SECTION 10.0

CONDENSERS

This section provides readers with guidance and procedures for the proper operation and maintenance of condensers used as air pollution control devices. This method of control is generally used in conjunction with other air pollution controls. Also, as an air pollution control technique, it is generally limited to gas streams with components that have a boiling point greater than 100°F (long-chain hydrocarbons).

10.1 General Description

Condensers are devices designed to separate one or more components of a vapor mixture by reducing the gaseous vapor to its liquid form. If sufficient heat is removed and pressure is increased all gases will become a liquid. The change from gas phase to liquid phase is accomplished by 1) increasing pressure and holding temperature constant, 2) reducing temperature and holding pressure constant, or 3) increasing pressure and reducing temperatures concurrently. Condensation occurs when the partial pressure of the gas equals its vapor pressure.

High-pressure, low-temperature, ultra-high-efficiency systems are costly to build and operate. The most common approach to air pollution control is to build a system that operates at the same pressure as the emission source and removes heat. Condensation techniques work best on gas streams that have contaminants with a low vapor pressure at moderately high temperatures. These techniques can be used on contaminants with high vapor pressure; however, economics generally discourage this application. Two different mechanical processes are in common use as air pollution control systems. The most common of the two is the surface condenser; the other is the direct-contact condenser. Figure 10-1 is a simplified diagram of a typical refrigerated surface condenser system. Figure 10-2 is a simplified diagram of a direct-contact condenser.

Surface condensers use common heat exchange concepts in which the refrigerant is separated from the vapors by a containment device. Some of the applicable types of condensers include shell-and-tube, double-pipe, spiral-plate, flat-plate, air-cooled, water-cooled, and extended-surface. Condensing can be accomplished either in the shell or in the tubes. In typical air pollution control scenarios the emission stream will contain large volumes of gases (air) that are not condensable within the operating range of the system. Hence, capture of the condensate is usually accomplished within the shell. Condensers may be either vertical or horizontal in layout.

Direct-contact condensers cool the vapor mixture by spraying cool liquids directly into the gas stream. Contact condensers are simpler, less expensive, and have fewer parts. They are, however, much larger and typically create a large volume of dilute liquid wastes. These systems also scrub particulate matter from the gas stream, and this dual capability allows designers to use them as a primary system for removal of particulate matter and as a preconditioner in front of fine particulate matter removal systems (electrostatic precipitators, fabric filters, etc.).

10.1.1 Design Overview

The design and operation of a condenser are greatly affected by the number and chemical and physical properties of the contaminants, the moisture and particulate content of the flare gas, gasflow rates, condensation temperatures, and required removal efficiency. The simplest form of condenser requires that the designer determine the condensation temperature, select a coolant, and size the condenser. In the most complex form, chemical engineering principles for gas dehumidification are required.

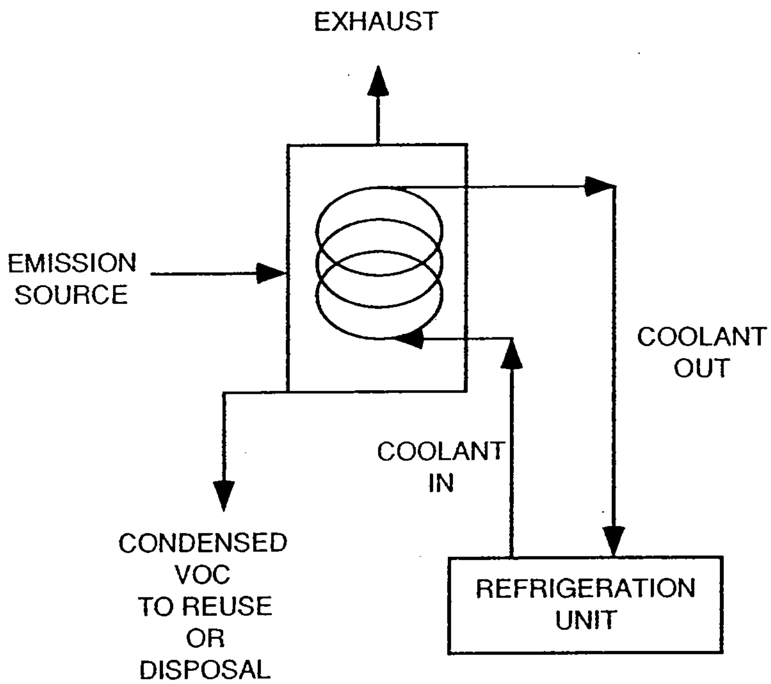

Figure 10-1. Typical configuration of a refrigerated surface contact VOC condenser system.

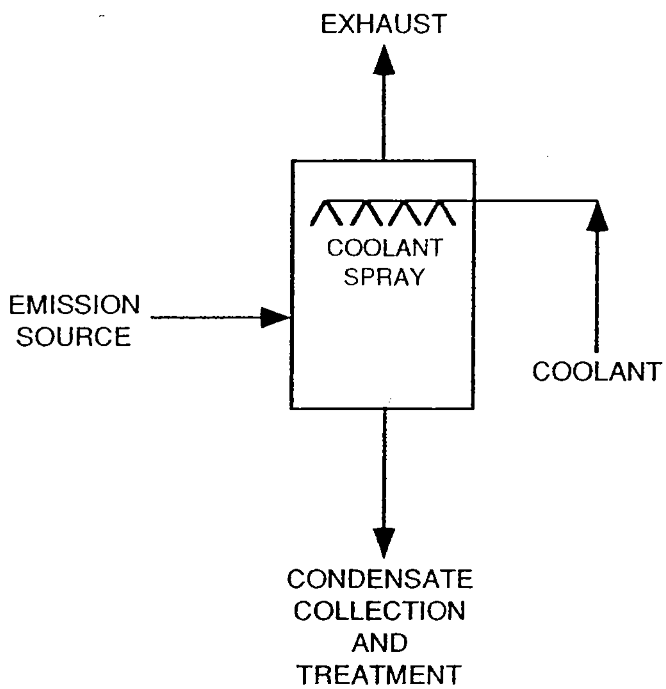

Figure 10-2. Typical configuration of a direct-contact condenser system.

Condensation Temperature--

Multicomponent gas mixtures are cooled by convection with the heat-transfer surface giving up its sensible heat until the gas becomes saturated with one or more of its condensable components. The temperature at which saturatization is achieved is known as the dew point. The dew point can be predicted from the temperature-vapor pressure curve for the component and its mole fraction in the vapor. The equation for this prediction is:

$$Y_i P = (P_i)_g \tag{1}$$

where Y_i = The mole fraction of component "i" in the vapor

P = The absolute gas pressure

$(P_i)_g$ = The partial pressure component "i" in the vapor.

Once condensation starts, the gas temperatures will only drop when latent heat and sensible heat have been removed in sufficient quantities to permit the gas to remain saturated with component "i". Because component "i" must diffuse heat to the transfer surface, the process is both heat- and mass-transfer-controlled. In systems with multiple condensable fractions, each fraction will condense as the gas becomes saturated with the fraction fulfilling the equivalent partial pressure relationship.

To determine the temperature that must be achieved for a specified emission level of component "i," one uses the following equations:

$$P = P_1 + P_2 + P_3 + P_{i+1} \ldots \tag{2}$$

$$V_i = Y_i \tag{3}$$

$$Y_i P = P_i \qquad (4)$$

$$P_i = \frac{n_i RT}{V} \qquad (5)$$

$$\frac{P_i}{P} = \frac{n_i(RT/V)}{n(RT/V)} = \frac{n_i}{n} = x_i \qquad (6)$$

where

	n_i	= Number of moles of the "i" fraction
	n	= Number of moles of the gas in the volume (V)
	R	= Ideal gas constant (0.082 l-atm k^{-1} mol^{-1})
	T	= Absolute temperature (°K)
	x_i	= Mole fraction of component "i"
	V_i	= The allowable volumetric fraction of component "i" in the emission
	Y_i	= The allowable mole fraction of "i" in the emission
	P	= The absolute total pressure of the gas
	P_i	= The allowable vapor pressure of component "i" in the emission

The required gas temperature is determined when the fraction "i" vapor pressure is equal to P_i on its vapor-pressure temperature curve. Figure 10-3 is a generalized example of a vapor-pressure volume temperature curve for a substance that contracts upon freezing (e.g., carbon dioxide). As shown on the figure the solid, liquid, and vapor phases appear as surfaces. One must recognize that two phases are present during any phase change and that in the transition from gas phase to liquid phase the change in volume is usually great.

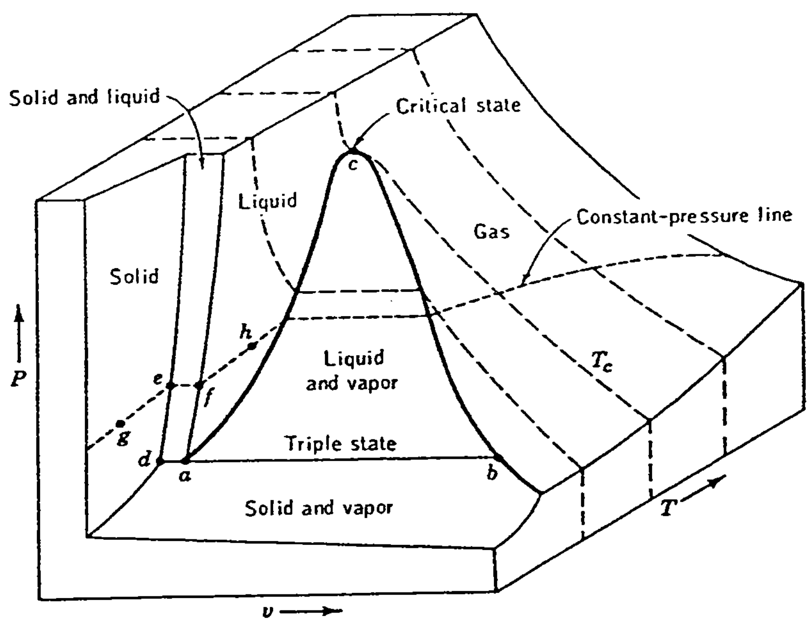

Figure 10-3. A pressure vs. volume vs. temperature surface for a substance that contracts on freezing.

As discussed, condenser removal efficiency depends on the concentration and nature of the emission stream. For example, compounds with high boiling points (i.e., low volatility) condense more readily than those with low boiling points. Table 10-1 lists common hydrocarbons and their boiling points. The temperature necessary to achieve a given removal efficiency or outlet concentration depends on the outlet vapor pressure of the "i" constituent at the vapor-liquid equilibrium.

TABLE 10-1. COMMON HYDROCARBONS AND THEIR BOILING POINTS

Name	Formula	Boiling point, °F
Alkanes (C_nH_{2n+2})		
Methane	CH_4	-258
Propane	C_3H_8	-44
Pentane	C_5H_{10}	31
Hexane	C_6H_{14}	155
Octane	C_8H_{18}	258
Alkenes (C_nH_{2n})		
Ethylene	C_2H_4	-152
Propylene	C_3H_6	-53
Butene	C_4H_8	21
Pentene	C_5H_{10}	86
Aromatics		
Benzene	C_6H_6	176
Toluene	C_7H_8	231
Ethylbenzene	C_8H_{10}	277
Naphathalene	$C_{10}H_8$	424

When the partial pressure is known, condensation temperature can be identified by consulting the vapor pressure-temperature chart for the gas. Vapor pressure-temperature charts have been compiled for many common organic constituents. For specific charts, the reader is referred to Perry's Chemical Engineers Handbook or Lange's Handbook of Chemistry, both published by McGraw-Hill.

Selecting Coolant--

Coolant selection is based on the condensation temperature. Ideally, the refrigerant will have 1) convenient evaporation and condensation pressures, 2) high critical and low freezing temperatures, 3) high latent heat of evaporation and high vapor-specific heat, 4) low viscosity and high film heat conductivity, and 5) chemical inertness. It will also be nonflammable, detectable by simple tests, and low in cost. Table 10-2 identifies several common refrigerants and their freezing-point temperatures. It is customary to use a refrigerant that has a freezing point that is not less than 10 degrees lower than what is theoretically calculated.

Condenser Sizing--

Condenser sizing must account for both heat and mass transfer. The calculation requires individual heat-transfer coefficients of the gas components, the coolants, and the specific heat exchanger. The heat exchange design process is extremely complex. It must account for temperature differentials, mass rate of flow, materials of construction, surface area, scale and corrosion buildup, emissity of surfaces, gas density, thermal conductivity, specific heat density, viscosity, velocity, coefficient of thermal expansion, and pressures. A conservative number for the overall heat transfer coefficient is 20 Btu/h per ft^2 per °F. This number represents an inefficient design, and its use will establish a surface area that is larger than a high-efficiency system would need. The equations and procedures required to estimate the surface area needed to condense a specified amount of vapor(s) can be found in most heat transfer textbooks and are not repeated in this document.

10.1.2 Key Operating Parameters

The basic operating parameters include the exhaust gas concentration of the most volatile fraction of concern, the exhaust gas temperature, and the inlet and outlet

TABLE 10-2. FREEZING POINT FOR IDENTIFIED REFRIGERANT

Refrigerant	Temperature, °F
Water	32
6% NaCl	25.5
8% NaCl	22.9
18% NaCl	6.7
6% CaCl	28
8% CaCl	24
18% CaCl	4.7
24% CaCl	-14.1
30% CaCl	-46
Ammonia	-107.8
Carbon dioxide	-110
Ethyl alcohol	-174
10% Glycerin	30.2
40% Glycerin	1.0
60% Glycerin	-31
Freon 11	-60
Freon 12	-90
Freon 13	-30

temperatures of the coolant. In addition, system pressures are key system operating parameters that can indicate proper flue gas flow and coolant flows to identify system plugging problems. Also, if a contact system is used, the nozzle operating pressure and the flow rates of the coolant are needed to assure good spray distribution patterns and to avoid short-circuiting.

10.2 Monitoring Condenser Operation

Routine monitoring and recording of the key operating parameters identified in Subsection 10.1.2 and preventative maintenance activities based on this monitoring will improve operations, extend service life, and minimize malfunctions. Historically, condensers have not included automatic recording thermocouples, pressure gauges, or flow-meters.

10.2.1 Monitoring Devices

Monitoring devices are generally limited to three basic functions, pressure, temperatures, and safety.

Pressure--

The measurements of certain pressures and pressure differentials are needed for safe and efficient operations because a drop in pressure corresponds to an increase in velocity and a decrease in heat transfer and condensate capture rates. The pressure gauge is used to measure pressure drop across nozzles, tubes, etc.

Pressure-measuring instruments take various forms, depending on the magnitude of the pressure and the accuracy desired. Manometers that may contain a wide variety of fluids are commonly used. Differential diaphragm gauges that use magnetic linkage are also available for low-pressure systems. Pressure-measuring devices should be located in positions that avoid errors caused by impacts, eddies, fluid hammers, etc. For differential pressure readings, using a differential pressure device is preferable to taking the difference between the readings of two instruments. Several problems can cause faulty pressure readings. Plugging and fouling of the tubing is the most common problem. Also, differential pressure transmitters are sensitive devices that can be damaged by excessive shock and vibration.

Static pressures are measured by use of manometers and/or pressure gauges. The most common problems with these devices are as follows:

- Fouling and plugging.
- Trapped air which gives false readings.
- Tap elevation is above or below the base of the gauge.
- Located too close to curves, obstructions, valves, etc.

Temperature--

Heat exchange rates, heat balances, partial pressures, and recovery efficiencies are all controlled by temperature. A means of recording, indicating, and controlling temperature are needed in the design, fabrication, operation, and testing of condensers. Temperature monitors should be installed in the following locations:

- Gas stream inlet (wet and dry bulb)
- Gas stream outlet (wet and dry bulb)
- Condensate pool
- Coolant inlet
- Coolant outlet

In the past, temperatures generally have not been continuously recorded. Continuous temperature data, however, can be used as an indicator of proper system heat transfer and gas flow rate.

Monitoring of temperature is essential to good performance. Hence, potential thermocouple problems must be identified because the temperature reading is the primary measurement used for control purposes. Measuring temperature requires care to be taken 1) to be certain the instrument indicates the correct temperature, and 2) to interpret the readings correctly.

The amount of variation from true temperature of the gas depends on the temperature and velocity of the gas, the ambient temperature, the size of the sensing element, and the physical construction of the sensing element. The temperature of a fluid (liquid or gas) flowing under pressure in the pipes is usually measured by inserting a glass thermometer, an electrical resistance thermometer, or a thermocouple into a well that projects into the fluid. The well must have the mechanical strength and rigidity to withstand the hydrostatic pressure. It must also be resistive to corrosion and erosion.

It is often desirable to know the temperature in different portions of the condensers to determine if safe conditions exist, or if conditions are uniform or unbalanced among tubes and also to determine differential measurements between inlet and outlets. These measurements are usually taken by thermocouples peened to the structure. These devices are subject to error because of thermal conduction in the wires and the specific conductance of the gas. Erosion and corrosion are major concerns.

Safety--

Conditions that could result in explosive mixtures of fuel and/or unsafe emissions of toxic gases are avoided by the installation of monitors capable of detecting combustible and toxic vapors in the exhaust gas. Continuous monitoring could be conducted to determine if an explosive atmosphere exists or if unacceptably high toxic air pollutants are being omitted. This monitoring could be done with direct reading instruments such as:

- Combustible gas indicator
- Flame ionization detector with gas chromatography
- Infrared spectrophotometer

Direct-reading instruments were developed as early warning devices for use in industrial settings where leaks or an accident could release a high concentration of a known chemical into the ambient air. All direct-reading instruments have inherent limitations:

- Accuracy is a function of calibration.
- Sensitivity varies by temperature, number of components, moisture content, particle content, and interferants.
- Response time varies by compound.
- Optical components get dusty and misaligned.
- Plugging and fouling of probes are common.

Because condensers are seldom the final control device prior to atmospheric discharge, safety monitoring is not commonly practiced.

10.3 Inspections and Maintenance of Condensers

10.3.1 Inspection and Maintenance Items

Within the constraints of the hardware, operation and performance enhancements are designed to control air emissions, to extend service life, to minimize malfunctions, to control operating costs, and to ensure safety. Daily inspections should be performed while the unit is operating. This inspection should include visual checks for the following:

Vibrations--

Vibrations can produce severe mechanical damage; therefore, operation should not be continued when vibration is evident. Vibration may indicate excessive flow rates, bypassing, vapor locks, erosion, pluggage, impaction, broken supports, worn impellers, open valves, etc.

Leakage--

Leakage may occur in several areas, depending on the type of condenser. The inspector should be looking for leaks in the coolant system, primary containment shell, and vapor ducts leading into and out of the condenser. If a contact system is used, the inspector also should look for evidence of windblown mist and capture-system overflow.

Pressure Drop--

Excessive pressure drop indicates fouling and plugging. Fouling and plugging can be so severe that thermal stress and mechanical damage may occur. Plugging and fouling increases noncondensable gas volumes, which in turn overload the vent control system or discharge unacceptable quantities of fraction "i" emissions.

Excessive Exhaust Temperature--

The systems performance is largely determined by changes in outlet gas temperatures. Increases in the exhaust temperature indicate that removal efficiencies are decreasing and emissions are increasing.

Lower Condensate Rate--

Changes in the rate of condensate collection may indicate a process upset condition. Careful review is needed to ensure that the proper rate units are monitored (e.g., weight per unit time, weight per unit manufactured, gallons per compressor kWh).

Exterior Corrosion--

Condensers often differ in materials of construction. They also may handle a wide variety of substances, including corrosive liquids and gases. Thus, special precautions may be necessary if any individual parts create a galvanic action that could dissolve tubing, fins, connectors, collectors, straps, grounding devices, etc.

Safe Working Temperature and Pressures--

The maximum allowable working temperature and pressure are indicated on the condenser's name plate. Condensers are designed to operate at specified temperatures. Variation in temperature and pressure and the rate of change may cause differential expansion, warping, increased brittleness, decreased emission transmissibility, leakage, gasket failure, increased flow rates, increased emissions, etc.

Proper Coolant Flow Rate and Temperatures--

Coolant flow rates determine if the system is operating efficiently. When coupled with low front end temperatures, excessive flow rates may cause freezing conditions, which in turn may cause compressor burnout, unwanted condensate formation, and/or excessive pressure.

10.3.2 Inspection Frequency

Typically, condenser operators make periodic inspections to ensure proper operation and to identify potential problems. Clearly, the manufacturer's recommended preventive maintenance schedule should be followed. Inspection activities are somewhat limited because of the simplicity of the process.

> Daily inspections should be conducted for vibration, leaks, broken gauges and monitors, proper calibration and span for monitors, and safe working pressures and temperatures.
>
> Weekly inspections should be conducted on all moving parts (e.g., pumps, fans, motors, and valves).
>
> Monthly inspections of ductwork, dampers, and structural components should be conducted for corrosion, erosion, settling, and misalignments.

In addition, an interior inspection should be conducted at least annually or whenever the equipment is shut down. Figures 10-4 through 10-6 are example inspection forms for a condenser unit. Figure 10-7 is an example maintenance report form.

10.3.3 Spare Parts

Generally, condensers are low maintenance systems. A facility should maintain a ready inventory of expendable items and tools for the system, as recommended by the manufacturer. Experience indicates that broken pressure gauges, thermometers, and transducers are the most frequently needed replacement parts.

DAILY CONDENSER INSPECTION FORM		
Facility Name:	Date of Inspection:	
Facility Location:	Time of Inspection:	
Process:	Name of Inspector (Print):	
Condenser ID:	Signature of Inspector:	
INSPECTION ITEM	COMMENTS/CORRECTIVE ACTIONS	
1) Leaks - Ducts - Pipes - Seals - Bonnets		
2) Monitor conditions (check strip charts if applicable) - Temperature - Pressure - Flue gas velocity (if applicable) - LEL monitor (if applicable) - VOC monitor (if applicable)		
3) Drains for condensate - Free flowing - Normal appearance		
4) Exterior appearance - Rust - Hangers and anchors in place - Other		
	Inlet	Outlet
Temperatures, °F Coolant Gas Pressures, in. W.G. Coolant Gas	 _____ _____ _____ _____	 _____ _____ _____ _____
LEL or VOC Monitor _______%	Gas Flow Rate ______ ft/min	

Figure 10-4. Example daily condenser inspection form.

WEEKLY CONDENSER INSPECTION FORM	
Facility Name:	Date of Inspection:
Facility Location:	Time of Inspection:
Process:	Name of Inspector (Print):
Condenser ID:	Signature of Inspector:
INSPECTION ITEM	COMMENTS/CORRECTIVE ACTIONS
1) Pumps and valves - Leaks - Packing - Visual appearance	
2) Fans - Abnormal noise or vibration - Housing condition	
3) Compressors - Leaks - Seals - Abnormal noise or vibration	
4) Condenser - Abnormal noise or vibration - Leaks - Temperatures and pressures in normal range	
5) Drains and drain cocks - Fouling - Free flowing	

Figure 10-5. Example weekly condenser inspection form.

MONTHLY AND ANNUAL CONDENSER INSPECTION FORM	
Facility Name:	Date of Inspection:
Facility Location:	Time of Inspection:
Process:	Name of Inspector (Print):
Condenser ID:	Signature of Inspector:
INSPECTION ITEM	COMMENTS/CORRECTIVE ACTIONS
1) Component conditions (rust, cracks, leaks) - Foundation - Fire suppression system - Galvanic protection system - Hangers and grounding straps	
2) Thermocouples, pressure gauges - Calibrate if applicable - Check strip charts and daily logs/forms for trends - Check for proper operation	
3) Other - Abnormal noise or vibration from condensers, fans, pumps, and compressors - Leaks	
Annually or During Shutdown	
1) Inspect internals for fouling, plugging, or corrosion. Clear or replace if necessary. - Tubes - Shell	
2) Pressure test condenser (coolant side) - Results	

Figure 10-6. Example monthly and annual condenser 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 10-7. Example maintenance report form.

10.4 Problems and Malfunctions for Condensers

Most of the problems that occur with condensers have a direct impact on emission rates. Condensers, however, are relatively immune to physical problems caused by overloading.

Excessive flow rates, however, may increase erosion and cause entrainment of liquids and particulate matter in the gas stream. Evidence or erosion first shows up in the monitoring devices that protrude into the liquid or gas stream. Exceeding design temperatures or thermal shock episodes cause differential expansion and contraction that may cause leakage and/or structural damage. Tightening of bolts and connectors should be confirmed if the temperature records indicate that temperature ranges have been exceeded.

Fouling and plugging results from the deposition of foreign material on the exterior and/or interior of tubes, pipes, valves, and monitors. Evidence of fouling is indicated when pressures increase or decrease, performance decreases, hot/cold spots occur, and short-circuiting of flow pattern are noted. Deposits are generally cleaned only during a major shutdown. Typically, shutdowns are scheduled when operating costs exceed the costs of downtime for repair or when emission standards are violated. Corrective measures include chemical flushes and mechanical scraping.

10.5 Operator Training

As with any piece of equipment, management's support and the willingness to provide its employees with proper training are essential to the proper maintenance of a condenser. Efficient operation of a condenser, promoted by adequate inspection and maintenance procedures, is important. Management and employees must be cognizant of proper procedures for preventing equipment malfunctions or failures.

Training should be provided by the manufacturer when a new system is commissioned. The manufacturer's startup services 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 the proper assembly and operation of the system components. Instructions will also typically include how to check and reset system instrumentation and controls, how to check for the proper operation of the dust-discharging system, and how to perform simple troubleshooting.

Following startup 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 installation will include manufacturer-recommended maintenance procedures. Annual in-house training should at least 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, equipment and procedures for system monitoring, routine maintenance procedures, and recordkeeping.

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