and hatches.

9.4.3 Corrosion

Corrosion problems arise frequently in wet scrubbers, especially when the gases being cleaned contain acid-forming compounds or soluble electrolytic compounds. The combustion of fossil fuels, especially coal, coke, and residual fuel oil, yields oxides of sulfur, which can produce sulfuric acid in scrubbing liquors. Metals-refining processes, such as copper and lead smelting, can also produce oxides of sulfur. Combustion of polyvinyl chloride plastics, commonly found in incinerator feeds, can produce hydrochloric acid in scrubbing liquors. Rotary aggregate dryers and similar process equipment can produce chlorides or fluorides, depending on the composition of the aggregate. The phosphate fertilizer industry and the feldspar industry are especially troublesome sources of fluorides. Acids and electrolytes in general are corrosive to mild steels, chlorides are corrosive to many stainless steels, and fluorides are harmful to nearly all stainless steels except certain specially formulated (and expensive) high-nickel alloys.[8] Recirculation of scrubbing liquors increases the concentrations of any corrosive agents they contain.

Prevention of corrosion is best handled through proper choice of materials of construction and through pH control. When a pH control system is to be the principal defense against corrosion, regular maintenance at frequent intervals is necessary, especially at the pH electrodes. Another common operating problem occurs when scrubber liquor blowdown rates are reduced to limit the emission of pollutants into surface waters. Reducing or eliminating blowdown can so greatly increase the acid and electrolyte concentrations in the liquor that otherwise acceptable materials of construction become ineffective against corrosion.

9.4.4 Abrasion

Abrasion can occur where gases or scrubbing liquors containing high concentrations of abrasive particulates are in the turbulent mode or are subjected to a sudden change in flow direction. Typical wear areas in scrubbing systems include venturi throats, walls of centrifugal mist collectors near the inlet duct, and elbows in the ductwork.[7] Solutions to abrasion wear include the use of precleaning devices and the use of large-radius turns in ductwork.

9.4.5 Wear of Rotating Equipment

Rotating equipment including fans, pumps, and clarifiers must receive special attention in scrubber service because of potential abrasion, plugging, and corrosion. Key wear areas in these components include the bearings and any components rotating in the fluid stream.[9]

Fan wear is a common problem. Forced-draft fans often suffer abrasion because of exposure to particulate-laden gases. Wear problems in forced-draft fans can be addressed by the use of special wear-resistant alloys, by reduction of fan rotation speeds (by installing a larger fan), or by moving the fan to an induced-draft location on the clean air side of the scrubber system. Induced-draft fans can undergo corrosion or solids buildup on the blades if mist is carried over from the liquid entrainment separator. Induced-draft fan problems can be addressed by use of corrosion-resistant materials or by improving liquid entrainment separation.

Pump wear is also a common problem in scrubber systems. Pump housings, impellers, and seals are subject to abrasion and corrosion by scrubber slurries. Rubber linings and special-alloy pump materials are often used to reduce abrasion and corrosion of the housings or impellers. Installation of a water flush in the seals can help reduce wear of the seals.[9]

9.5 Operator Training

Similar to any piece of equipment, a wet scrubber will not receive proper maintenance without facility management support and the willingness to provide its employees with proper training. Efficient operation of a wet scrubber, promoted by adequate inspection and maintenance procedures, is as important as the operation of process equipment. Management and employees must take a proactive approach to the operation of a wet scrubber in order to prevent production-stopping equipment malfunctions or failures.

The training and motivation of employees assigned to monitor and maintain a wet scrubber are critical factors. These duties should not be assigned to inexperienced personnel that do not understand how a scrubber works or the purpose behind assigned maintenance tasks.

System training should be received from the scrubber manufacturer when a new system is commissioned. The manufacturer's start-up services will generally include introductory training for facility operators and maintenance personnel. The field service engineer involved in startup procedures will instruct plant personnel in the methods to ensure proper assembly and operation of the system components, check and reset system instrumentation and controls, check for the proper operation of the scrubber liquid conditioning system, and perform simple troubleshooting.

Following start-up training, regular training courses should be held by in-house personnel or through the use of outside expertise. The set of manuals typically delivered as part of a new scrubber installation will include manufacturer-recommended maintenance procedures. Annual in-house training should at a minimum include a review of these documents and confirmation of the original operating parameters. Training should include written instructions and practical experience sessions on safety, inspection procedures, system monitoring equipment and procedures, routine maintenance procedures, and recordkeeping. For plant personnel involved in taking opacity readings, U.S. EPA Reference Method 9 requires a semi-annual recertification in method procedures.

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