

## SECTION 3.0

### MECHANICAL COLLECTORS

Proper operation and maintenance (O&M) of mechanical particle control devices is crucial to obtaining their design control efficiency. Routine inspections and scheduled maintenance of a control unit are important facets of typical operations. The upkeep of mechanical collectors will provide the required collection efficiency for regulatory compliance and proper system operation.

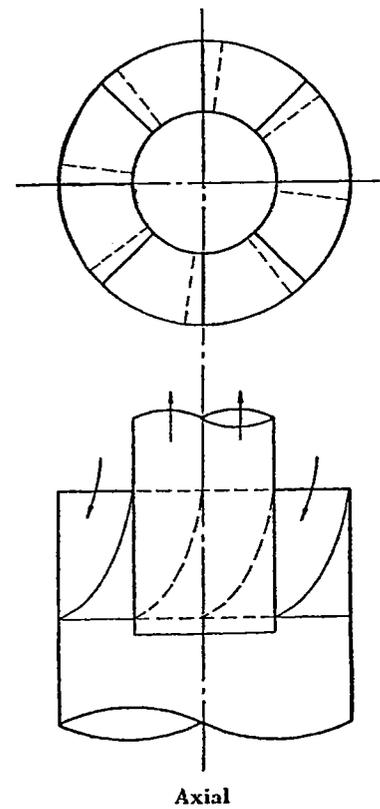
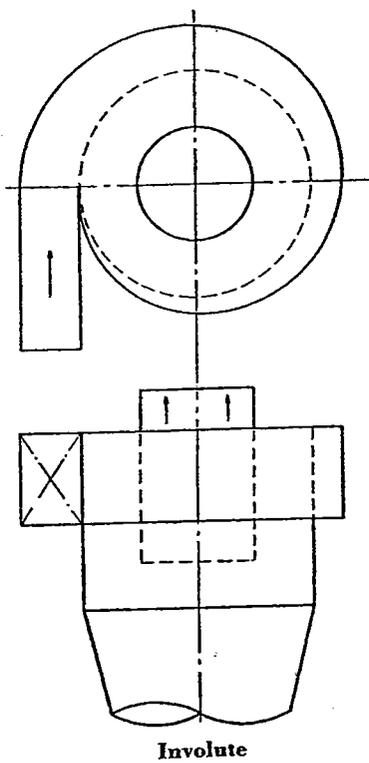
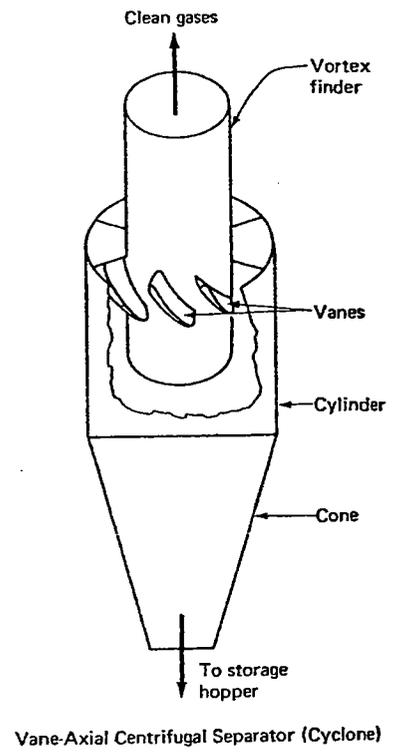
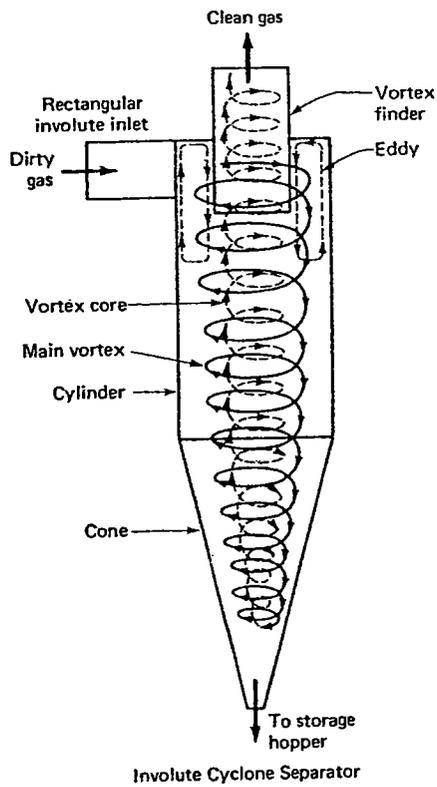
This section discusses the general O&M procedures for cyclones, multicyclones, and Roto-Clones. Roto-Clone is the tradename of a commonly used type of mechanically aided scrubber distributed by American Air Filter. The name is used in this section because it is familiar to potential users of this document. Its inclusion is not intended to be an equipment recommendation.

Mechanical collector O&M procedures included in this section are presented in a general format, and they should be modified to accommodate the specific control unit, configuration, and process specifications.

#### 3.1 Description of Mechanical Collectors

Mechanical gas-cleaning devices such as cyclones, multicyclones, and Roto-Clones use centrifugal force as the primary collection parameter (water spray is used with the Roto-Clone). Mechanical collection devices are widely used to collect particles from emission sources having high exit temperatures or sources with emissions containing particulates with a relatively large mean particle diameter (greater than 15  $\mu\text{m}$ ).<sup>1</sup>

The cyclone (Figure 3-1) is a single gas-cleaning device that uses a centrifugal force generated by a spinning gas stream to separate the particulate matter from the carrier gas. The single cyclone can be made in a number of configurations to allow for



**Figure 3-1. Cyclone separator schematic.<sup>1,2</sup>**

higher collection efficiency or increased volumetric throughput. It can be used as a large single unit (Figure 3-1), in parallel for increased volumetric capacity, in series for increased particle removal efficiency, or in a multiclone configuration (Figure 3-2).<sup>3</sup> Multicyclone tubes are used for handling larger gas volumes. The cyclone tube arrangement is generally square or rectangular, and the tubes are arranged linearly. The number of cyclone rows is kept to a minimum to prevent hopper crossflow and to reduce gas distribution problems.<sup>3</sup> Roto-Clones use a water spray in conjunction with a centrifugal collector to separate and remove particles from the gas stream.

A variety of cyclones are in use, but they generally fall into two major classes-- involute and vane axial (Figure 3-1). The difference in these classes is the method by which the gas stream is introduced to the cylindrical shell. The involute cyclone has a rectangular inlet with the inner wall tangent to the cylinder. The inlet is designed to blend gradually with the cylinder over a 180° involute. The vane axial type of cyclone is the one generally incorporated into the design of a multicyclone. The cyclone motion of the gas is imparted to the axially descending dirty gas by a ring of vanes. The centrifugal force resulting from the high rate of spin forces the dust particles to the outer walls of the cylinder and cone.<sup>1</sup>

The cyclone is a relatively simple particle-collection device consisting of several key operating components: the cylindrical body, a tangential inlet through which dirty gas enters, an exit pipe for clean gas discharge, and a conical base equipped with a dust discharge hopper (Figure 3-3). Cyclones are typically operated in a vertical position; however, because the main force of collection is centrifugal and not gravitational, horizontal or inclined arrangements have similar collection efficiencies.<sup>3</sup>

The gasflow patterns within the cyclone are complex. Three main flow patterns carry the particle-laden gas through the collection device. The main vortex carries the separated dust down the walls of the cyclone to the dust hopper. The vortex core is an ascending spiral that rotates in the same direction as the main vortex but carries the cleaned gas from the cyclone or dust hopper inlet to the gas outlet. The radially inward flow is the transition area that feeds the gas from the descending main vortex to the ascending vortex core. The dust collection hopper is the point of final separation of the

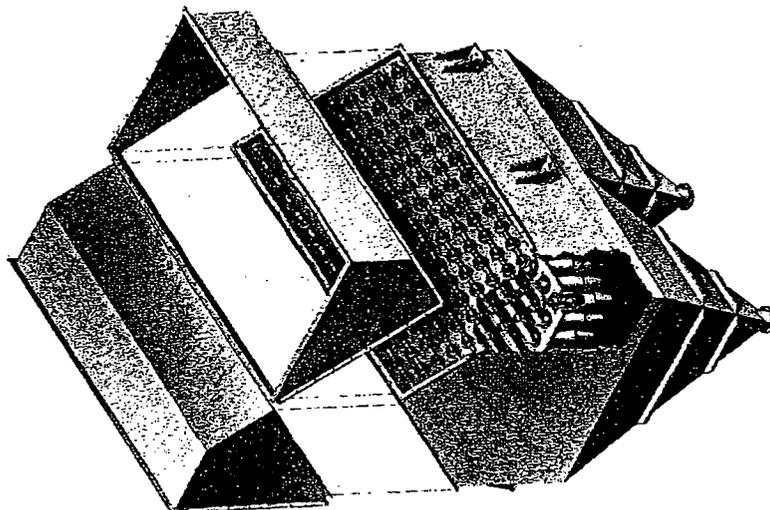
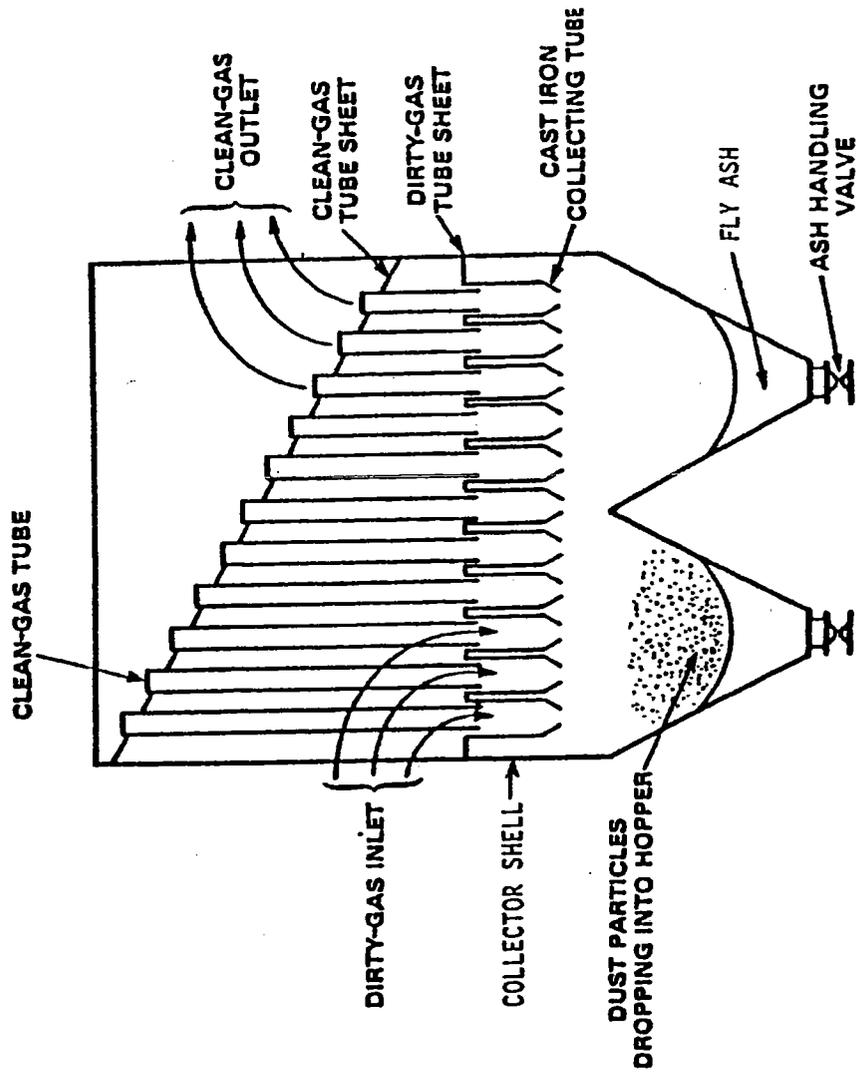
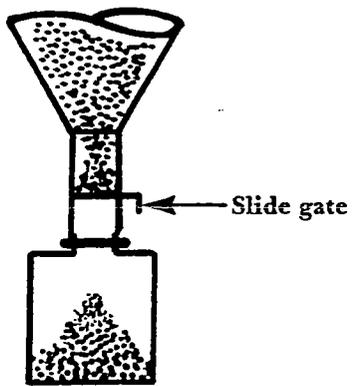
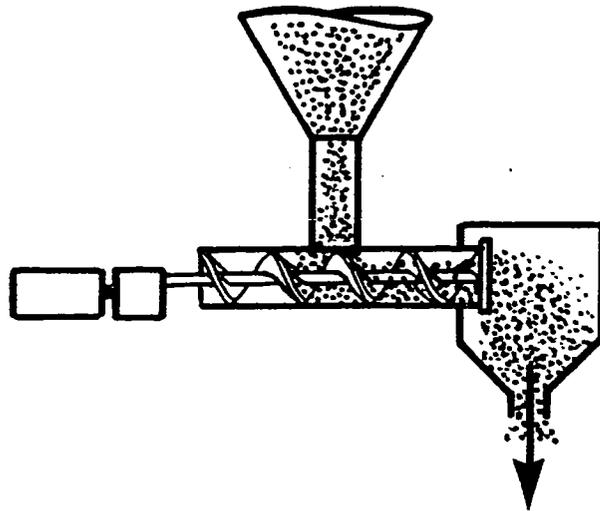


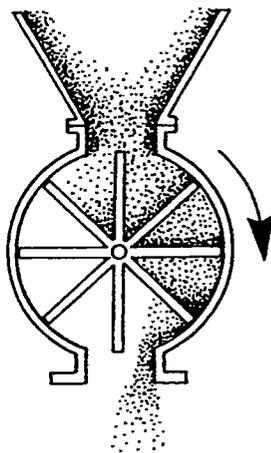
Figure 3-2. Multiclone separator schematic.<sup>1,4</sup>



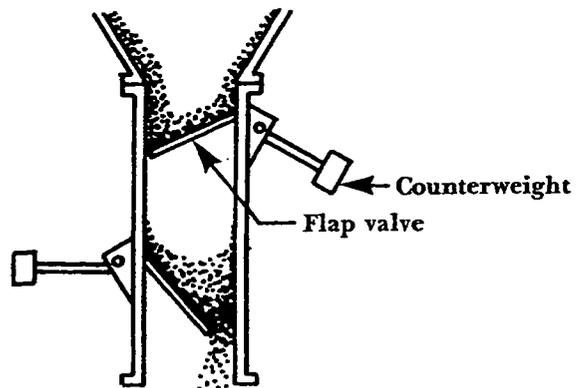
Simple manual slide gate



Discharge screw feeder



Rotary valve



Automatic flap valve

Figure 3-3. Common types of dust hopper mechanisms.<sup>4</sup>

particles from the spiralling gas stream. In this zone, the total gasflow reverses direction and is fed to the ascending spiral flow.<sup>3</sup>

The flow patterns are generated by the creation of a double vortex, which centrifuges the dust particles to the walls. When the particles reach the walls, they are transported down the sides of the walls to the collection hopper, which is isolated from the spinning gases. The downward flow along the cyclone walls must remain smooth and unbroken to minimize particle reentrainment. The flow patterns of the outer vortex depends greatly on the smoothness of the inner walls. Rough surfaces caused by particle abrasion, dents, caking, or corrosion results in a potential turbulent flow regime that tends to promote reentrainment of particles.

As shown in Table 3-1, the collection efficiency of a cyclone also depends on pressure drop, inlet dust loading, velocity, particle size distribution, particle density, and inlet gas stream temperature.<sup>3</sup> For maintenance of the proper collection efficiency of the cyclones or multicyclone, the pressure drop across the unit, inlet gas velocity and inlet gas temperatures should be monitored to assure they are at or near the levels recommended by the manufacturer's design criteria.

**TABLE 3-1. PARAMETERS AFFECTING CYCLONE AND MULTICLONE COLLECTION EFFICIENCY**

Parameter	Effect on Efficiency
Temperature	Decreases as temperatures increase due to gas viscosity changes.
Inlet loading	Increases with inlet loading.
Pressure drop	Increases with pressure drop up to a certain limit where turbulent flow occurs.
Velocity	Increases with velocity and falls off sharply below 25 ft/s.
Specific gravity	Increases with higher-specific-gravity materials.

Roto-Clones incorporate water spray (with the exception of the Type D Roto-Clone, which is a dry collection unit) with the centrifugal force as the collection mechanisms for

particulate matter. Roto-Clones are constructed in a variety of configurations: Type W, wet centrifugal collection (Figure 3-4); Type D, dry centrifugal collection (Figure 3-5); Type N, hydrostatic precipitator (Figure 3-6); and Type R, wet centrifugal collection (Figure 3-7). Each Roto-Clone type has a variety of arrangements to allow for proper particle collection in a given application.

The Type W Roto-Clone can be arranged in two ways (A and D) to facilitate particle collection. Arrangement A, shown in Figure 3-8, is typically applied to light loadings of granular dusts and mists. The dust-laden air enters the Roto-Clone, where it is subjected to a fine water spray. Because the water and dust combination is heavier than air, it impinges on the blades of the impeller and is then directed into the water cone by the blades and the centrifugal force resulting from the rotating impeller. The collected slurry drains from the unit through the sludge chute to the expansion chamber. The clean air is discharged in front of the water cone and pushed through the outlet chamber. The Arrangement D, Type W Roto-Clone, shown in Figure 3-4, is used in situations having a heavy concentration of granular dust. This type of unit is equipped with a centrifugal precleaner that removes a high percentage of the incoming dust from the air stream.<sup>5</sup>

The Type D Roto-Clone (shown in Figure 3-5) is a dry centrifugal dust collector that consists of three major components--the impeller, the housing, and the dust chamber. When the process exhaust stream contains heavy concentrations of abrasive dust, this unit can be operated in conjunction with an air skimmer. The rotating impeller performs three tasks: it pulls the air through the unit at high velocity, it streamlines the air flow, and it concentrates the particles at the periphery by centrifugal force. The housing of the Type D Roto-Clone encloses the impeller and it has two air passages. The primary passage is for cleaned air emerging from the central part of the impeller. The secondary passage, which is reserved for heavily dust-laden air, leads into and through the air-tight dust hopper at the base of the unit. The radial blades are contained hyperbolically to create a converging pattern for all particles. The particles concentrated by the streamline flow are caught by the tips of the blades that bend downward into the secondary air passage and are swept into the dust hopper. The air velocity in the secondary unit is greatly reduced in the dust hopper to allow particle settling.<sup>5</sup>

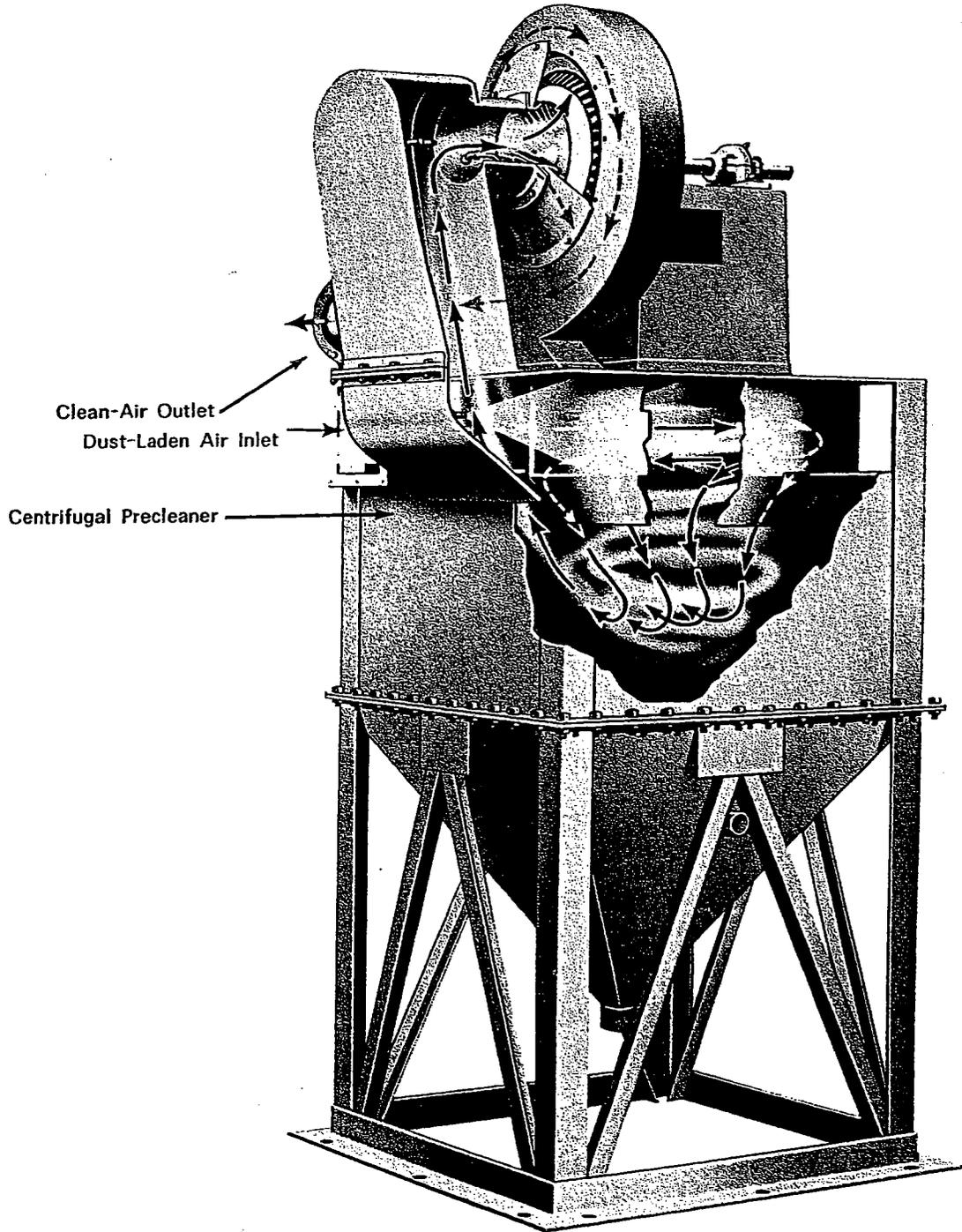
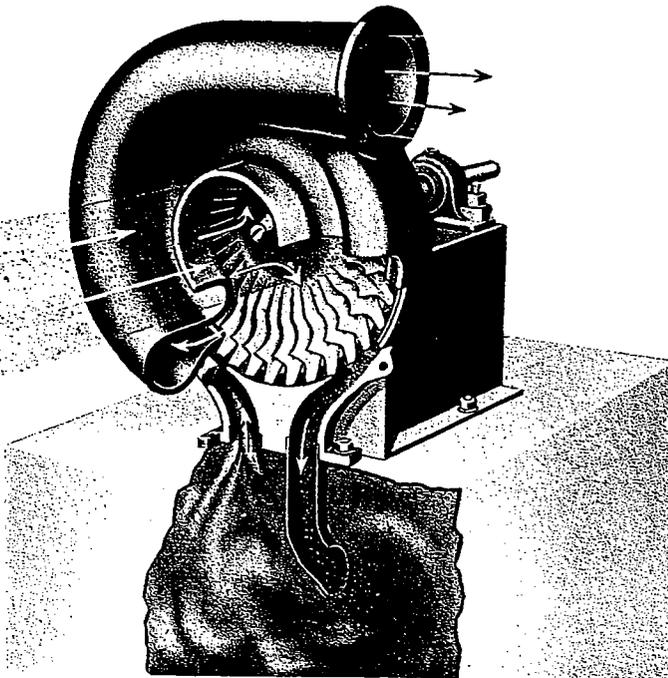
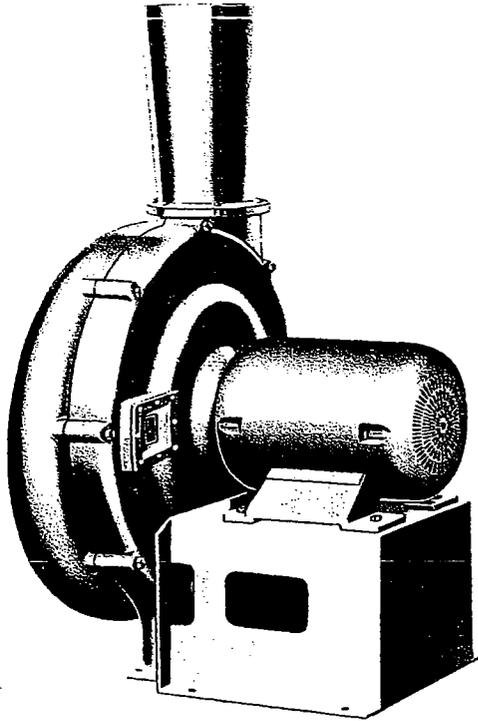


Figure 3-4. Type W Roto-Clone, Arrangement D.<sup>5</sup>  
(American Air Filter)



**Figure 3-5. Type D Roto-Clone<sup>5</sup>  
(American Air Filter)**

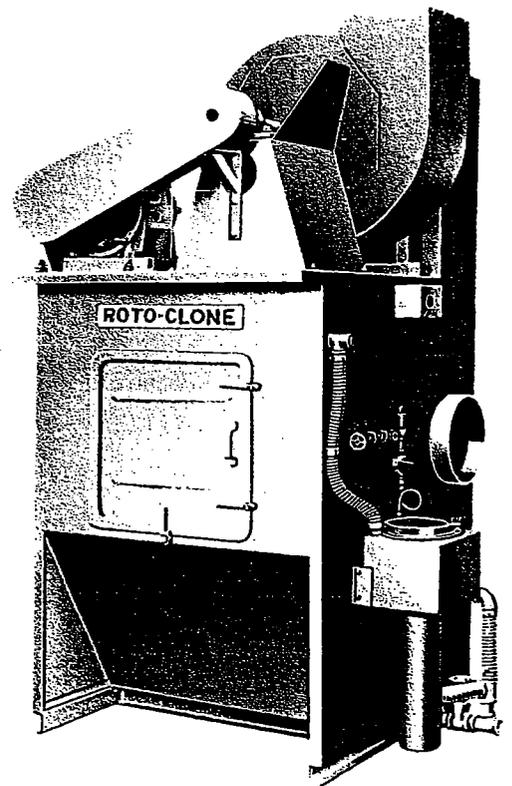
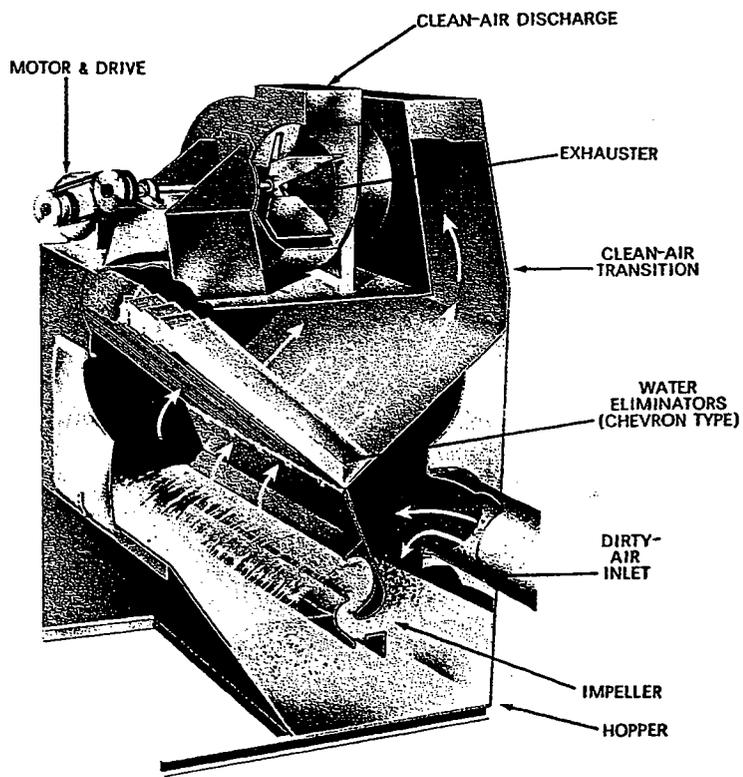


Figure 3-6. Type N Roto-Clone, Arrangement B.<sup>5</sup>  
(American Air Filter)

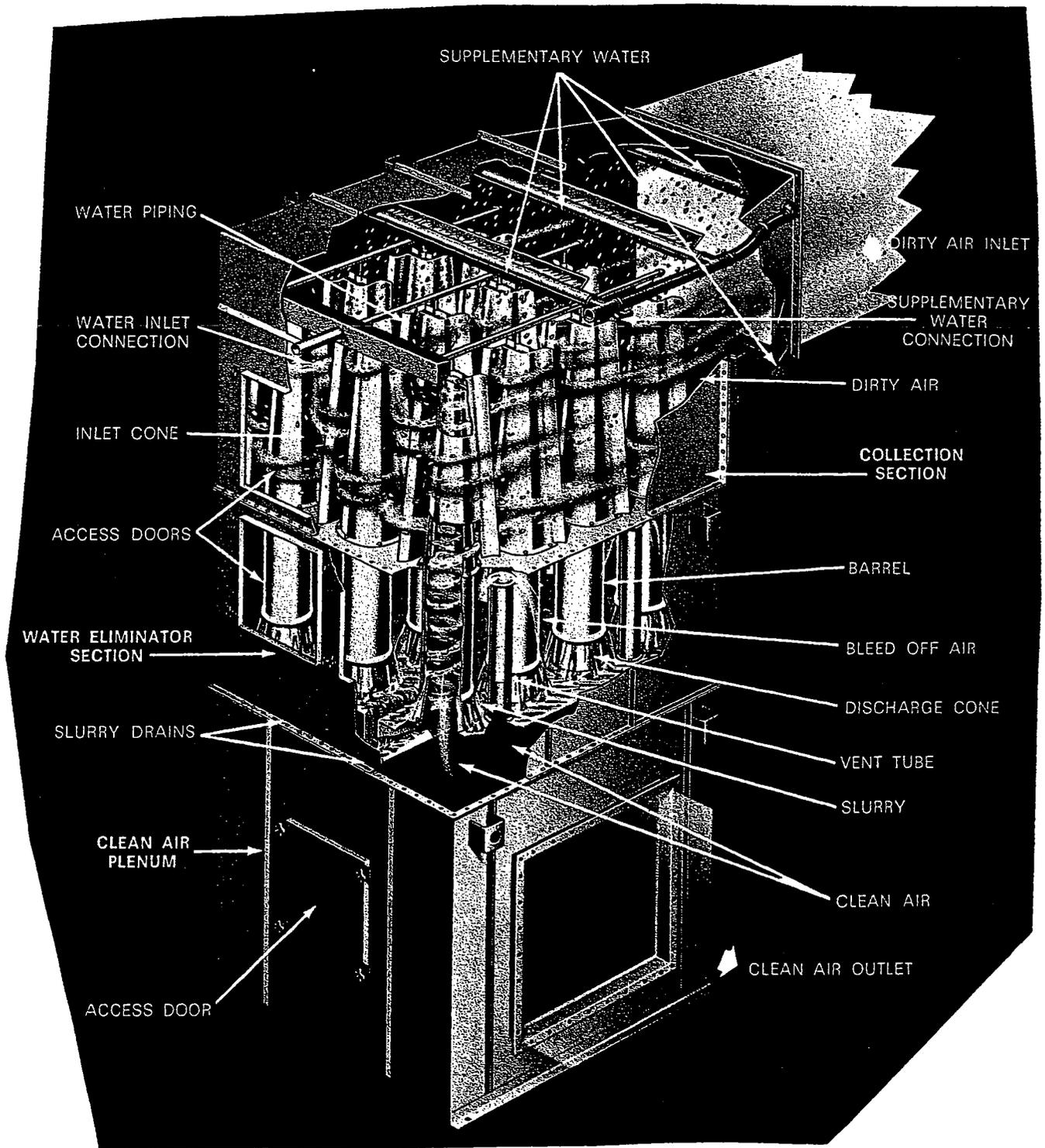
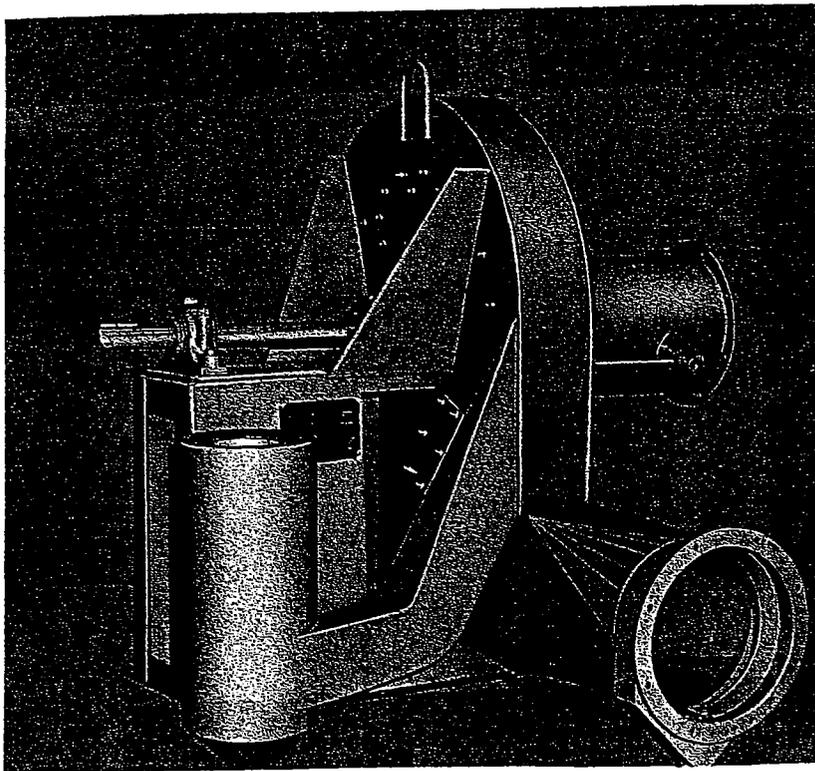


Figure 3-7. Type R Roto-Clone.<sup>5</sup>  
 (American Air Filter)



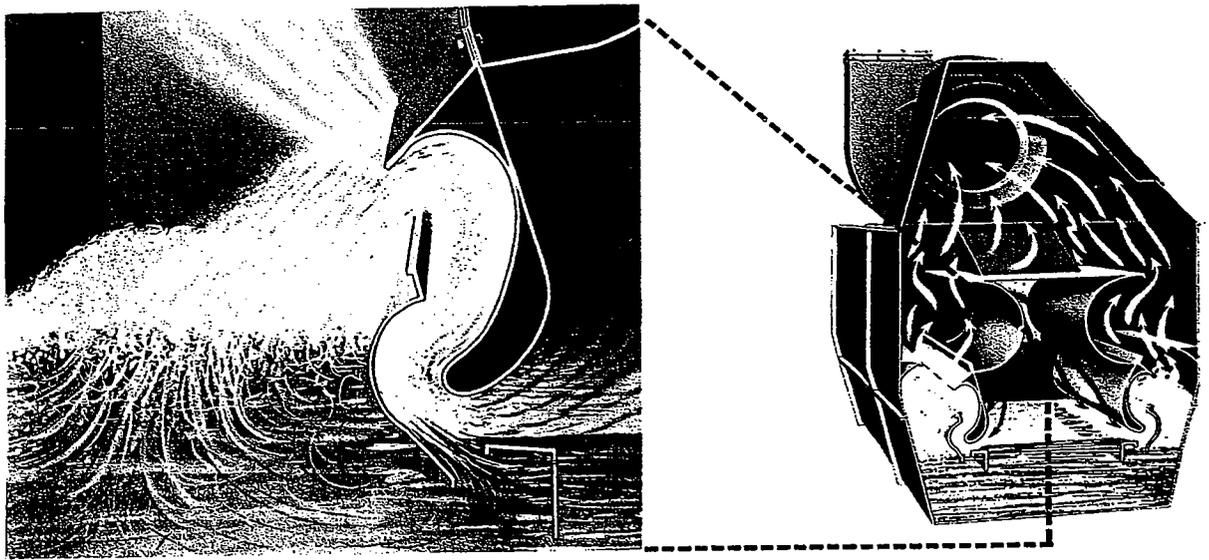
**Figure 3-8. Type W Roto-Clone, Arrangement A.<sup>5</sup>  
(American Air Filter)**

The Type N Roto-Clone can be used in three arrangements. Arrangement B is designed for low cost and manual sludge removal. Arrangement C provides automatic sludge removal. Arrangement D is designed so that the collected material can be sluiced to a process or disposal point. The different arrangements of this unit allow for a variety of sludge-removal techniques, but all collect particles in a similar manner. The particles are separated from the exhaust stream by means of a water curtain created by the flow of gas through a stationary impeller (shown in Figure 3-9). The exhaust gas flowing through the impeller at high velocity carries the water with it in a turbulent sheet. This force causes the particles to penetrate the water droplets and become permanently trapped within them. The particle-laden water droplets are then removed by water eliminators.

Typical operation of the Type N Roto-Clone involves a flange to flange pressure drop of from 5.0 to 12.0 inches w.g. As with the cyclones, the pressure drop across the Roto-Clone is a key parameter in maintaining the proper collection efficiency. The pressure drop depends on two items that require monitoring: 1) inlet gasflow rate, and 2) water flow rate through the impeller. This type of Roto-Clone has a specific standing water level within the unit, which is controlled by an overflow weir within the water level control box.<sup>5</sup>

The Type R Roto-Clone (Figure 3-7) uses wet impingement as the collecting mechanism. Water is introduced into each cone and is carried to the periphery by high-velocity air concentrated with particulate matter entering through two tangential inlets on each cone. The particles impinge against the wetted peripheral surfaces. As the incoming air spins down the inlet cone, the water and a portion of the air is forced between the barrel and outlet cone. Clean air is passed through the center of the outlet cone, and the bleed-off air is passed through a vent tube and into the clean-air plenum.

The typical monitoring parameters for the Roto-Clone particle-collection units are pressure drop, water volume throughput, inlet velocity, and impeller speed. These parameters should be monitored to assure proper operation with respect to manufacturer specifications.



**Figure 3-9. Schematic and cut-away view of Type N Roto-Clone water curtain.<sup>5</sup>  
(American Air Filter)**

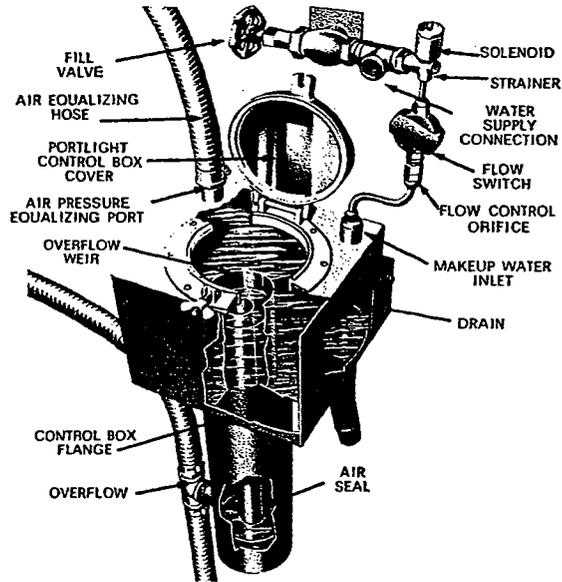
## **3.2 Monitoring Mechanical Collector Operation**

Mechanical collection devices require some basic daily monitoring to assure proper operation of the specific unit. Poor monitoring practices could result in decreased collection efficiency and increased particle emissions.

### ***3.2.1 Monitoring Devices for Mechanical Collections***

The major parameters affecting cyclone and multicyclone performance are pressure drop across the unit, and gas volume through the unit. In addition, changes in visual emissions at the gas outlet indicate a change in performance. Each device is designed to perform within certain design criteria. The design pressure drop, gas volume, and opacity should be monitored to assure operation within these limits. The pressure drop across the unit can be monitored with a magnehelic pressure gauge or manometer setup. Gas throughput can be monitored by traversing the inlet duct with a pitot tube and manometer as described in USEPA Method 2. An equivalent means of determining inlet gas volume can be used to monitor static and velocity pressures. The opacity should be monitored frequently by certified personnel, as a spot check on the equipment's collection efficiency. If monitoring proves that one or more of the parameters are out of specification, the possibility of malfunctions should be investigated. (These are discussed later in Section 3.3.)

The monitoring of the Roto-Clone control devices is similar to the monitoring of the cyclones. For units operating as the only piece of control equipment or as the primary control unit, the opacity of the exit gas should be monitored visually. This is a simple method for determining relative collection efficiency and potential unit malfunction. The pressure drop across each unit also should be checked to see if it is within the design specifications. The pressure drop not only dictates collection efficiency but also relates to the fan requirements and, in turn, the operating cost. The pressure drop can be monitored with a magnehelic gauge or manometer attached to the unit. The monitoring of pressure drop and opacity is important in troubleshooting the mechanical collectors. The water level and/or throughput also should be monitored on the wet collection units.



**Figure 3-10. Type N Roto-Clone water level control box.<sup>5</sup>  
(American Air Filter)**

This can be done with a level control box, as shown on the Type N Roto-Clone in Figure 3-10.

### **3.3 Inspection and Maintenance Procedures for Mechanical Collectors**

This section describes the frequency of and procedures for maintaining cyclones, multiclones, and Roto-Clones in general. These procedures must be adjusted to individual system installations.

#### **3.3.1 Cyclones**

In addition to the continuous monitoring of pressure drop and spot visual opacity inspections, weekly inspections of each unit should be performed and logged on an Inspection Form (Figure 3-11) to assure proper operation. A well-planned maintenance program will assure satisfactory operation of all collection components, including ductwork, fan, collector, and exhauster.

The inspection of single cyclones should consist of a general visual inspection of primary and ancillary components. During the inspection, the inspector should attempt to identify any disruptions in the cone, cylinder, inlet duct, vortex finder, axial vanes, hopper, hopper discharge, and all connecting hardware and welds. These disruptions could consist of dents, holes, broken seals, worn seals, or any other type of deterioration that could result in decreased collection efficiency due to flow disruption.

In boiler applications, the hopper should be inspected to assure that no combustion is occurring. This would cause distortion (plate separation) and allow air leakage into the system. If system shutdown is possible, the interior should be inspected periodically for particle accumulation on the cyclone wall or deterioration due to particle abrasion. The interior of the cyclone should also be inspected to assure that moist particulate matter has not caked on the interior collection surface.

Maintenance of the cyclone can consist of routine items such as painting to protect the unit from corrosion, sandblasting the interior to retain wall smoothness, and replacing fan components. Cyclone components with dents or holes should be replaced immediately, and a stock of spare parts should be on hand or readily available from the

WEEKLY CYCLONE OR MULTICLONE INSPECTION FORM	
Facility Name:	Date of Inspection:
Facility Location:	Time of Inspection:
Process:	Name of Inspector (print):
Control ID:	Signature of Inspector:
INSPECTION ITEM	COMMENTS/CORRECTIVE ACTIONS
1) CLONE - Holes - Dents - Deterioration	
2) CYLINDER	
3) INLET	
4) VORTEX FINDER	
5) AXIAL VANES	
6) HOPPER - Seal leaks - Combustion	
7) HOPPER DISCHARGE	
8) FAN	
Pressure Drop _____ in. w.g. Inlet Velocity _____ fps Interior Check (optional)? (Yes/No) _____ Noticeable Deterioration? (Yes/No) _____ % Opacity _____	

Figure 3-11. Example weekly cyclone inspection form.

manufacturer. All maintenance should be performed in accordance with site safety procedures.

The following are some typical cyclone component replacement parts.

- Inlet duct
- Vortex finder
- Cylinder
- Cone
- Vane
- Hopper release mechanism
- Hopper
- Fan drive belt

These items should be replaced on an as-needed basis, based on the results of the weekly inspections. The maintenance should be scheduled and recorded on a report form similar in format to that shown in Figure 3-12.

### **3.3.2 Roto-Clones**

Inspection and maintenance of Roto-Clone particle control units depend on the specific type of unit and its arrangement. Generally, several major collection components, in addition to the inlet ductwork and exhaust mechanism, must be inspected and maintained on a routine basis. Each control unit should be inspected weekly in accordance with site safety procedures and recorded on a form similar to the one shown in Figure 3-13. Typical components that should be inspected are as follows:

- The bearings on the Roto-Clone should be inspected to assure proper lubrication. The pillow block on the Roto-Clone shaft should be flushed and refilled with the proper quantity of grease every six months. The ounces of grease required for each pillow is dictated by the manufacturer.
- The spray nozzles should be inspected to assure proper water delivery.
- The inlet to the Roto-Clone should be inspected by opening the inspection door to the units. Accumulation of material in the inlet at the borderline of the wet and dry section should be noted and removed during inspection or scheduled for maintenance. The cleanout of accumulated material should be scheduled so that the accumulation does not exceed 1/10 of the total cross section area.

**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 3-12. Example of maintenance report form.**

<b>WEEKLY ROTO-CLONE INSPECTION FORM</b>	
Facility Name:	Date of Inspection:
Facility Location:	Time of Inspection:
Process:	Name of Inspector (print):
ROTO-CLONE ID:	Signature of Inspector:
INSPECTION ITEMS	COMMENTS/CORRECTIVE ACTIONS
1) BEARINGS - Greased?	
2) NOZZLES & STRAINER - Proper water delivery?	
3) ROTO-CLONE INLET - Quantity of accumulated material	
4) PRECLEANER INLET	
5) ROTO-CLONE IMPELLER	
6) SLUDGE DRAIN	
7) EMERGENCY OVERFLOW	
8) FLAT SPRAY NOZZLE - Parallel to blade edges?	
Pressure Drop Check _____ in. w.g. Water Pressure Check _____ in. w.g. Opacity _____ % Interior Duckwork Check (optional)? (Yes/No) _____ Noticeable Deterioration? (Yes/No) _____	

**Figure 3-13. Example weekly Roto-Clone inspection form.**

- If a precleaner is installed with the unit, the borderlines of the dry and wet zones to the inlet should be inspected for particle deposition. This deposit should be removed during scheduled maintenance, based upon the inspection. The particle deposit should not exceed a level more than 1/4 the area of the precleaner inlet.
- The Roto-Clone impeller should be inspected for accumulations of foreign material or obstructions in the blade hooks. The buildup of particles on the hooks disrupts the collection mechanism of the unit. The removal of the material can be performed by manual scraping or high-velocity water spray through the access door in back of the unit and from the front side of the impeller.
- The flat spray of the flushing nozzle, located at the impeller, should be parallel to the blade edges. The spray should be in operation during the inspection to assure proper positioning.
- The grating in the bottom of the Roto-Clone hopper and the sludge drain pipe should be kept clean. Removal of any particle accumulation should occur during routine maintenance.
- An emergency overflow is provided on the side of the hopper to drain off the water in case the hopper drain pipe becomes clogged. This should be inspected periodically so that the stoppage can be cleaned out immediately. If an overflow has been provided with an open funnel discharge connection to the disposal line, the hopper drain should be cleared at the first opportunity.

### **3.3.3 Multicyclones<sup>6</sup>**

This section describes the procedures for evaluating the operating condition of a multicyclone collector to determine points of collector bypass, gasket leaks, collection-tube wear, pluggage, or flow maldistribution.

#### *Inspection of Multicyclone--*

The following is a general step-by-step procedure for inspecting multicyclones. This procedure should be tailored to the individual collector unit but a complete inspection should be performed at least once per year or whenever the process is shut down for repairs.

- For internal inspection of the collector, the process must be taken off line prior to the inspection in accordance with site lockout tag-out procedures.
- The collector should be purged, and particulate should be removed from the collector hoppers to aid in cooling (where applicable) and to prevent its resuspension into the gas stream.
- Because of thermal draft when controlling hot gas streams, a certain amount of natural draft is expected during the cool-down period. After the cooling period, the I.D. fan dampers should be closed to reduce the draft to the collector and the suspension of particles from surfaces.
- All access doors to the collector should be opened, and the gasket material should be checked for burnt areas, hardness, or breakage. The gaskets should be soft and make continuous contact with the door seat. Deficiencies should be noted, and checks should be made of each door during smoke testing to determine if leaks occur.
- After being equipped with appropriate safety equipment (i.e., hard hat, safety glasses and shields, dust respirator, gloves, coveralls, steel-toed shoes, etc.), the facility's inspector should enter each section of the collector, perform the following tasks, and take appropriate notes:
  - a) Look for dust patterns on collector walls, joints, seams, and the lower tube sheet between tubes. A shiny area may indicate the location of outside air inleakage into the hopper area or plenum. Dust patterns should be noted, which indicate gasflow patterns or particle stratification.
  - b) Inspect all seal-welded seams, nuts, and bolts on the inlet, outlet, and hoppers for integrity and any evidence of air inleakage.
  - c) Make note of the number and location of tubes that are loosened from the dirty-gas tube sheet, which can indicate areas of flue gas leakage from the inlet plenum into the collection hopper.
  - d) Make note of the location of areas of particle buildup inside the hopper, which may indicate an area of cool gas inleakage.
  - e) Make note of the number and location of worn or chipped tubes or tubes that are uneven at the dust discharge opening.
  - f) Note the number and location of tubes that contain scale or hardened fly ash on the internal collection tube surfaces.

- g) Note the number and location of collector-tube dust outlet plugs.
- h) Note the number and location of fallen-pressure recovery turning vanes in the collector tubes.
- i) Note the location and severity of particle buildup on the dirty-gas tube sheet in the dirty-gas plenum.
- j) Note the location of any particulate buildup and pluggage of the inlet turning vanes or ramps.
- k) Inspect the inlet turning vanes for wear, and note the location and number of each.
- l) Inspect the leading-edge side (gas inlet side) of the gas outlet tubes for abrasive damage and wear. Note the number and location of penetration points.

When a visual inspection of the collector has been completed, it should be completely cleaned to remove any hardened material. Depending on the extent of tube scaling and material buildup, the cleaning may be done with chipping hammers, scrapers, wire brushes, or other mechanical devices. Final cleaning may include sandblasting and water-washing. The purpose of the final cleaning is to aid in the visual inspection of the collector for penetration during pressurization and smoke testing. Sandblasting tends to remove protective coatings (paint, epoxy, etc.), and these coatings will have to be reapplied after the testing.

Washing should be done with a high-pressure water jet with sufficient velocity to dislodge hardened scale. It should begin at the highest point in the collector, that allows water and sludge to drain through the unit and out of the hopper. The hopper valves should be opened or cycled to prevent containment of material in the hopper.

The clean-gas tube sheet area should be washed first. Particular care should be taken to remove scale or deposits in each of the exits of the outlet gas tubes. Removal of scale is important because a positive seal is required between the plug and tube wall in subsequent steps involving pluggage of the collector.

The second wash area includes the dirty-gas inlet, the bottom of the clean-gas tube sheet, the inlet turning vanes, and the dirty-gas tube sheet. The third wash area

includes the underside of the dirty-gas tube sheet, the collector tubes, and the hopper. The inside of each collector tube should be scraped and hand-cleaned to ensure complete removal of scale and deposits that could interfere with collector-tube plug sealing.

After washing is completed, all doors should be opened and the collector allowed to dry. A final check of the clean collector should be made to determine major penetration points or openings in the tube sheets.

#### *Flue Gas Bypass or Penetration Evaluation--*

This section describes methods that may be used to determine if flue gas is bypassing the clean-gas tube sheet, if flue gas is penetrating the dirty-gas tube sheet into the hopper, or if ambient air is leaking into the hopper or into the inlet gas plenum.

Penetration occurs through the tube sheet, around gaskets, and through welds when a pressure differential exists across the opening. In normal operation, this difference in pressure is equivalent to the collector static pressure drop. Because access to the openings is internal to the collector, they can not be directly observed or measured. To overcome this deficiency, the following procedure has been developed for visually observing the penetration points by use of a smoke test. Although this method is time-consuming and man-power intensive, it is the only positive means of determining the location of gas bypasses.

Pressurization is accomplished by use of the boiler forced-draft fan. Major areas to be pressurized are the inlet gas plenum and dust hopper (Figures 3-14 and 3-15). Pressurization of Area 1 allows penetration to be observed through the dirty-gas tube sheet, clean-gas tube sheet, and collector body. Pressurization of Area 2 allows penetration to be observed through hopper doors, ash valves, and the hopper shell.

The gas openings through the turning vanes and gas outlet tubes must be sealed before pressurization can be accomplished. Each collector-tube dust outlet and gas outlet tube must be sealed with a pneumatic sewer plug or an inflatable rubber plug.

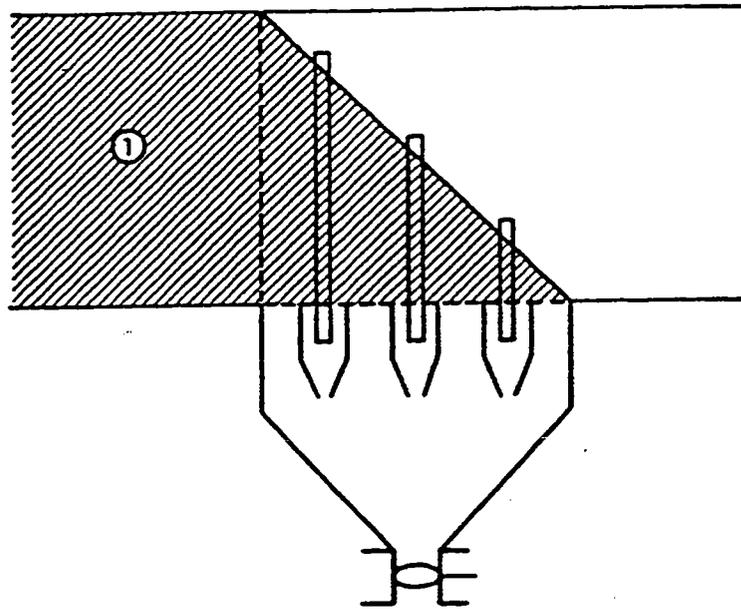


Figure 3-14. Inlet gas plenum.<sup>6</sup>

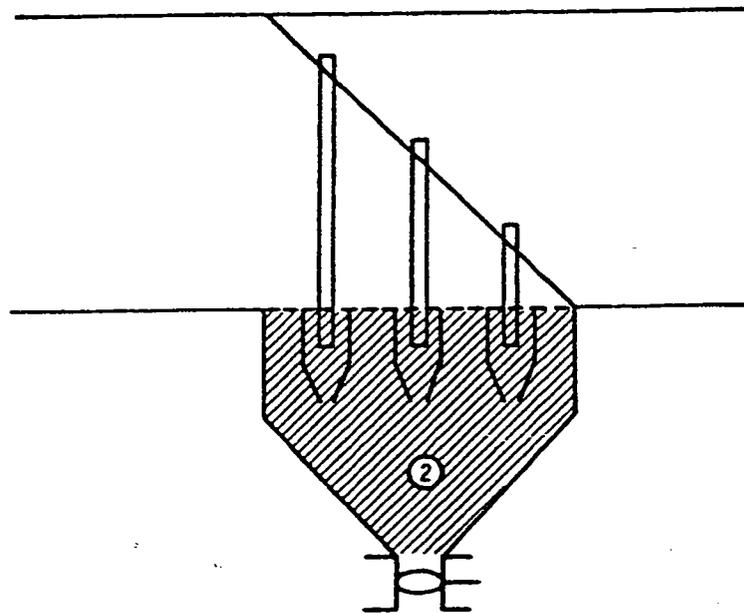


Figure 3-15. Dust hopper.<sup>6</sup>

The pneumatic plug consists of a rubber washer between two metal plates. Normal diameter of the rubber washer is increased by compressing the rubber between the washers with a large wing nut. The metal plug is available in various sizes depending on the diameter of the collector tube dust outlet. Selection of a plug with the proper diameter is important to ensure that the system is completely sealed.

Pluggage of both gas outlet tubes and dust discharge openings can also be accomplished with an inflatable rubber sphere. The plug is inserted in a tube, and compressed air is then used to inflate it. Each inflatable plug is equipped with a pneumatic check valve and fitting for an air check. The fitting is a conventional outside-thread valve that allows the attachment of a flexible rubber hose extension. Each plug is attached to a large metal chain to keep it from being lost down the gas outlet tube when it is deflated. The chain is used to hold the plug in position during installation.

Plugs may be purchased in various sizes (4, 5, or 6 inches in diameter) and may be over-inflated to accommodate intermediate sizes. A 4-inch diameter may be extended to 6 inches without rupturing the plug. With both plugs in place, the inlet side of the collector (Area 1) can be pressurized with the forced-draft fan. When several of the dust discharge tube plugs are removed, the forced-draft fan can be used to pressurize both Areas 1 and 2.

After the collector has been washed and allowed to dry out, metal diaphragms or pneumatic plugs should be installed in the dust outlet of each collector tube. If diaphragms are used, the lower edge of the rubber washer should be even with the bottom edge of the tube. When the diaphragm is compressed, the assembly must be held in position until a secure seal is achieved. Because many dust outlet tubes are tapered, the assembly may tend to move upward during expansion. The tightness of each tube should be checked by pulling downward on the tightening wing nuts.

If expandable plugs are used, they should be inserted half-way into the tube opening and inflated to create a tight seal. The amount of compressed air used during inflation should be limited to prevent plug rupture.

In an inclined clean-gas tube sheet of conventional design, access to the clean-gas tube outlets is relatively easy. Plugs should be installed in the upper rows, first, then installed downward towards the clean-gas outlet. Either inflatable plugs or diaphragms may be used, depending on the tube edge configuration.

If gas outlet envelopes are used to direct the cleaned flue gas, the gas outlet tube exit may not be accessible for direct plug insertion. Because of the narrow passage and depth of the envelope, diaphragm plugs cannot be inserted and tightened by hand.

The limited space also makes the placement of inflatable plugs difficult and time-consuming. Adding to this difficulty, the plug is attached to the mechanical arm by friction fitting it into the arm yoke, which allows the arm to be detached with minimum effort after plug placement. Figures 3-16 and 3-17 are drawings of the mechanical arm used to put the plugs in the proper place. Rubber air extension tubes must be used to allow inflation of the plugs from outside the envelope area. Extensions may be purchased in various lengths (2, 3, or 4 feet) and used in combination as required (Figure 3-18).

Plugs should be placed in the front tubes first, then installed toward the rear of the envelope. Inflated plugs in the front rows may be used as a fulcrum to aid in the positioning of tubes in the rear rows. Considerable manual dexterity is required to place the plugs in the openings. The work area (e.g., tube openings) must be lighted from above the envelope opening and above the personnel installing the plugs. During placement, the tube opening is typically in the shadows of the plug and mechanical arm. Experience indicates that placement is best achieved by feel and estimating distance rather than by visual attempts.

Because the placement of the plug is by feel, bumping and/or scraping of the plug against the envelope wall is likely, and this motion frequently results in losing the plug from the yoke. Retrieval of the plug may be difficult if the attached ring is lost over the end of the placement arm. The loss of the plugs can be prevented by placing the inflation line on top of the arm and placing tension on the line pulling the plug against the yoke.

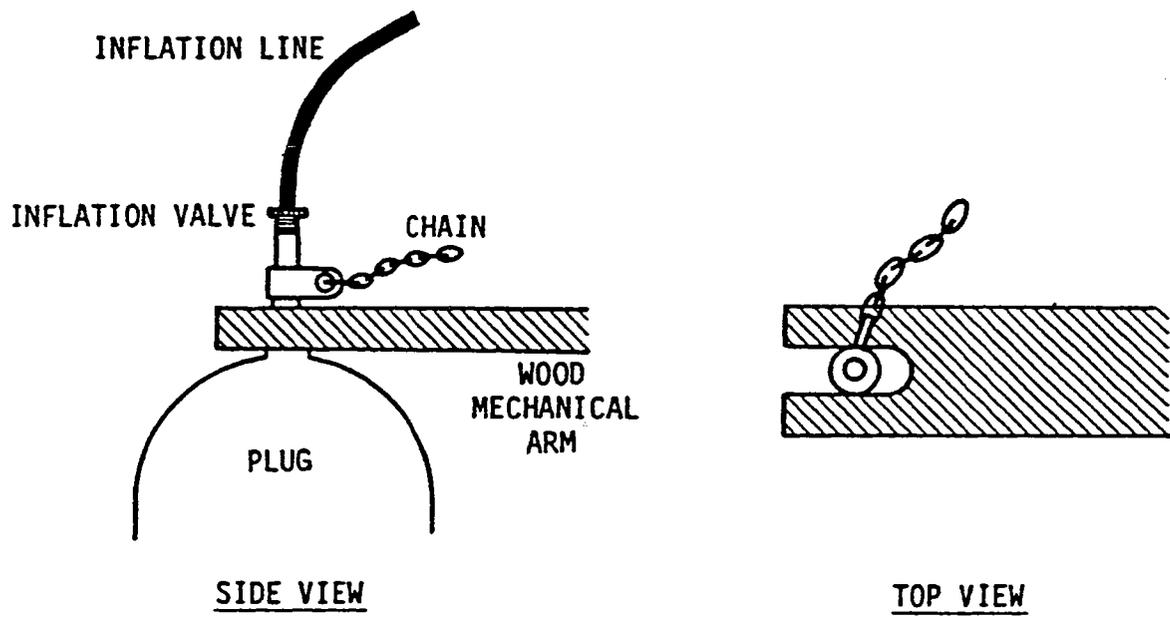


Figure 3-16. Enlarged view of plug, chain, and mechanical placement arm.<sup>6</sup>

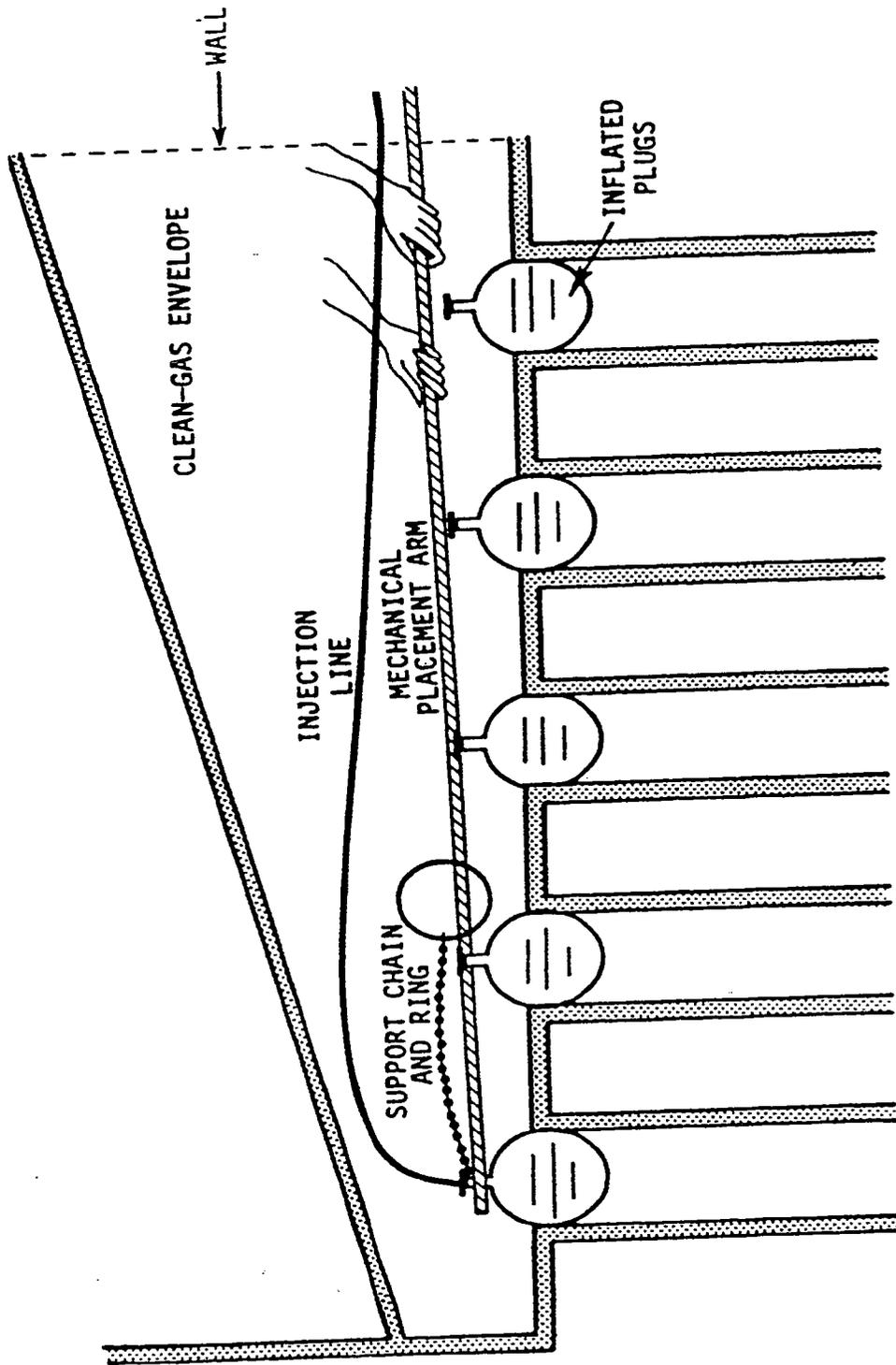


Figure 3-17. Diagram of mechanical placement arm with inflation lines removed for clarity.<sup>6</sup>

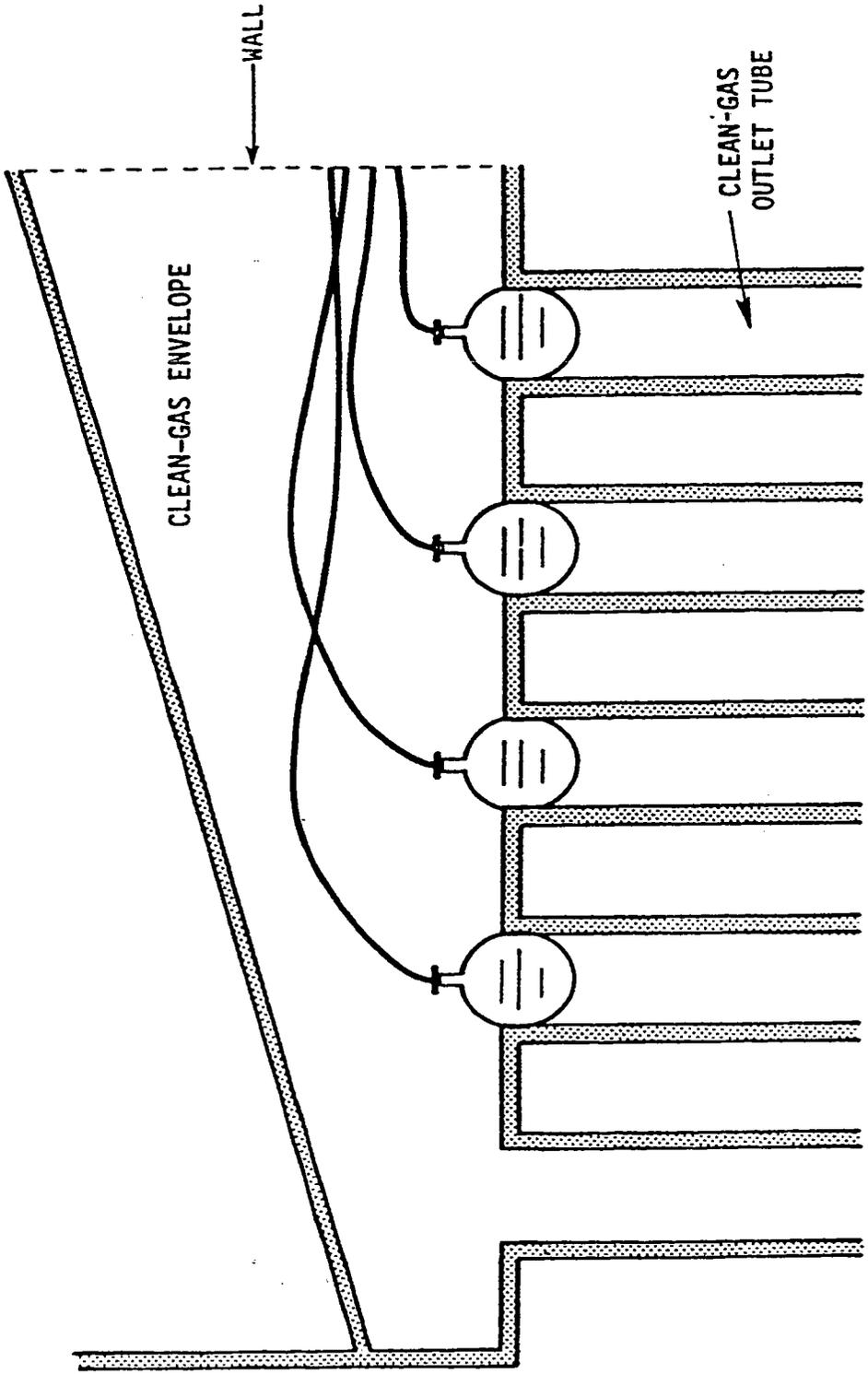


Figure 3-18. Placement of plugs in clean-gas outlet tubes.<sup>6</sup>

If the uninflated plug drops down in the gas outlet tube, the metal ring will prevent its loss. The plug must be retrieved, however, and placed in position for complete sealing. Considerable effort is required to place the plug in the farthest outlet position because of the cantilever position of the mechanical placement arm.

Because of the limited work space and the difficulty in plug placement, this task may require many man-hours. During this period, compressed air may leak from defective inflation valves and allow deflation. After all tube plugs have been installed, the envelopes should be visually checked for dropped or defective plugs. All dropped or defective plugs should be repaired and/or replaced.

At this point, all plugs should have been placed and the collector should be available for pressure testing.

#### *Pressure-Testing of Dirty- and Clean-Gas Tube Sheets--*

The following procedure should be used to determine gas leakage through the tube sheets and around collector-tube seal gaskets:

- 1) Close the collector I.D. fan damper.
- 2) Close the dirty-gas plenum access doors.
- 3) Start the forced-draft (F.D.) fan with dampers full open.
- 4) Measure the fan static pressure on the collector inlet with a magnehelic gauge or manometer. The pressure should be greater than or equal to the anticipated collector static pressure drop.
- 5) Check ceiling plugs (gas outlet tubes and collector dust discharge) for leaks and/or removal due to F.D. fan pressure.
- 6) Stop F.D. fan and replace or reinflate improperly placed plugs (determined from Step 5).
- 7) Place ignited smoke bombs into the dirty-gas plenum. Multiple bombs may be required, depending on collector size and/or plenum configuration. An effort should be made to place the bombs on the dirty-gas tube sheet and not on the inlet duct to the collector. For complete detection of penetration points, the density of smoke near the tube sheet openings must be at a maximum. The diffusion of the aerosol smoke in the plenum is relatively

slow, and unless a complete coverage is obtained, major penetration points may be overlooked.

- 8) Start F.D. fan and maintain required forced-draft static pressure.
- 9) From the outlet gas plenum, inspect all seams, flanges, and gas outlet tube welds and seals for penetration of aerosol smoke, which indicates gas bypass points. Note location and describe type of penetration point (weld, gasket, etc.).
- 10) Check the underside of the dirty-gas tube sheet for gas bypass through welds, flanges, and collection-tube seal gaskets. Note location and describe all penetration points.
- 11) Stop F.D. fan and remove several clean-gas outlet tube plugs to allow the smoke in the dirty-gas plenum to dissipate.

#### *Pressure Testing of Hopper and Ash Valve--*

The following procedure should be used to pressure-test the hopper and ash valves for evidence of inleakage:

- 1) Reinstall plugs in clean-gas outlet tubes removed in the previous procedure.
- 2) Remove half of the plugs from the bottom of the collection tubes to allow the hopper to be pressurized by the F.D. fan.
- 3) Close hopper doors and insert an ignited smoke bomb into each hopper apex through an inspection port or a rod-out hole.
- 4) Reseal inspection ports or rod-out holes.
- 5) Start F.D. fan and maintain required forced-draft static pressure.
- 6) Observe all hopper seams, welds, hopper doors, inspection ports, and ash valves for visual evidence of gas penetration. Note areas of leakage and describe the penetration point.
- 7) Stop F.D. fan and open access door to allow smoke to dissipate.
- 8) Deflate and remove all sealing plugs from the collector.

### *Preparation of Inspection Report--*

A final report identifying scale, buildup, plugging areas, and inleakage points should be prepared. This report should include a narrative on the particular deficiency and a location chart of the tube sheet.

Although all scale and pluggage problems are eliminated by collector washout, these problems should be documented for future reference. Figure 3-19 shows an example location chart.

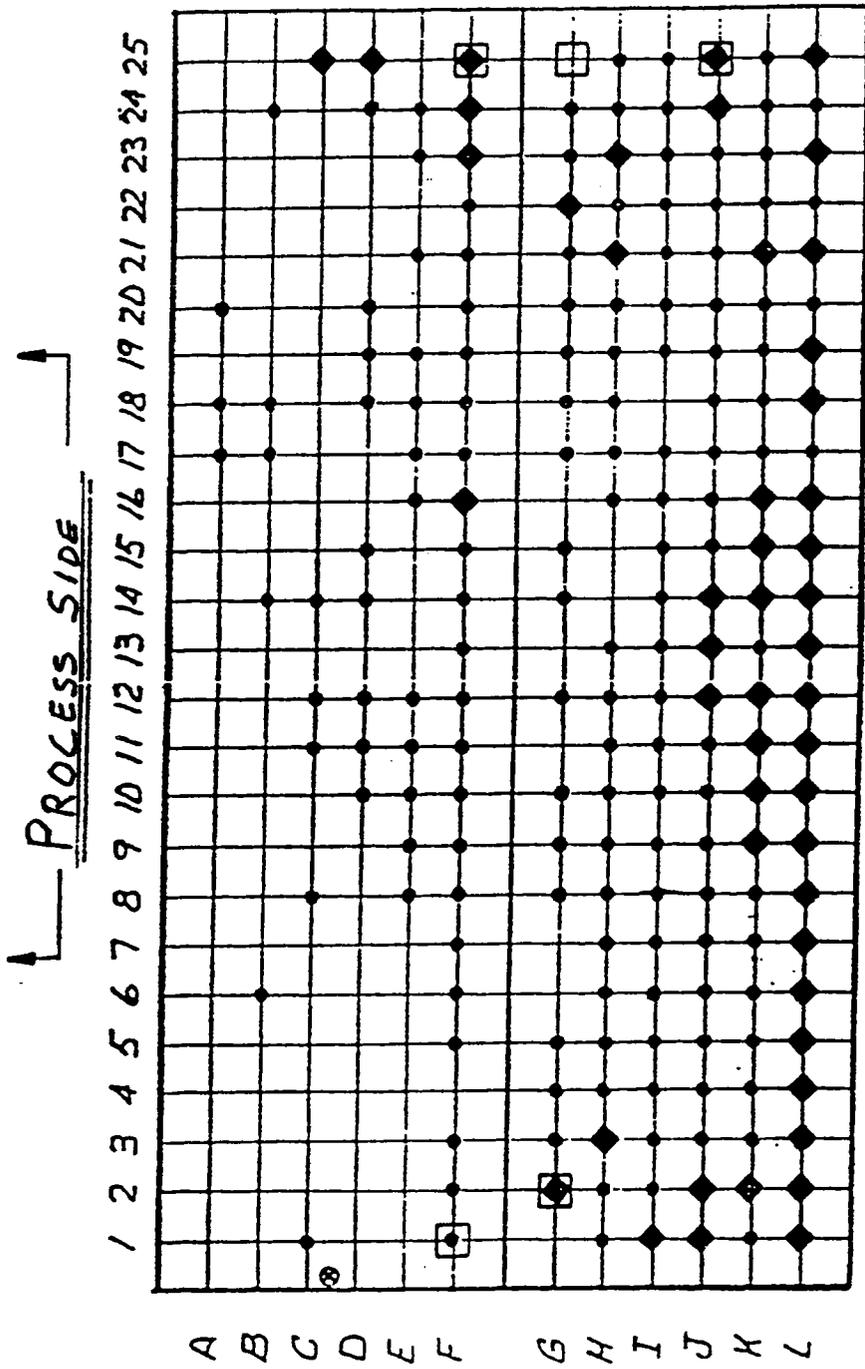
### *Repair of Collector Penetration Points--*

The following repairs should be made to penetration points in the collector:

- Tube sheet weld seams - Clean, brush, and weld penetration points.
- Tube sheet gasket - Clean and brush affected area and seal openings with high-temperature caulk, epoxy, or castable joint compound. The original seal gasket is typically composed of asbestos, and replacement is almost impossible without disassembly of the collector.
- Collection-tube gasket - Remove collection tube, clean and brush setting surface, and replace gasket. If tube sheet is scored or wrapped, castable cements, epoxies, or other compounds may be used to enhance the seal.
- Collector shell - Clean, brush, and weld penetration points.
- Hopper doors - Replace sealing gasket and/or replace warped doors and door joint.
- Ash valve - Replace valve flange gasket and/or repair ash valve to ensure positive seal.
- Clean-gas outlet tubes - Weld patches on penetration points or replace clean-gas outlet tubes as necessary. Install deflector plates on tubes to prevent damage.

### *Replacement of Worn or Failed Components--*

The following repairs should be made to return the collector to proper operating condition:



- SCALE IN TUBE
- ◆ TUBE PLUGGED
- LEAK AROUND TUBE
- ⊙ HOLE IN TUBE SHEET

Figure 3-19. Example location chart.<sup>6</sup>

- Replace worn collection tubes that show wall penetration or distorted dust outlet tubes.
- Replace worn inlet turning vanes.
- Replace worn pressure monitoring devices.

### **3.4 Major Problems or Malfunctions of Mechanical Collectors**

Several operating conditions and/or malfunctions can reduce collector performance. These conditions and parameters are discussed in this section, along with a cause and/or potential solution to the problem.

#### **3.4.1 Cyclones**

A decrease in cyclone particle collection can be noted during routine inspections of exit gas opacity and unit components. If a decrease in efficiency is noted, a number of parameters can be checked to correct the problem. Some of the key items for malfunction correction are listed in Table 3-2.

#### **3.4.2 Roto-Clones**

Roto-Clone particle collection units all have similar malfunctions and problems, even though they vary in types and arrangements. The general problems and possible corrections for these units are discussed in this section.

An excessive quantity of water in the exhaust could be attributed to one or a combination of several of the following:

- Incorrect impeller rotation. (The proper rotation for the collection impeller is counterclockwise.)
- Improperly sized cone spray or auxiliary nozzles and incorrect spray patterns (i.e., flat spray at 7 o'clock and parallel to blades and cone spray centered at the wheel).
- Sharp inlet elbows. (These can seriously reduce air volume and may result in water carryover.)

- Bent blade tips and obstructions in impeller, such as rags, excessive paint, collected material buildup, etc.
- Plugged or obstructed drain pipes.
- Incorrect outlet piping location. (The bottom of the outlet pipe should never be above the bottom of the Roto-Clone scroll.)
- Improper gasketing of water cone.
- Worn, torn, or cracked gaskets.

**TABLE 3-2. PROBLEMS AND MALFUNCTIONS IN CYCLONE PARTICLE COLLECTION**

Problem	Possible Malfunction	Corrective Action
Fluctuation in pressure drop	Fluctuation of inlet velocity	Correct velocity to design specifications. Adjust fan.
	Particle accumulation	Pressure-wash interior. Decrease moisture content. Adjust particle inlet distribution.
	Particle abrasion to cylinder cone or vortex finder	Coat interior with abrasion-resistant material. Replace worn component.
	Particle reentrainment	Check hopper for leaks.
Flow disruption	Dent in cone/cylinder	Repair or replace component.
	Hole in cone/cylinder	Repair or replace component.
	Particle maldistribution	Eliminate flow disturbances (i.e. bends or turns in ductwork) immediately before inlet. Pressure wash interior and inlet.
	Vane wear	Replace worn vanes.
	Air inleakage	Seal leaks in hopper and/or connecting ductwork.

Excessive particle concentration in the outlet gas (increased opacity) can be attributed to one or more of the following:

- Equipment is running dry or with insufficient water supply due to clogged spray nozzles or strainer or low water pressure. Most Roto-Clone types require a minimum nozzle pressure of 40 lb.
- Impeller blade hooks are obstructed.
- Precleaner spray nozzle is misaligned. A flat spray must discharge in a vertical plane.

### **3.4.3 Multicyclone<sup>6</sup>**

Several operating conditions and/or malfunctions can reduce multicyclone performance. Most of these conditions result in disturbance of the cyclone vortex, pluggage of gas passages, or interference with dust discharge from the cyclone tube. The following discussion identifies the major failure mechanisms and their effect on multicyclone collector efficiency.

#### *Gas and Particulate Maldistribution--*

For each cyclone tube to receive the same amount of particle loading, the distribution of gasflow must be uniform, both horizontally and vertically, across the multicyclone inlet. Proper duct inlet design often requires the use of turning vanes. Sharp dust turns or improperly joined ducts may result in particle stratification at the outer radius of the turn, which increases abrasion. In many systems, duct expansion causes the gas stream to decelerate at the entrance to the collector. Stagnation or low velocity can result in dust buildup on the approach to the inlet turning vanes of the collector tube. Reduction in gas velocity can also cause particle fallout if the velocity is decreased below transport velocity. Continued deposition and dust hardening can occur when the system periodically passes through either the moisture or acid dew point. This situation can create obstructions to flow at the entrance to individual cyclone tubes.

Minor deposition generally occurs in almost all multicyclones as a result of secondary flows and operation at lower than design gas volumes during process

variations and/or startup and shutdown periods. Heavy deposition generally does not occur in well-designed systems and is limited by particle reentrainment from the deposit area.

Heavy deposits that harden or are located in low-velocity areas, however, may eventually change the flow pattern in the collector. Although these deposits might not affect the pressure drop across the unit, they would increase particle penetration.

Maldistribution can also aggravate abrasion and/or pluggage of the turning vane which, in turn, may cause increased penetration and increased maintenance. If maldistribution is suspected, based on visual inspection of the collector, velocity profiles and particulate concentrations should be obtained at the multicyclone entrance. The flow patterns in Figure 3-20 indicate particle stratification at the inlet to the collector. Gasflow is generally from the upper right downward. The gas then makes a turn from the lower left to right into the entrance of the multicyclone. As a result of their inertia, particles are concentrated on the outer radius of the turn. Upon entering the collector, particles are concentrated in the lowest area of the gas stream. This flow distribution results in the first row of tubes receiving the greatest particle mass and the largest particles. Finer particles in the upper portion of the gas stream are concentrated in the back of the collector.

#### *Gas Volume and Pressure Drop--*

The potential collection efficiency of the collector is a function of the gas volume handled by each cyclone tube. Passage of the gas through the turning vane and subsequent change in gas direction require energy to be expended. Energy is stored as kinetic energy in the gas stream. The expenditure of energy that manifests itself as static pressure drop must be provided by the collector I.D. fan.

For the collector to achieve maximum separation efficiency, the inlet gas velocity must be at the maximum design value for the specified tube diameter (i.e., maximum gas volume passing through a fixed area inlet). Because the gas volume and static pressure drop are proportional for a given collector, pressure drop is considered an indicator of the proper operating point for the collector. Operation above the design pressure drop may

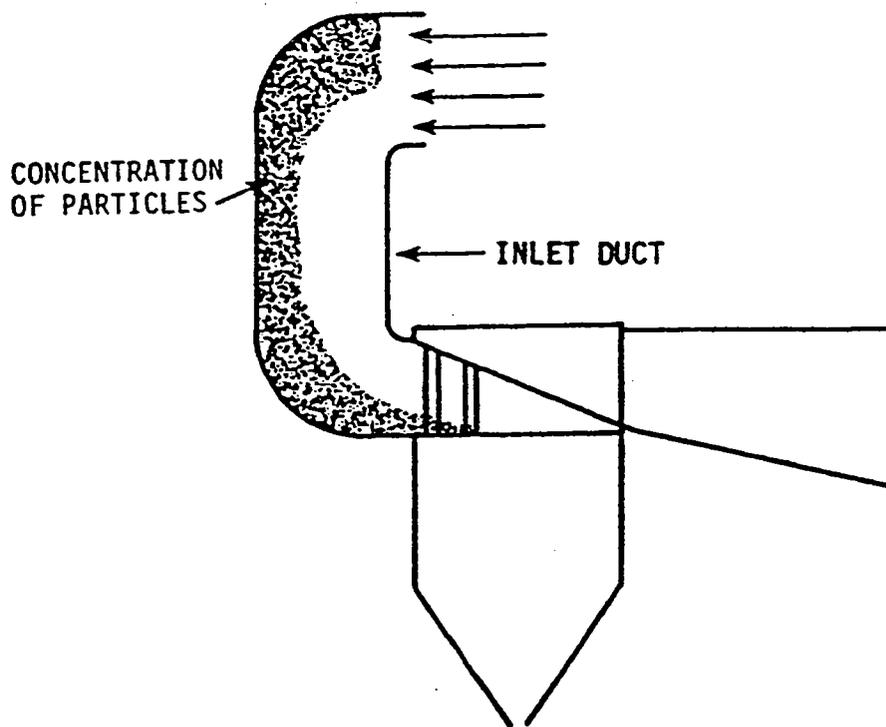


Figure 3-20. Inlet duct of multicyclone, indicating particle stratification.<sup>6</sup>

increase turbulence and decrease collector efficiency. Conditions that could cause high gas volumes include operation at high excess air and ambient air leakage in the duct preceding the collector. High excess air does not generally occur in utility boiler operations, but it is common in industrial boiler applications.

To yield maximum efficiency, the collector must operate at the design gas volume. The design volume is generally at the maximum process rating and gas temperature. When the process is operated at reduced capacity, it usually generates less than the required flue-gas volume and the collection efficiency decreases. The reduction in efficiency can be significant when the process is operated at 20 to 50 percent below the design gas volume.

The actual operating conditions should be reviewed and a corresponding adjustment in gas volume (e.g., reducing excess air, repairing duct leakage) should be made to permit the collector to operate within the design limits. This review may result in the expansion of the number of tubes in the collector or the removal of tubes (tube sheet opening repaired) to obtain optimum operating conditions.

#### *Inlet Turning Vane Wear--*

The inlet turning vane or ramp is designed to impart a tangential motion to the inlet gas stream of the collector. This tangential motion transforms into a vortex in the collection tube. Impaction of particles on the turning vane surface causes abrasion and metal wear over the life of the collection tube. Severe damage results in disturbance of the vortex and increased gas turbulence and limits collection efficiency.

Three materials are typically used to form the inlet turning vane: mild steel, gray iron, and white iron. The relative life of each material in an abrasive environment is a function of the Brinell hardness of the material. Nominal Brinell hardness of gray iron is about 180 and white iron, about 400. The relative life of white iron compared with that of gray iron is about 200 percent.

Severe abrasive damage generally lowers the effective pressure drop across the collector. The change in pressure drop occurs over months or years and is generally not noticeable. If this change is not referenced to a baseline pressure drop, it may not be

discernible. As the wear becomes more acute, inlet vane structural failure can occur that allows complete bypass of particles through the inlet turning vane. Because the abrasive damage does not occur uniformly over the tube matrix, bypass may occur through a few tubes without any significant change in operating parameters.

Periodic internal inspection of the collector is required to determine vane condition and to remove eroded components. Tube sheet location failure records should be maintained to determine if repeat failures are occurring at the same locations. Repeated failures could be indicative of particle stratification and/or gas maldistribution.

#### *Inlet Ramp Pluggage--*

Material buildup on the turning vane or ramp may occur as a result of particle fallout, or it may develop as a scale. The scale may develop in boiler applications as sulfuric acid condenses on the cool metal surfaces at low boiler-load conditions. Fly ash combines with the acid and forms a hard scale when the boiler load and flue gas temperature increase. The deposits can generally be found on the ramp, tube sheet, ductwork, and clean-gas outlet tubes.

The initial effect of inlet ramp fouling on collection efficiency is similar to turning vane wear in that the vortex is weak or it fails to form. An improperly developed vortex results in turbulence and short-circuiting of the gas volume to the gas outlet tube without particle separation. Also, because about 90 percent of the tube pressure drop is generated by creation of the vortex, a low resistance path occurs through a partially plugged inlet. This can result in flow disturbance across the tube sheet and increased cross-hopper flow.

Complete pluggage of the inlet ramp results in loss of the collection tube and increased flow to the remaining tubes, which causes a marginal increase in static pressure drop across the collector. In a typical 200-tube collector, complete pluggage of 25 percent of the tubes would only increase the pressure drop from 3.5 to 4.0 in. H<sub>2</sub>O at the design gas volume.

As with inlet vane wear, the changes in static pressure drop may not be identifiable before complete failure. Frequent interval inspections are necessary to determine the

magnitude and extent of tube plugging. Correction may include periodic washing of the collector, mechanical cleaning, or changes in process operation (e.g., operating levels, material inputs, etc.).

#### *Collection Tube Wear--*

Contact of abrasive particles with the walls of the collection tube results in erosion and eventual failure of the collector tube. Normal wear occurs at the bottom of the cast-iron tube. As the metal thins, holes may appear along the bottom of the tube, or the dust outlet may become elliptical or egg-shaped. These conditions result in a poorly formed gas vortex and an increase in surface roughness and turbulence. Erosion of the dust outlet opening increases particle reentrainment and decreases cyclone collection efficiency. When abrasive particulate matter is being collected, annual inspection of the collection tubes is recommended.

#### *Collection Tube Scale--*

For mechanical collectors controlling combustion gases, scaling in the collection tube as a result of acid dew point condensation increases surface roughness and particle reentrainment in the outlet gas vortex. Whether scaling is periodically scoured off by the particulate in the vortex or develops into complete pluggage depends on operating temperatures, and concentrations of gaseous pollutants in the flue gas stream.

#### *Gas Outlet Tube Pluggage--*

Scaling of the collector may also occur in the gas outlet tube. Because the cross-sectional area of the outlet tube is less than that of the collection tube, a thick scale may close the tube completely. Also, the removal of larger abrasive particles in the collection tube limits the self-cleaning scouring effect in the outlet gas stream. Because the outlet gas stream may receive infiltrated ambient air that leaks into the ash hopper, the gas may be at a substantially lower temperature than the inlet flue gas. This reduced temperature may cause localized sulfuric acid condensation at low process loads. Increased static pressure drop across individual tubes results in downward flow from the dirty-gas plenum

into the hopper, and as a result of cross hopper ventilation, gas flows upward into the tubes with low static resistance.

#### *Dust Outlet Tube Pluggage--*

Severe scaling of the cyclone collection tube may result in complete closure of the dust outlet opening at the bottom of the tube. When the outlet is plugged, particles may begin to build up in the tube. The turning vanes can become so restricted that there is no flow through the tube. As with inlet turning vane pluggage, the loss of the collection tube reduces the size of the collector and increases the gas volume through the remaining tubes. If complete closure of the gas passage does not occur, the opening becomes a bypass through the tube sheet (flow entering through the inlet vanes and exiting through the gas outlet tube) and particles are discharged with the gas.

#### *Air Inleakage--*

Air inleakage into the flue gas stream or into the collector as a result of the system being under negative pressure can result in abnormal collector operation. Air inleakage can also limit operation, depending on the point of inleakage. Inleakages can be classified into three types: 1) inleakage into inlet plenum and entrance ducts, 2) inleakage in the outlet plenum, and 3) inleakage into the collector hopper. Inleakage into the hopper appears to have the most detrimental effect on collector performance.

Total air inleakage into exhaust streams with less than 21 percent oxygen (e.g., combustion sources) may be determined by simultaneous measurement of flue gas oxygen and the temperature of the flue gas before and after the collector. Sampling locations should be selected to provide representative gas-stream conditions with minimum gas-stream stratification. Multipoint samples (traverses) should be used to ensure the collection of a representative sample. An increase in oxygen content with a simultaneous decrease in gas-stream temperature is indicative of ambient air infiltration. Because of radiation and convective heat loss through duct and collector walls, a decrease in gas-stream temperature may be noted even when there is no inleakage (increase in flue gas oxygen content). For example, if 30,000 scfm of air inleakage

occurs in a gas stream containing 100,000 scfm at 6 percent oxygen, the final gas stream of 130,000 scfm will contain 9.46 percent oxygen.

Points of inleakage can also be noted during internal inspection by identifying gas jets or clean metal areas and in dust deposits on duct and collector walls.

#### *Inleakage into Inlet Plenum--*

When air entering the inlet plenum is colder than flue gases containing acid gases, it can severely lower the flue gas temperature below the acid dew point. This depression in dew point may be confined to wall areas, or it may be more general, depending on the location of the opening and amount of mixing in the gas stream. In most cases, the infiltrated air stratifies along the wall and causes condensation and/or corrosion damage. Large amounts of air combined with operation of the process at high excess air levels can result in gas volumes that exceed those of the collector design. It can also lead to lower collection efficiency.

#### *Inleakage Into Outlet Plenum--*

The effects of leakage in the outlet gas plenum are similar to those associated with inlet plenum leakage. The increased gas volume, however, does not have an effect on collector performance. Inleakage at this location increases the gas volume that must be handled by the fan, which increases the horsepower requirements of the fan.

#### *Air Inleakage into Particulate Hopper--*

In some applications, the fan is located downstream of the multicyclone. This location places the collector and ductwork under negative atmospheric pressure. In a well-operated unit, the dirty-gas stream may be operated at a negative pressure of 5 to 15 in. H<sub>2</sub>O while the clean side is operating at a negative pressure of 9 to 19 in. H<sub>2</sub>O (4-inch pressure drop).

At this negative pressure, any opening in the flue gas stream obviously results in significant air inleakage into the system. The hopper is generally operating at a negative pressure that is very close to the collector outlet pressure, as most of the collector pressure drop is developed across the turning vanes.

Inleakage may occur in the hopper area. Such inleakage creates a gasflow from the hopper through the dust outlet of the collector tubes and into the gas outlet tubes. Depending on the condition of the hopper seals, this flow may account for 10 to 20 percent of the collector gas volume. The upward flow of gas through the narrow dust discharge opening at the bottom of the collection tube increases the reentrainment of fine particles at the dust outlet and reduces collector efficiency. As shown in Table 3-3, the following are the major points of hopper inleakage: gaskets between shell flanges, poorly constructed field welds, joint between hopper and shell, gasket between ash hopper and ash valve, ash valve, manhole door gaskets, doorframe gasket, and inspection port.

**TABLE 3-3. CHECKLIST OF MAJOR POINTS OF HOPPER INLEAKAGE**

Hopper Inleakage
◦ Gaskets between shell flanges
◦ Field welds
◦ Joint between hopper and shell
◦ Gasket between ash hopper and ash valve
◦ Ash valve
◦ Manhole door gaskets
◦ Doorframe gasket
◦ Inspection port

Major inleakage may be determined audibly as the inleaking gas passes through the openings. Noise in the process area can mask these sounds, however, and many small leaks may not be detectable. Hopper leaks may be identified more effectively by plugging the gas outlet tubes of the collector and pressurizing the inlet plenum and hopper through the use of the forced-draft fan. Leaks may be visually located by use of a white smoke bomb placed in the hopper. Insulation may prevent identification of weld

breaks in the hopper wall, or it may diffuse the smoke over a wider surface before it is emitted into the air.

#### *Flue Gas Inleakage Into Particulate Hopper--*

The dirty-gas tube sheet, which separates the inlet gas plenum from the particulate hopper, is the point where the cyclone tubes are attached. Normal flow is through the cyclone inlet turning vanes, which creates the vortex. The gas then flows out through the gas outlet tube. Because most of the multicyclone pressure drop is generated at the turning vane and the hopper operates near the outlet plenum pressure, a substantial pressure differential is present across the tube sheet. Any openings between the inlet plenum and hopper form an orifice that allows high-velocity gas to penetrate. The gas, which contains substantial amounts of uncollected particulate matter, bypasses the cyclone tubes and enters the hopper area.

Bypass and hopper inleakage have similar effects on multicyclone efficiency. The flow of gas in the hopper creates cross-hopper ventilation and upward gasflow into the dust outlet tubes. Upward velocity prevents the discharge of fine particles from the tube and reentrains particles from the particulate collection hopper.

The most common areas of dirty-gas tube sheet penetration are around the gaskets or O-rings sealing the cyclone tube to the tube sheet or around tube-sheet welds and/or section joints. Figure 3-21 shows the location of the sealing gasket in a typical tube attachment. Openings may also occur where the tube sheet is attached to the collector wall.

The dirty-gas tube sheet can become distorted because of thermal stress and vibration (as during startup and shutdown) and prevent the gaskets from providing positive seals. The number and severity of such bypasses may increase when collector operating practices are changed. For example, a change from base-load operation to peaking or cyclic operation may create severe bypass problems.

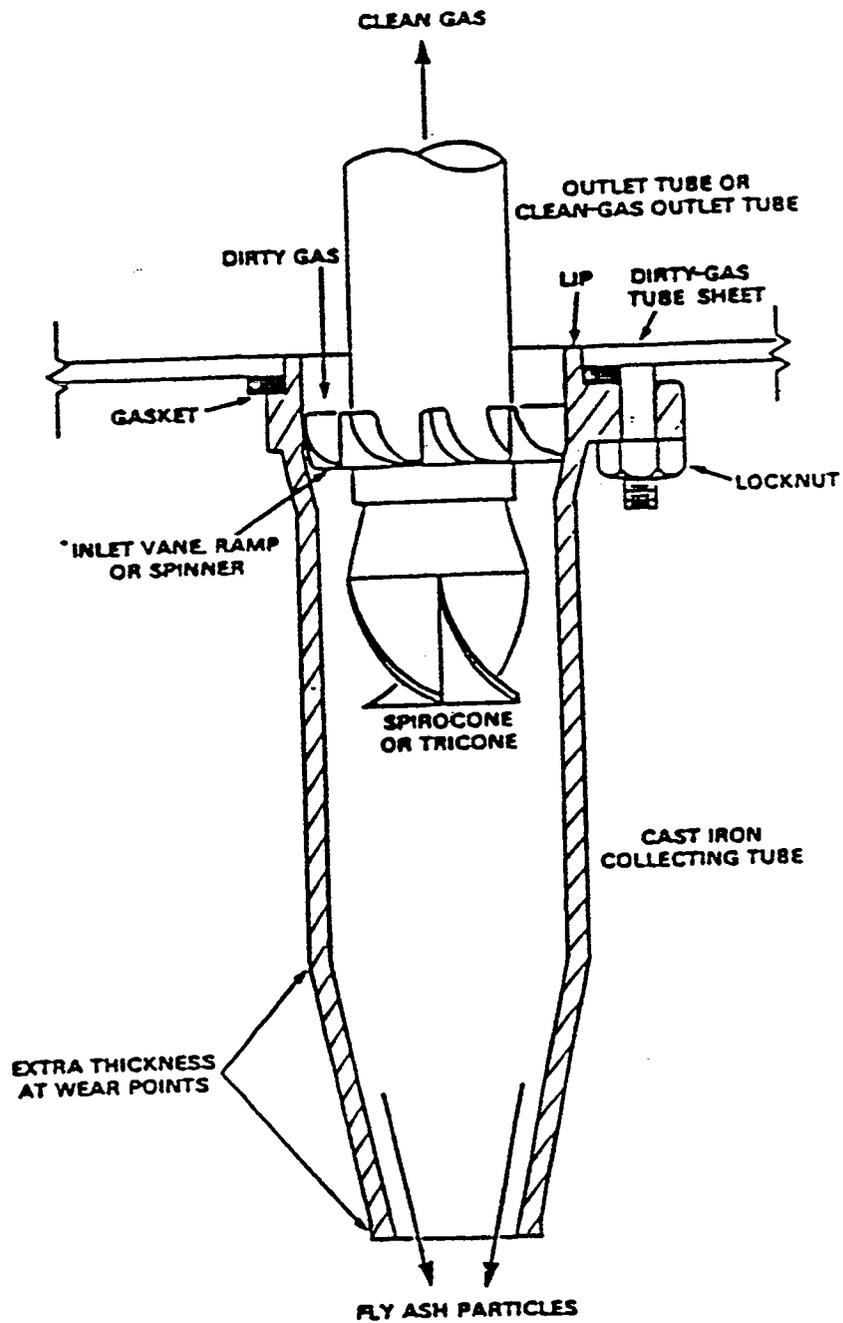


Figure 3-21. Cross section of collection tube showing gasket seal.<sup>6</sup>

On-line measurements may be unable to determine this form of bypass. Visual identification is possible, however, during an internal inspection or through smoke testing.

#### *Collector Bypass--*

Penetration of flue gas from the inlet plenum to the clean-gas plenum is defined as collector bypass. Any opening in the clean-gas tube sheet or clean-gas tube forms an orifice through which particles may pass.

Major areas of bypass are the gasket seal between the gas outlet tube and the tube sheet, the weld or press joint between the gas outlet tube and the tube sheet, and the weld or joints between the tube-sheet sections or wall. Figures 3-22 through 3-24 show several examples of these penetration points.

Penetration may also occur through holes on the leading edge of the gas outlet tube in the dirty-gas plenum (Figure 3-25). The tubes are exposed to the dirty gas. Abrasion damage occurs as the gas is directed to the collection-tube turning vanes. In most cases the pressure drop across the penetration point is equivalent to the collector pressure drop (3 to 4 in. H<sub>2</sub>O). As a result, substantial gas bypass occurs through the orifice.

Because most bypass occurs internally, it is difficult to determine the points of inleakage while the collector is on line. A visual inspection of the tube sheet, outlet tubes, gaskets, and welds can identify major penetration points and allow corrections to be made. Many penetration points, however, are hidden and can only be identified under a static pressure differential. For these leaks to be found, the collector must be sealed and pressurized, and the penetration must be observed visually by use of a white aerosol smoke.

#### *Hopper Crossflow--*

Because of space limitations, multicyclone collectors are designed with multiple rows of collection tubes in the direction of gasflow. For maximum efficiency, the design must ensure that all collection tubes receive an equal volume of flue gas. As gas is passed through the initial leading row of tubes, the total gas volume is reduced and the

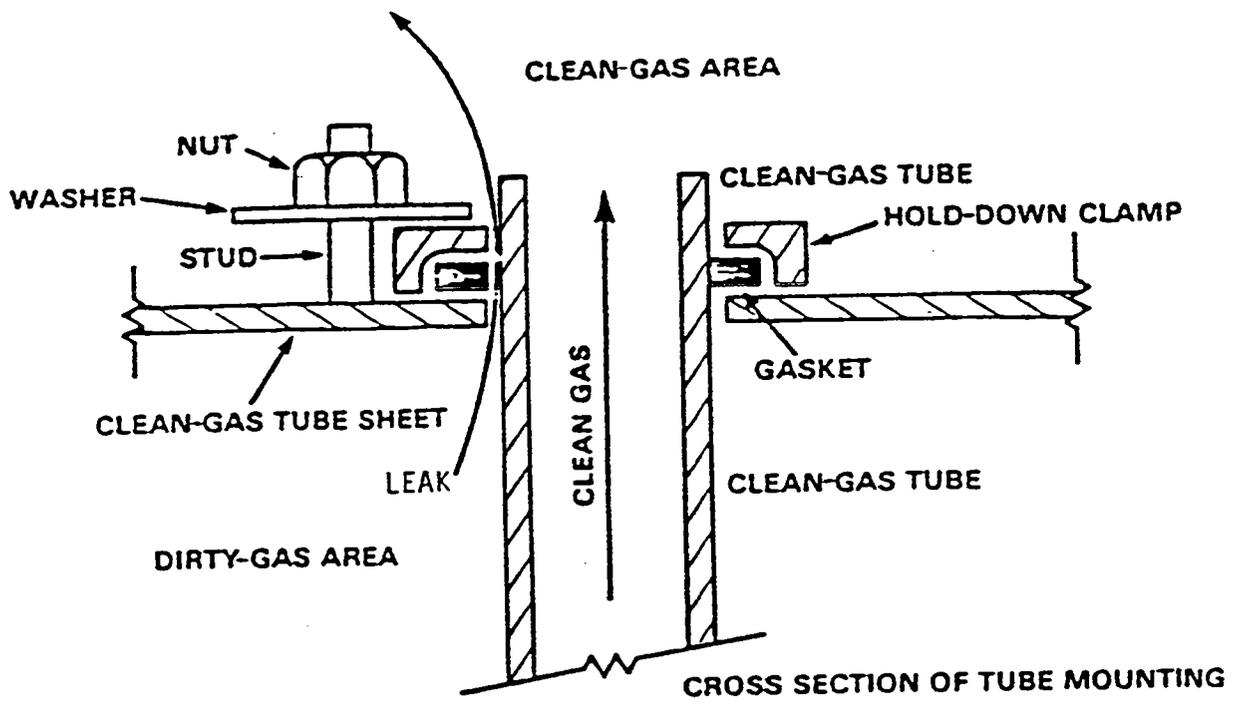


Figure 3-22. Example of gasket leaks.<sup>6</sup>

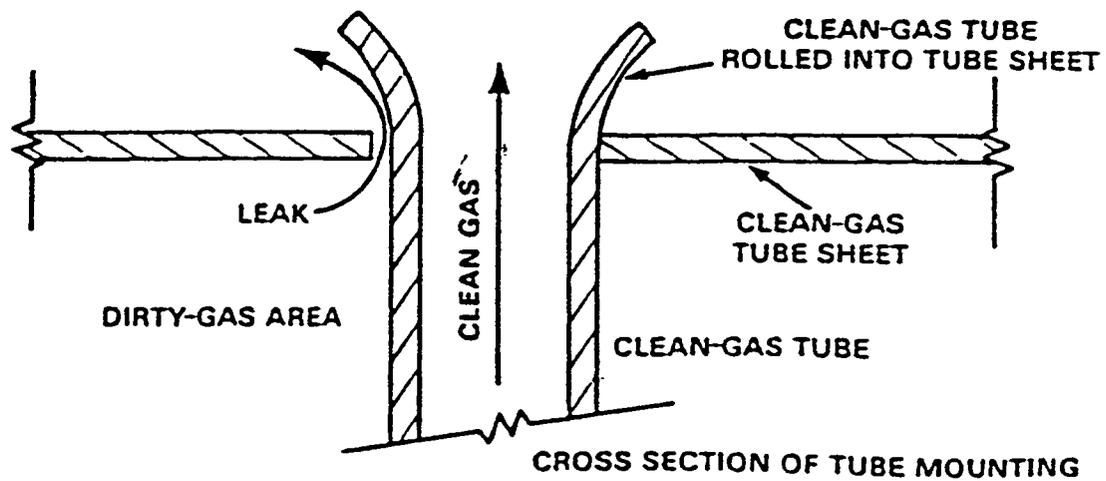
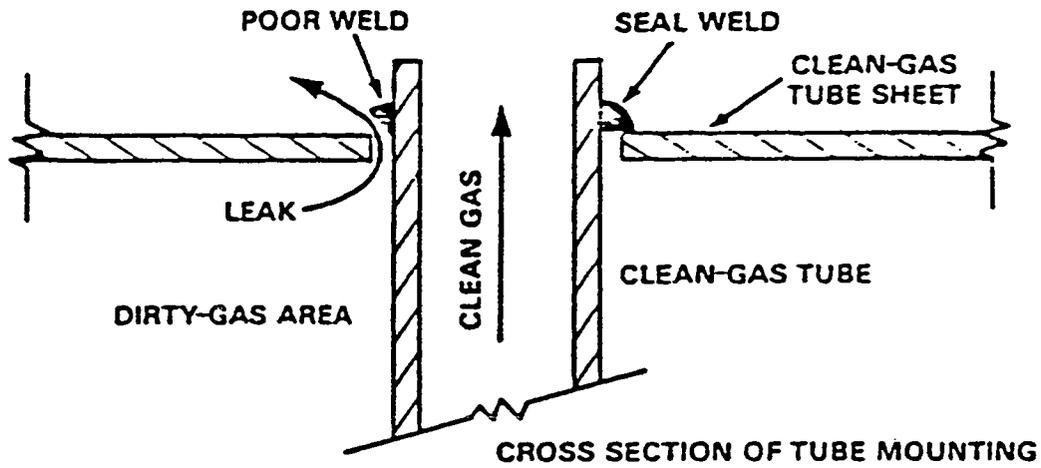


Figure 3-23. Example of clean-gas outlet tube and clean-gas tube sheet leaks.<sup>6</sup>

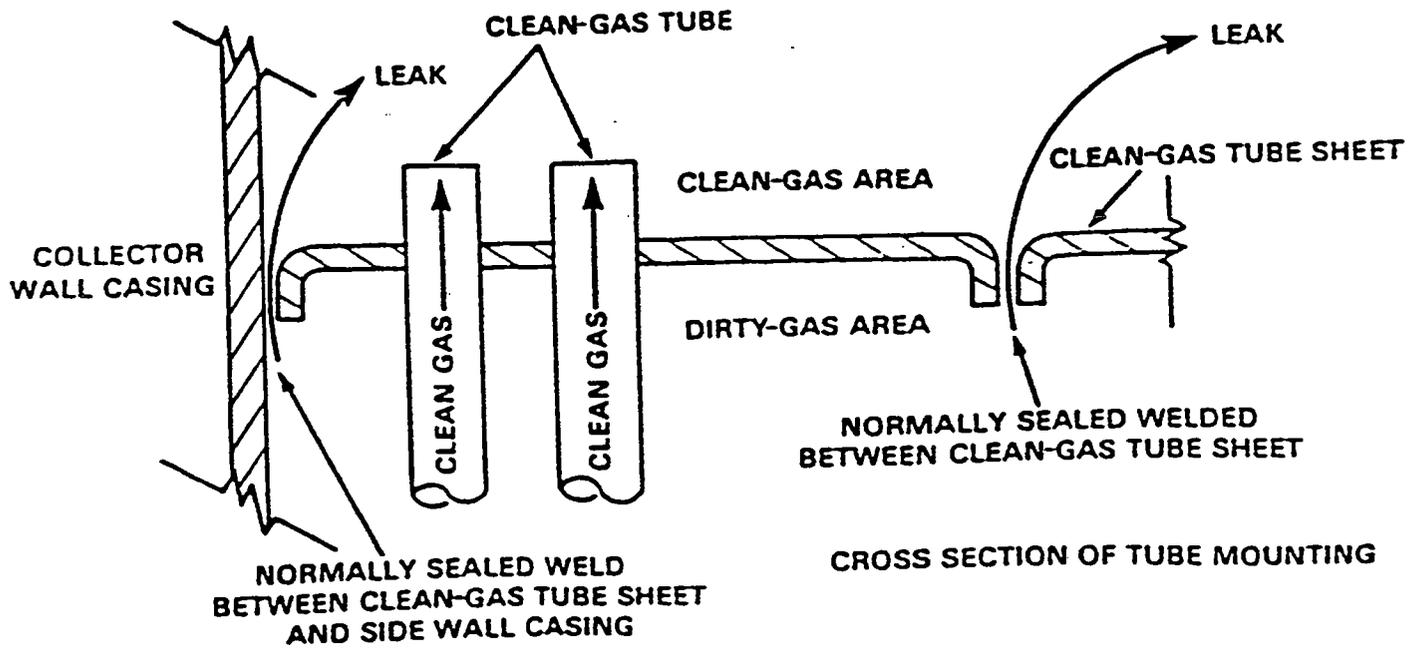


Figure 3-24. Example of leaks between tube sheet sections<sup>6</sup>

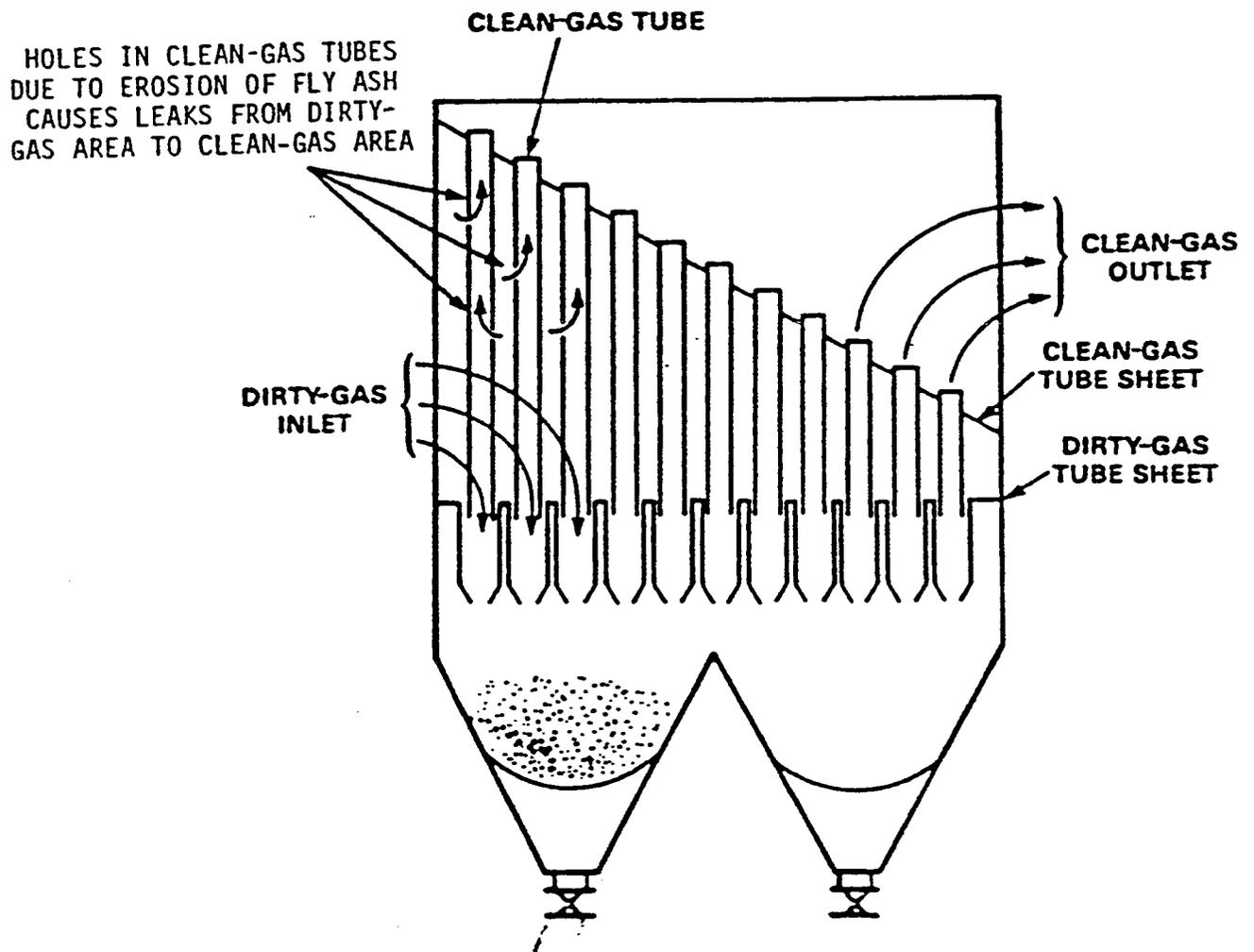


Figure 3-25. Collector bypass through holes in gas outlet tubes.<sup>6</sup>

gas velocity in the plenum is reduced. In many designs, the clean-gas tube sheet is inclined to maintain uniform velocity.

In theory, this should maintain uniform flow to each row of tubes. In practice, however, the gas incurs greater total pressure loss when it passes through the rows of clean-gas tubes between the first and last row. As a result, less gas flows into the inlets of the rear rows of tubes. Because there is less flow to these tubes and because the gas outlet tubes are shorter, pressure drop decreases substantially across these tubes. This reduction in pressure drop offers a point of minimum gas resistance that allows gas to flow down through the dust outlet of the leading tubes and through the hopper. The gas then enters the dust discharge of the rear tubes (Figure 3-26). The gasflow exiting the front-tube dust discharge theoretically increases the efficiency (similar to hopper evacuation), but this is negated by dust entrainment in the hopper and penetration of dust into the rear clean-gas tubes via the cyclone dust discharge.

The effects of cross-hopper ventilation may be increased if other abnormal operating conditions occur, such as hopper inleakage, plugged turning vanes, plugged gas outlet tubes, plugged cyclone dust discharge, or dirty-gas tube-sheet bypass.

The potential for cross-hopper flow increases with the number of cyclone rows in the direction of gasflow because of increased pressure differential between tube rows. For prevention of this flow, many facilities use collectors with multiple hoppers having positive seals between hoppers (i.e., baffles) or a single hopper with a baffle (Figure 3-27). The baffle in a single hopper must extend into the apex of the hopper, and the ash level is used to maintain a seal between sections.

### **3.5 Operator Training**

Training in the proper procedures for inspecting, maintaining, operating, and troubleshooting mechanical particle-collection devices is a key parameter for productive facility management. Management must establish a training frequency for APC equipment inspection, maintenance, and operation that allows new employees to become

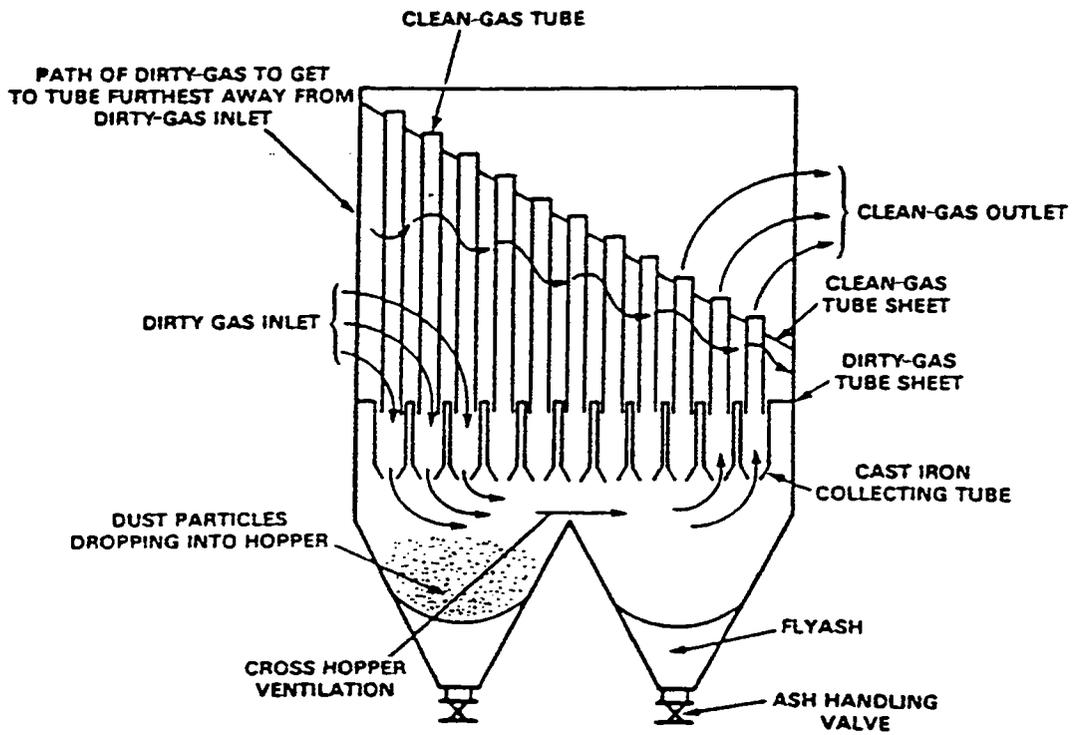
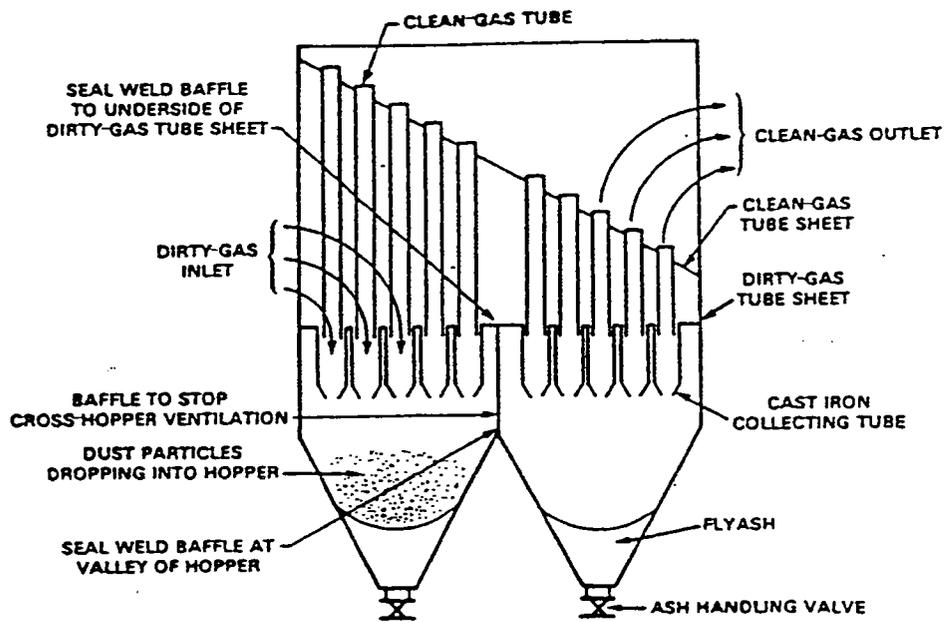
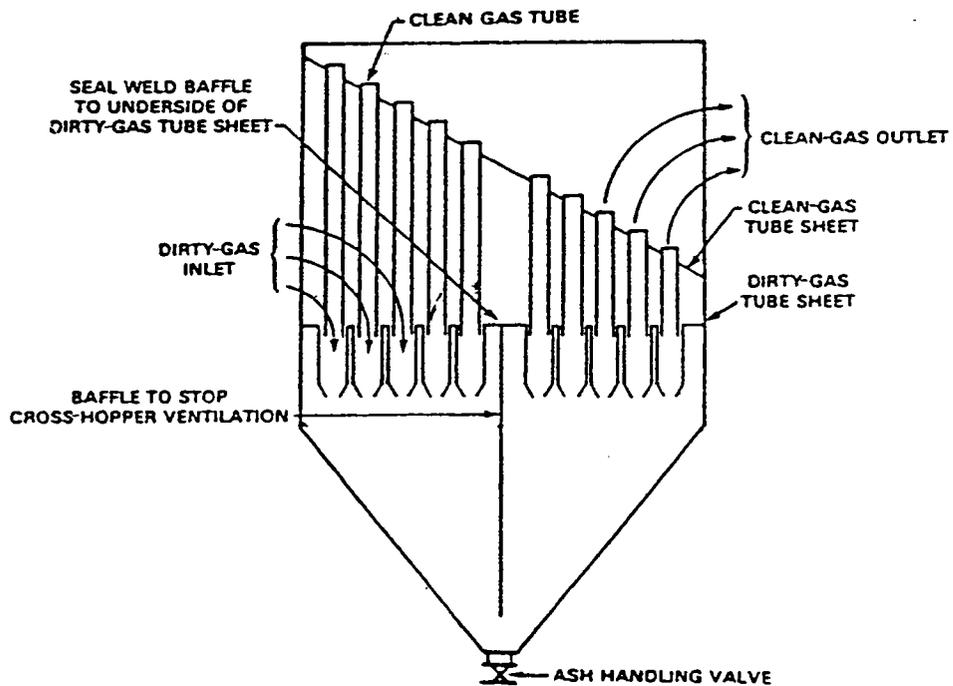


Figure 3-26. Poor distribution and hopper crossflow.<sup>6</sup>



MULTIPLE HOPPERS WITH BAFFLE



BAFFLE IN SINGLE HOPPER

Figure 3-27. Methods to reduce hopper crossflow.<sup>6</sup>

accustomed to the proper operating procedures and seasoned employees to stay current with these procedures.

Training in proper startup, shutdown, inspection, maintenance, and operation should be provided by the equipment manufacturer for newly installed units. For existing units, process engineers should be knowledgeable in the workings of each unit. After startup training, regular training courses should be held by in-house personnel or through the use of outside expertise. A set of users manuals discussing the procedures should be kept available for quick reference. Each training session should include specific written instructions and practical experience on safety, inspection procedures, system monitoring equipment and procedures, routine maintenance procedures, and recordkeeping.

Training should also include opacity verification in accordance to U.S. EPA Reference Method 9. This method requires semiannual recertification in method procedures. This time schedule would also provide a good benchmark for equipment training as well.

### REFERENCES FOR SECTION 3

1. Ward, K., and C.F. Warner. Air Pollution, Its Origin and Control. 2nd Edition. Harper and Row, New York. 1981.
2. Stern, A.C., P.D. Bush, and K.J. Kaplan. Cyclone Dust Collectors. American Petroleum Institute, New York. 1955.
3. Cheremisinoff, P.N., and R.A. Young. Pollution Engineering Practice Handbook, Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan. 1975.
4. U.S. Environmental Protection Agency. APTI Course 413, Control of Particulate Emissions. EPA-450/2-80-066. October 1981.
5. American Air Filter. Roto-Clone Installation, Operation, and Maintenance Instructions. Undated.
6. PEI Associates, Inc. Multicyclone Inspection Procedures Manual. Prepared for the USEPA under Contract No. 68-01-6310. February 1984.