SECTION 7.0

THERMAL FUME AND CATALYTIC INCINERATORS

This section provides operators with guidance and procedures to properly operate and maintain thermal and catalytic incinerators. This section is also designed to assist regulatory personnel responsible for inspections at facilities using thermal incineration systems. This information is intended to improve recognition and understanding of failure mechanisms and improve reliability of control systems.

7.1 Thermal Fume Incinerators

7.1.1 General Description

Thermal incineration systems are generally used to destroy combustible gases or vapors that are present in gas streams. These vapors can be present in low concentrations (lean) or high concentrations (rich) in an air/oxygen or inert gas atmosphere. The design and operation of the devices are critically dependent on the pollutant concentration, type of pollutant, presence of other gases, level of oxygen, and stability of the processes served by the system.

In general, fume incinerators can achieve destruction efficiencies of $\geq$ 99 percent. Special units have been designed to achieve removal efficiencies of 99.99%. The destruction efficiency for an individual pollutant species is controlled by peak combustion temperature and time of exposure (i.e., residence time). Failure to achieve the designed removals are related to the degree of mixing (i.e., turbulence), carrier gas composition, and flame stability. Overall, the destruction efficiency follows the 3 T's of classical combustion theory: time, temperature, and turbulence.

A fume incinerator consists of an oxidation chamber, auxiliary fuel source and burner, preheat system, heat recovery system, combustion control system, and safety devices.

Typically the oxidation chamber consists of a steel shell lined with a refractory material which is either cast, blanket, or brick. Refractory is typically 4 to 8 inches thick and designed to retain heat and protect the shell from thermal stress and corrosive gases. Typical combustion temperatures are ≥ 2000°F and shell temperatures are 180° to 400°F. Refractory materials are specified based on flue gas composition [i.e., moisture, acid gases (SO_2, HCl, HF, etc.)] and peak temperature.

Burners are used to increase carrier gas temperature to the desired combustion temperature to achieve the designed destruction efficiency. The burner also serves as a pilot for positive ignition and as a preheater for system start-up. Burner fuels may be natural gas, propane, diesel fuel, No. 2 oil, or byproduct gases/fuels. Depending on the composition of the carrier gas and fumes to be oxidized, the oxygen used for combustion may be provided by the carrier gas, ambient air, or oxygen enrichment. For flame stability, a premix burner design is typically used with fuel and air premixed in the burner. When elevated levels of water vapor are present in the carrier gas, ambient combustion air is required to provide flame stability.

Figure 7-1 is a generalized cross section of a combustion chamber. This representation employs a burner at one end of the chamber. Alternative designs also use tangentially fired burners and tangential fume inlets to increase residence time and improve mixing.

In order to reduce fuel requirements, heat exchangers are used to recover heat from the stack exhaust and/or preheat process exhaust streams. A typical arrangement is provided in Figure 7-2. Limits on preheat temperature may be imposed to prevent preignition of fumes in the heat exchanger.

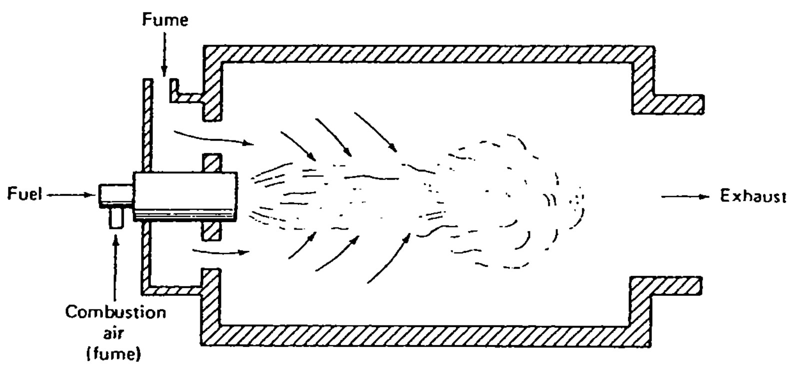

Figure 7-1. Combustion chamber.

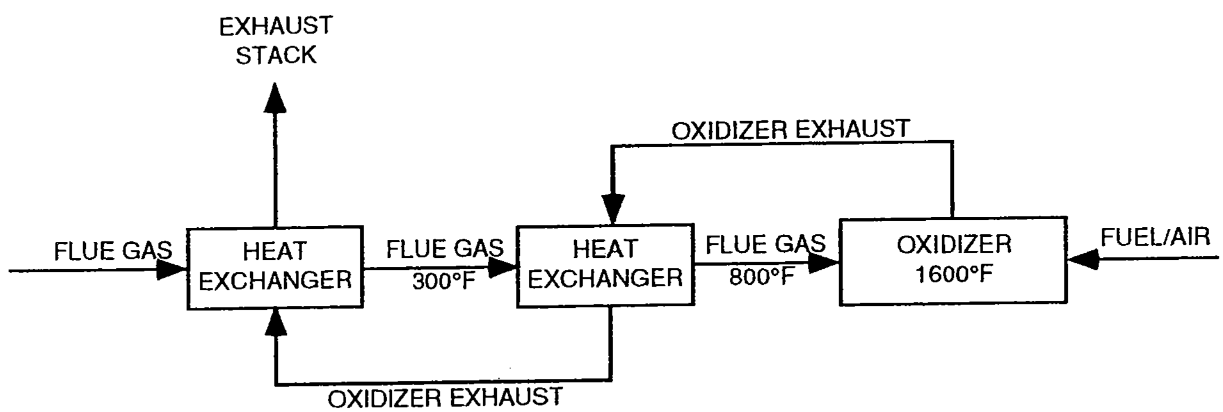

Figure 7-2. Arrangement of heat exchangers.

7.1.2 Key Operating Parameters

The key operating parameters of any thermal oxidation (incineration) system are primarily the temperature to which the pollutant is exposed and the time of exposure. Figure 7-3 shows the typical relationship between destruction efficiency and time/temperature. As can be seen, as residence time is increased the temperature required for a given pollutant destruction efficiency is decreased. The exact relationship is specific for each hydrocarbon species and combination of species.

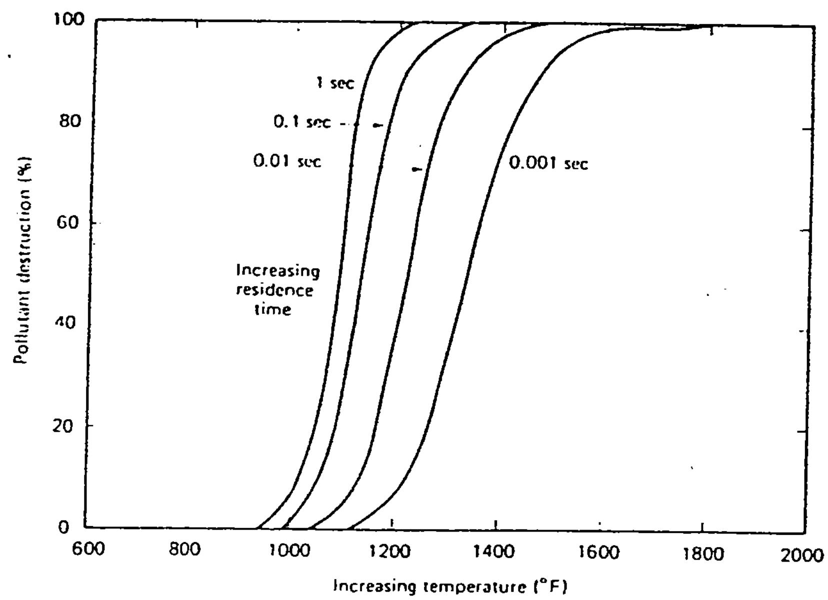

Figure 7-3. Coupled effects of temperature and time on rate of pollutant oxidation.[2]

Residence time of the incinerator is typically specified by the regulatory agency or by the vendor to ensure adequate destruction of the pollutant. The value is defined by the physical dimensions of the chamber, combustion temperature, primary gas volume, and the fuel rate necessary to reach combustion temperature.

Another important operating parameter is the gas volume rate through the combustion chamber. This parameter is expressed in actual cubic feet per minute (acfm) and is the sum of the primary gas volume and the products of combustion produced by oxidation of fuel and pollutants. In systems where oxygen in the primary gas is not sufficient for combustion and air is supplied from the ambient environment, the total gas volume may be estimated by adding the products of combustion of fuels and pollutants to carrier gas volume. In addition, most incinerators are operated with excess oxygen. This additional oxygen and the associated nitrogen (from air) must be considered in the total gas volume calculations. When oxygen is supplied from the primary gas volume, the calculation of total combustion gas volumes requires a detailed combustion calculation. The methodology for these calculations are described in detail in combustion textbooks and are not presented in this document.

The temperature that may be achieved by combustion of a given fuel is dependant on the mass of the flue gas products and primary gas (m), specific heat of the gases (C_p), and the heat released by combustion (Q). For most combustion calculations the specific heat of the flue gas products is 0.26 Btu/lb °F, but if the primary gas stream contains a significant percentage of water vapor, it may be higher (e.g., 0.30 Btu/lb °F). The mass of the combustion gas stream may be estimated using standard stoichiometric combustion constants for the fuels. The weight of the primary gas stream may be estimated by carrier gas composition. If the stream is primarily air, the weight is 0.075 lb/dscf. The weight of moisture in the carrier gas must be included at a weight of 0.046 lb/wscf.

The equation for expected temperature increase is

$$\Delta T = \frac{Q}{mCp}$$

where Q = Heat input Btu/min

m = Mass of final gas stream, lb/min

Cp = Average specific heat for final gas stream, Btu/lb °F

ΔT = Temperature rise, °F.

7.1.3 Monitoring

Monitoring fume incinerator performance can be done by measurement of hydrocarbon and carbon monoxide outlet concentrations or by monitoring operating variables such as incinerator temperature, fuel rate to the incinerator, and fan current. Table 7-1 summarizes the equipment that can be used to monitor these parameters.

Monitoring of Gas Concentrations--

Direct monitoring of the outlet hydrocarbon concentration is costly, technically difficult, and is not necessarily required if other parameters are monitored (see below). The monitoring of this parameter, however, provides a direct indication that the incinerator is effectively destroying the hydrocarbons fed into the system. The measurement can be accomplished using a total hydrocarbon (THC) analyzer or a gas chromatograph (GC), which identifies individual hydrocarbon (HC) species. In complex gas systems, the destruction of multiple species is not equal at a given temperature. There is also the possibility of creation of species by recombination and/or incomplete combustion.

TABLE 7-1. METHODS OF MONITORING INCINERATOR PERFORMANCE

Method	Instrument	Variable	Usage
Outlet gas concentrations	FID	THC	Primary
	GC	HC species	Primary
	NDIR	CO	Secondary
Operating parameters	Thermocouple	Temperature	Primary
	Ammeter	Fan current	Secondary
	Flow meter	Fuel rate	Secondary

The use of a total hydrocarbon analyzer provides an indication of the relative overall destruction efficiency of the system. When the composition of the process gas stream changes, the response of the analyzer may be affected. For example, when multiple processes are captured for destruction and when process units cycle in and out of the system, both the rate and species may change. This may result in an increase or decrease in the measured outlet concentration. This change may be a true change in HC weight due to thermal destruction efficiency or simply a change in response of the instrument. Interpretation of the monitor output may be difficult and require a baseline and/or range of normal operation conditions to be determined to permit a comparison of measured values.

The use of a GC may be appropriate to target a major species present in the input gas stream that is considered difficult to thermally degrade. This species can be the surrogate for monitoring the overall performance of the system. Because of the number of possible products of incomplete combustion, tracking of all species may not be technically feasible.

For most HC species the last product of incomplete combustion is carbon monoxide (CO). This species is considered difficult to oxidize and is a stable compound. If sufficient oxygen, temperature, and turbulence are provided to complete combustion to CO_2, a low level of CO may be expected (i.e., $\leq$ 30 ppm). CO may be monitored using a nondispersive infrared analyzer which is a good indicator of overall system performance.

Monitoring of Temperatures and Gas Flows--

Monitoring of the temperature and gas flow operating parameters provides an indication to insure that the incinerator achieves the required destruction efficiency. For example, if a stack test determines that a removal efficiency of 99 percent is achieved at 1500°F and at a residence time of 0.75 seconds, monitoring of the combustion temperature and/or residence time may be appropriate. In general, residence time is not a measured variable and must be calculated from other measured variables (i.e., volume of the combustion chamber and gas flow rate). For most systems, continuous monitoring of the combustion temperature with a thermocouple is considered adequate to demonstrate performance.

There are several conditions, however, when temperature may be misleading:

1. If primary gas volume exceeds design values, residence time may decrease.

2. If the system becomes self fueling and required oxygen exceeds the oxygen that is available, products of incomplete combustion (HC, CO, etc.) are produced and primary fuel may be reduced to a minimum.

Both of these conditions may be identified by monitoring of operating variables such as primary fan current or fuel rates.

7.1.4 Thermal Incinerator Inspection and Maintenance

A thermal oxidizer system has few moving parts and therefore has low maintenance requirements. As with all mechanical systems, alignment and lubrication of bearings is necessary to prevent failure. Lubrication of mechanical linkages, slides, and other metal moving parts is required.

Filters and strainers for liquid fuels should be changed periodically to ensure even fuel flow. Parallel (duplicate) piping of strainers and filters is required for online service.

Prefilters used to prevent particulate matter entry to the oxidizer must be changed on a regular schedule to prevent draft losses and capacity limitation. Burner tips should be inspected and cleaned to ensure proper fuel mixing and efficient combustion.

Inspection of thermal incinerators requires regular observation of monitoring devices (i.e., thermocouples, gas monitors, recorders, etc.). Most incinerators will have continuously recorded inlet and outlet incinerator temperature and auxiliary fuel input. Fuel pressure and fan current are also generally available using a magnehelic gauge and ammeter, respectively. Where heat recovery is used, inlet and outlet heat exchanges temperatures are monitored using thermocouples. Ideally, outlet carbon monoxide and oxygen will also be continuously monitored. Set points on each monitor are used to notify operator of incinerator malfunction between inspections (e.g., high and low temperature, high CO levels). A review of strip charts should be conducted once per shift to determine if operating conditions are typical of normal conditions and to note any trends. Figure 7-4 is an inspection checklist that can be used during the shift inspection. Figure 7-5 shows an example maintenance report form.

A more detailed physical inspection of the system should be made on a quarterly basis. This should include external and internal system components including refractory, heat exchangers and electrical systems. Figure 7-6 shows an example quarterly inspection form. This form should be modified for each incinerator based on incinerator design, process application, and applicable regulatory requirements.

7.1.5 Common Problems or Malfunctions of Thermal Incinerators

The categories of potential problems may be divided into operational, startup, and long-term maintenance. Each may have an effect on reliability, destruction efficiency, or cost of operation. The following is a brief discussion of problems typically encountered in a fume incineration system.

SHIFT/DAILY INCINERATOR INSPECTION FORM			
Facility Name:	Date of Inspection:		
Facility Location:	Time of Inspection:		
Process:	Name of Inspector (Print):		
Incinerator ID:	Signature of Inspector:		
INSPECTION ITEM	COMMENTS/CORRECTIVE ACTIONS		
1) Temperature alarms during shift: - High CO - Low			
2) Gas monitor alarms? - High CO - Low oxygen			
3) Fan operation - Abnormal sounds?			
4) Strip charts operational? Check paper and ink.			
Flue gas to incinerator	Range ______°F	Reading ______°F	
Combustion temperature	Range ______°F	Reading ______°F	
Flue gas CO monitor	Range ______°F	Reading ______°F	
Flue gas oxygen monitor	Range ______°F	Reading ______°F	
Fan Current	______ amps		
Fuel rate	______scfm		
Heat Exchangers (for heat recovery)	IN	OUT	PRESSURE DROP
#1 Process gas	______°F	______°F	______ in. H_2O
Combustion gas	______°F	______°F	______ in. H_2O
#2 Process gas	______°F	______°F	______ in. H_2O
Combustion gas	______°F	______°F	______ in. H_2O

Figure 7-4. Example shift/daily incinerator 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 7-5. Example maintenance report form.

QUARTERLY INCINERATOR INSPECTION FORM	
Facility Name:	Date of Inspection:
Facility Location:	Time of Inspection:
Process:	Name of Inspector (Print):
Incinerator ID:	Signature of Inspector:
INSPECTION ITEM	COMMENTS/CORRECTIVE ACTIONS
Refractory condition? (cracks, spalling, corrosion)	
Burner condition? (warpage, corrosion, fouling)	
Heat exchanger(s) and combustion chamber condition? (fouling, corrosion, leaks)	
Pressure seals condition? (check packing glands)	
Shell condition? (thermal shock, welds condition)	
Check auxiliary fuel piping train and note condition.	
Check interlocks, electrically operated valves, shutoff dampers, gauges, continuous recorders and thermocouples for proper operation. (calibrate where applicable)	

Figure 7-6. Example quarterly incinerator inspection form.

Startup and Shutdown Procedures and Problems--

The most critical period in the operation of a fume incinerator is the period during startup from a cold or hot condition. Insurance companies and the National Fire Protection Association (NFPA) have established guidelines (procedures) to ensure fire/explosion protection during a system startup. These guidelines have been adopted by most manufacturers and have a history of preventing catastrophic failure of the thermal treatment system. It is important to remember that the fume that is being incinerated is a fuel/air mixture capable of releasing heat when ignited. Depending on the mixture, oxygen, temperature, and ignition source, spontaneous and explosive oxidation can occur.

In general, the procedures summarized in Figure 7-7 should be followed for startup, operation, and shutdown of a thermal treatment source. Each step must be completed and verified prior to moving to the next step. Each device should be interlocked electrically, which requires clearance before the next step can occur. Override of a specific item is not recommended without a full understanding of the potential risk, effect, and cause of the failure. For example, if a flame sensor will not allow continued firing of the burner, manual override may be used intermittently to verify failure of the sensors. Bypass of the interlock is not allowed for continuous operation for obvious reasons. The flame sensor is installed expressly for the purpose of detecting a flame out condition in which raw fuel may be injected into a hot combustion chamber without an ignition source. When this occurs, an explosive gas mixture can be created.

Not all systems are fully automatic. Smaller systems may be semiautomatic or manual in the startup sequence. The automatic system requires only the initiation of the firing sequence and a preset program is initiated, which follows the NFPA startup sequence. This program also shuts down the system if a fault is detected. Depending on program sophistication, the system may list faults, go to back up systems, call for operator action, or restart of the system.

1. Prepurge

    a. Power on to control system
    b. Fan motor on
    c. Airflow verified
    d. Fuel valves closed

2. Purge

    a. Airflow to maximum rate
    b. Purge timer starts (length of time set to allow furnace to be purged of any combustible fumes; eight complete air changes considered sufficient)

3. Ignitor sequence

    a. Airflow to light-off rate
    b. Auxiliary fuel pressure verified as sufficient; temperature verified, if required
    c. Ignitor electric spark mechanism starts
    d. Ignitor timer starts
    e. Ignitor fuel valve opens, fuel is ignited in furnace by sparking mechanism
    f. Ignitor flame sensed by flame scanner
    g. Ignitor timer ends time cycle, shuts off sparking mechanism (if no flame sensed by flame scanner, ignitor fuel valve immediately closes, and postpurge cycle starts)

4. Main burner sequence

    a. Main burner fuel-control valve verified in light-off position
    b. Atomizing fluid (air or stream) valve opens (needed only on certain oil-fired units)
    c. Burner timer starts cycle
    d. Main burner fuel shut off valves open--allowing fuel to main burner
    e. Main flame ignites from ignitor flame

Figure 7-7. Startup, operation, and shutdown summary procedures for thermal incinerator. (continued)

f. Burner timer ends time cycle, ignitor fuel valve closes (if main flame not sensed by flame scanner, fuel shutoff valves immediately close, and postpurge cycle starts)

g. Interlocks verifying light-off positions on fan and control valves are now by-passed, allowing fuel and air rates to be adjusted

h. Main burner is now in service subject to the following conditions:

   (1) Fan on
   (2) Airflow proven
   (3) Flame detected
   (4) Fuel pressure adequate
   (5) Furnace temperature not high

5. Normal operation

   a. Fuel and airflow are now adjusted to provide optimum furnace temperature for incinerator; this may be done manually or automatically; on refractory-lined units, warm-up must be done gradually to prevent thermal shock to the refractory
   b. Once the incinerator reaches its operating temperature, fumes can be introduced into the furnace
   c. Proper incinerator operation is maintained by controlling incinerator outlet temperature and fume, auxiliary fuel, and airflow rates

6. Normal shutdown

   Normal shutdown is accomplished by closing the fume flow valves, then the auxiliary fuel valves; the systems then proceed to the postpurge cycle

7. Postpurge

   a. Fan adjusted to maximum flow rate
   b. Postpurge timer starts time cycle
   c. Keeps air flowing until five complete air changes have occurred in the furnace
   d. Postpurge time ends cycle, fan turned off, incinerator is shut down

Figure 7-7. Startup, operation, and shutdown summary procedures for thermal incinerator.

The semiautomatic system is the most common operating protocol. This requires the operator to initiate steps in the procedure after verification of system interlock clearances. These steps are generally verified through indicator lights or alarms.

For a completely manual system, the start sequence is initiated and confirmed by the operator. If the established sequence is not followed, explosion or failure can occur.

Burner Fouling--

Burning of a dirty fuel oil containing high levels of ash, water, or metals can generate a slag or deposit on the burner surfaces that impairs fuel/air mixing. If a dirty fuel is used, frequent inspection and cleaning are recommended. If the carrier gas volume is used for combustion air, precleaning (filters) may be required to prevent burner fouling. This may also be required if the source of ambient air is in a dirty environment. Special care should be taken if the fume is composed of organic vapors that may polymerize on surfaces (i.e., styrene, cellusolve, etc.).

Preignition--

When a heat exchanger is used to preheat the process gases prior to the oxidizer, a danger of preignition is present. For maximum heat recovery and minimum fuel usage, process gases are heated using the exhaust gases from the oxidizer. Typically the tendency is to recover as much heat as possible and reduce the heat lost to the stack. This may allow a preheat of 1000° to 1200°F depending on combustion temperature in the oxidizer. When oxygen is present in the carrier gas and organic vapors are rich, the spontaneous ignition temperature may be exceeded. If this occurs combustion is initiated in the tube and shell heat exchanger, which thermally stresses the tubes. Failure of the tubes allows passage of fumes from the fume side to the flue gas side, effectively bypassing the oxidizer. Most heat exchangers have a leakage rate of one percent or less and thermal stress can increase the leakage rate substantially. Preignition cannot generally be detected by thermal methods, but can be identified as a decrease in carrier gas oxygen content between heat exchanger inlet and oxidizer. For typical protection, preheat of the carrier gases should be limited to 800°F.

Thermal Expansion--

A rapid increase in either flue gas or carrier gas temperature can result in thermal stress of the heat exchangers, which increases leakage and results in fume bypass. Preheat of the system must conform to the manufacturer's recommended heat up schedule to prevent thermal failure of the heat exchanger. Thermal expansion must also be considered in the preheat of the oxidizer if castable or monolithic refractory is used. Rapid heat up and cycling will increase refractory failure.

Inleakage--

Inleakage of ambient air into a rich gas stream can result in dilution of the pollutants. If this dilution places the concentration of the fume in the explosive range, catastrophic failure can occur (i.e., concentration of combustibles greater than lower explosive limit and less than upper explosive limit). Periodic integrity verification of the gas transport system is recommended to reduce inleakage.

When inleakage occurs in a lean system, the ability to capture emissions at the process source is decreased. This limits the capacity of the system because of tramp air.

Heat Exchanger (HEX) Fouling--

Fouling of the preheat system reduces the heat transfer rates from the exhaust gas to the preheated media. This causes a decrease in the preheat temperature and an increase in the stack temperatures. Fouling can occur from failure of the prefilters in the air pollution control equipment used to prepare the carrier gas stream for incineration. Certain pollutants may also present problems when exposed to elevated temperatures. These pollutants polymerize or pyrolize under exposure to heat. Limits must be imposed on preheat or preheat eliminated to minimize fouling.

Refractory Failure--

Refractory failure is typically associated with thermal stress. Rapid or frequent cycling of heat rates results in expansion and contraction which stresses materials. Block and castable refractories are more prone to this failure mechanism. Cracks and shock damage (spalling) should be repaired using castable (plastic) materials.

Corrosion of the refractory may occur if the carrier gases contain chlorine, sulfur or fluorides. Oxidation of these gases can have a detrimental effect on refractory and/or metal components of the system. A shutdown purge is designed to remove corrosive gases before the gases can condense on the surfaces.

Draft Restrictions--

Draft loss (pressure drop) across the incinerator system can occur as a result of fouling of the prefilters, heat exchangers, or ducts. Draft losses are considered in the equipment specification and dictate fan selection for the design. Increases in draft losses, decrease the available gas volume which can be treated. Operation at higher than optimal combustion temperatures can also increase draft losses due to an increase in fuel combustion products.

Temperature of Combustion--

The temperature of combustion of the oxidizer is dictated by the total carrier gas volume, fuel fired, and fume incinerated. Because all of these are variable, a feed back system is necessary to limit fuel rates to achieve the desired combustion temperature. Typically a thermocouple is placed at the outlet of the oxidizer to measure the average combustion temperature. This sensor is connected to a programmable controller that sets fuel flow to maintain the desired combustion temperature. Due to the location of the thermocouple, a high failure rate is expected and dual sensors are recommended. Because a portion of the flue gas heat input is supplied by the pollutants in the gas stream, a minimum fuel flow setting must be maintained to prevent extinguishing of the ignition source and provide positive feedback control.

Slaging/Fouling--

Because of the elevated temperature in the oxidizer, the potential exists for fouling of the chamber with foreign materials. Dust and dirt not removed in prefilter systems or air pollution control equipment may become liquid and adhere to refractory surfaces. These deposits (slags) may increase refractory failure and change combustion characteristics of the chamber.

Flame Safety--

Flame safety is an important aspect of all combustion processes. Failure to detect flame out may result in the continued introduction of fuel or fume into a hot combustion chamber in which ignition has ceased. A rich gas mixture is produced, which then spontaneously combusts with violence. The resulting explosion can destroy the incinerator and adjacent process equipment.

All components of the flame safety system must be inspected frequently and spare parts accessible for replacement. Under no circumstances should the flame safety be bypassed or disabled during normal operation. Disabling interlocks and safeties should only be used as part of troubleshooting or fault detection by trained service personnel.

Self- Fueling System/Run Away Combustion--

The most serious failure mechanism that may occur for a fume incineration system is a self fueling scenario. Self fueling is a term applied to a condition in which the heat release necessary to achieve a set combustion temperature is supplied solely by pollutants in the carrier gas. Under these conditions the auxiliary fuel system is reduced to minimum fire or pilot condition. Without the benefit of auxiliary fuel modulation control, the upper limit of the combustion temperature is removed. If oxygen for combustion is supplied by ambient air with the auxiliary fuel system, the combustion process can proceed in an air starved mode in which increased levels of incomplete combustion, CO, and fume may be exhausted from the oxidizer. As fume concentration continues to increase, heat release rates exceed set points and temperatures exceed design limits.

In a high concentration event, total control of the process is lost and failure of the system occurs. The term run-away is descriptive of the event. Short event increases in the concentration may be noted as spikes on the temperature recorder. Thermal mass of the refractory and heat exchangers tend to prevent these events from being of concern. A gradual increase in fume concentration, which forces the auxiliary fuel rate to minimum is a potential concern. When fuel rates approach the minimum and the control function is in danger of being lost, operator intervention is required.

The only possible mechanism that can be employed to stop a self fueling condition is to reduce the input of fume (fuel) to the oxidizer. This is usually accomplished by diverting the carrier gas stream to the atmosphere or a standby flare. If this scenario is a real possibility, procedures and bypass contingencies should be installed as part of the design.

In general, self fueling occurs only in rich gas streams where an increase in pollutant rates can occur rapidly. These are usually associated with release events from process sources such as reactor vessels or other pressure sources. Lean systems typically have sufficient dilution air to accept a moderate increase in fume concentration.

Table 7-2 summarizes the failure mechanisms, associated symptoms, and possible corrective actions.

7.2 Catalytic Incinerator

7.2.1 General Description

Catalytic incinerators are special types of thermal incinerators in which hydrocarbons are exposed to media, which increase the kinetic rate. This media is defined as a catalyst and is usually in the form of a solid matrix or pellet. The effects of a catalyst are as follows:

TABLE 7-2. SUMMARY OF FAILURE MECHANISMS, SYMPTOMS, AND CORRECTIVE ACTIONS FOR THERMAL FUME INCINERATORS

Failure mechanism	Symptoms	Corrective actions
Burner fouling	High CO Insufficient combustion air Flame instability Flame out	Clean burner tips Prefilter ambient air Filter process stream Cease using process combustion air Improve fuel source
Preignition in heat exchanger	Decrease in carrier gas O_2 Leakage from fume side to flue gas side (bypass) Unexplained increase in outlet HC concentration	Reduce preheat temperature Retube heat exchanger
Thermal expansion (heat exchanger)	Tube failure Inleakage and bypass to flue gas side	Retube Conform to manufacturer's recommended preheat schedule Limit maximum temperatures
Thermal expansion (oxidizer)	Refractory failure Shell failure due to heat stress	Repair refractory Limit maximum temperature and preheat rates Limit thermal cycling
Inleakage (rich system)	Decreased concentration of fume below UEL Potential for explosion	Periodic integrity check of transport system UEL monitors
Inleakage (lean system)	Decreased concentrations of fume below 25 percent of LEL Reduced capture volume at source	Periodic integrity check of transport system LEL monitor
Inleakage (heat exchanger)	Increased stack HC concentration Tube failure	Retube HEX Limit temperature excursions

Failure mechanism	Symptoms	Corrective actions
HEX fouling	Decreased preheat temperature (i.e., ΔT decreased) Increased stack temperature	Prefilter carrier gases Reduce heat exchanger temperature Eliminate preheat heat exchangers Clean heat exchangers
Refractory failure	Cracks Spalling Crumbing	Reduce cycling Limit peak temperature Post shutdown purge to remove corrosive gases
Draft control	Increased pressure drop Decreased capacity Decreased capture capacity	Reduce fouling Reduce combustion temperature Reduce transport air inleakage
Temperature control	Irregular combustion temperature	Feed back temperature control system Dual temperature sensors
Slaging	Deposits in oxidizer Refractory failure Increased draft losses	Prefilter carrier gases Prefilter ambient combustion air
Flame safety	Flame out due to interlock protection Irregular flame	Inspect and replace sensor Relocate sensor's position
Self fueling	Increased temperature with no auxiliary fuel control	Vent to bypass Vent to flare

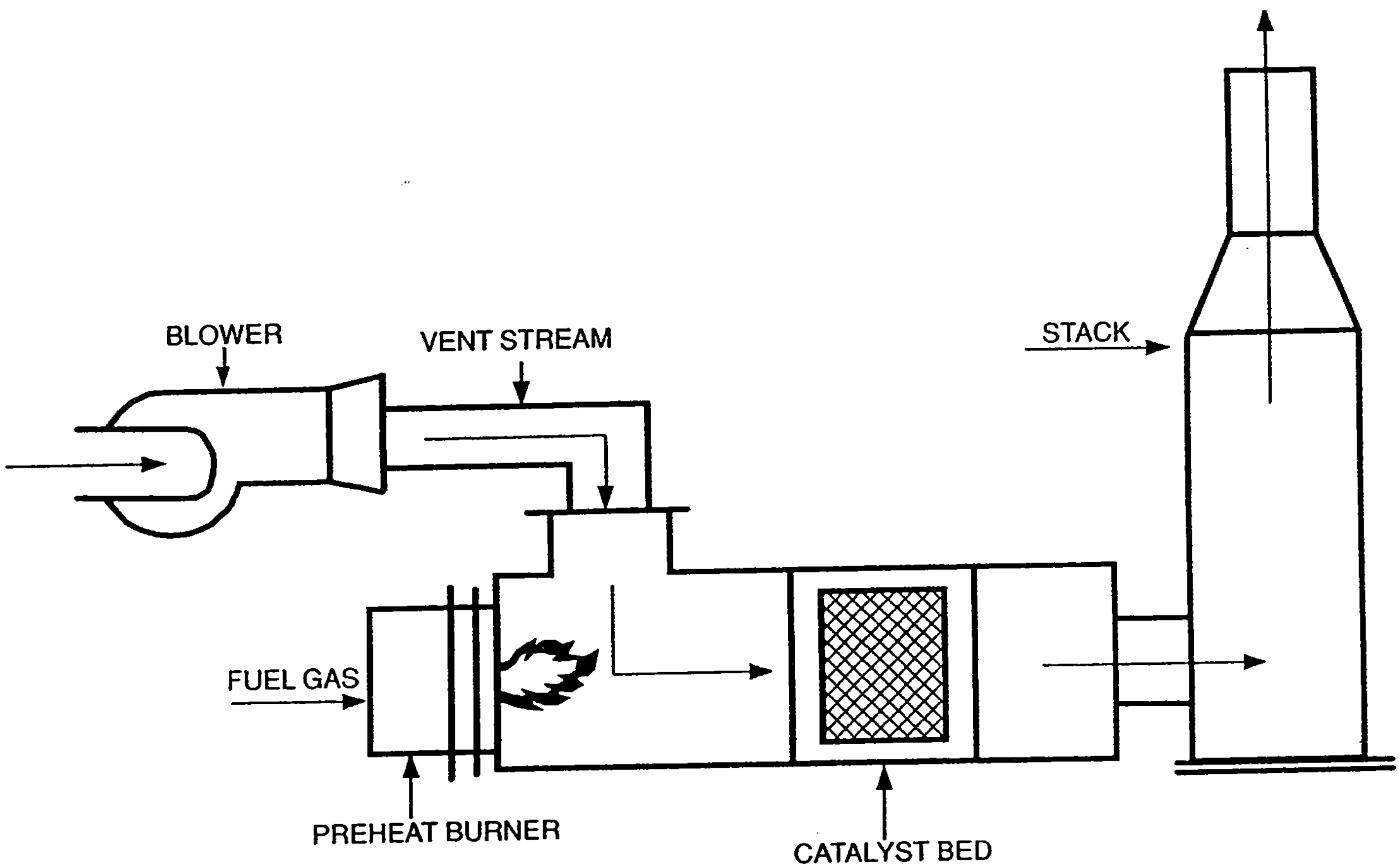

Figure 7-8. Schematic of catalytic incinerator without any heat recovery.

1. It increases the reaction rate (i.e., oxidation)

2. It allows the reaction to occur at lower temperatures.

In general, a catalytic incinerator consists of a preheater, catalyst bed, auxiliary air system and heat recovery section. Figure 7-8 is a schematic of a system where no heat recovery is used and Figure 7-9 is a schematic of a system where heat recovery is used to preheat the carrier gas (fume).

7.2.2 Theory of Operation

Fumes containing hydrocarbons and oxidant (i.e., oxygen in air or enriched oxygen) are preheated to the minimum activation temperature necessary to initiate oxidation in the presence of a catalyst. The fume is then passed through a matrix or bed constructed of a ceramic material. An active catalyst is impregnated on the surface of the material, which forms the active sites for the reaction to occur.

The most active catalyst is a platinum metal, but oxides of vanadium, nickel, cobalt, copper, and chromium may also be used. Several of these are deactivated (poisoned) by metals or halogens, and the selection of catalyst type must be determined by the composition of the gas stream to be incinerated. Typical catalyst poisons include antimony, arsenic, iron oxide, zinc, phosphorous and sulfur.

Catalysts do not alter the position of the equilibrium reaction, but accelerate the reaction, thereby lowering the operating temperature. Because the catalyst forms a site for completion of the reaction, it is not consumed.

Catalysts used for VOC control are typically platinum or palladium. Typical destruction efficiencies are between 90 and 98 percent, but can be designed for up to 99.99 percent. The degree of destruction is controlled by the following parameters:

a. Inlet temperature of the gases entering the bed, °F.

b. Specific volume of the catalyst, ft^3/scfm.

c. Type of catalyst metal and volume used.

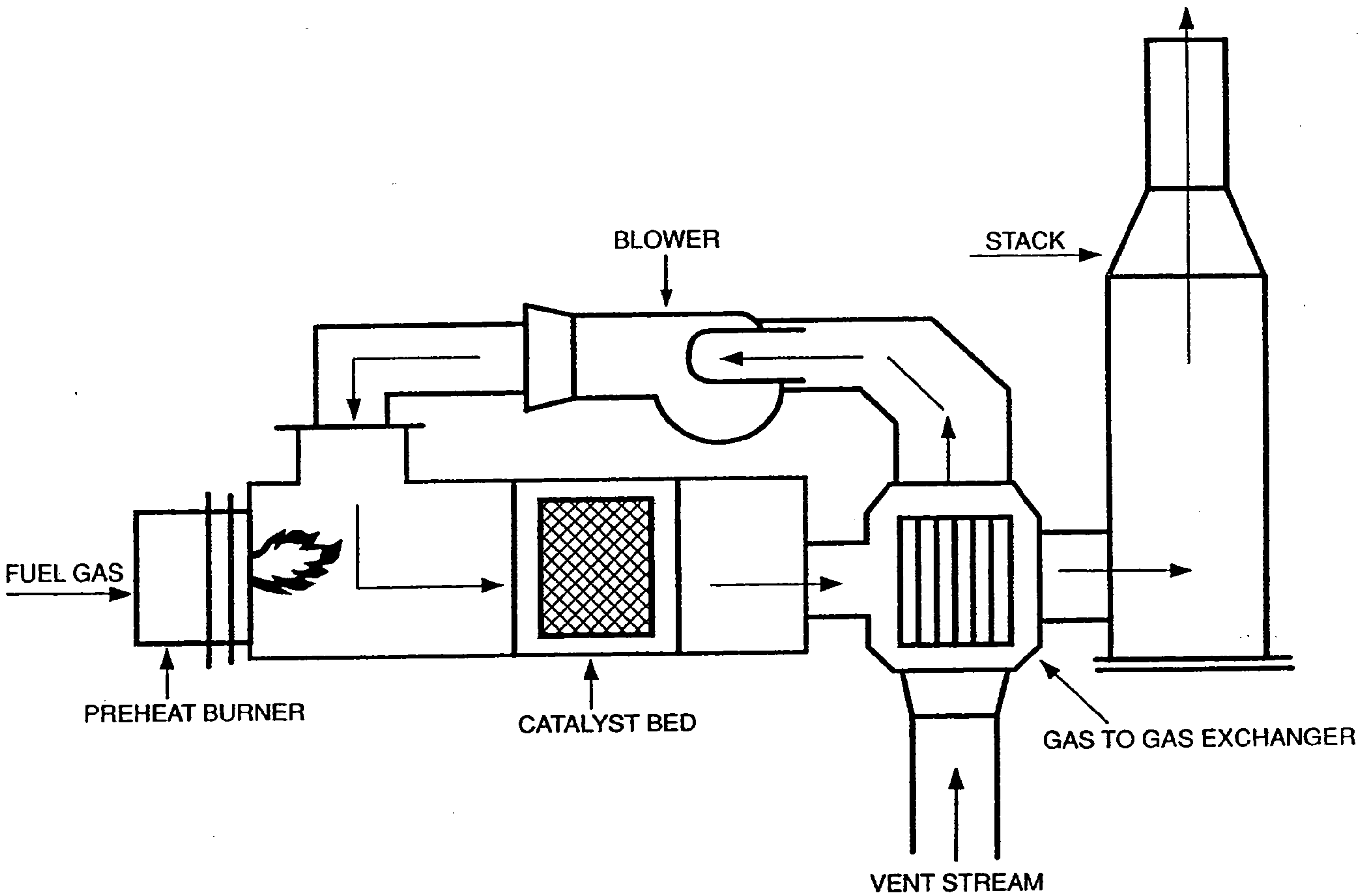

Figure 7-9. Schematic of a catalytic incinerator using heat recovery.

Certain hydrocarbon species are more difficult to destroy, and higher temperatures and/or increased catalyst volumes are required to achieve effective removal. In general, alcohols are easily oxidized and alkanes and chlorinated compounds are more difficult. Table 7-3 compares the relative destructibility of various compound groups.

TABLE 7-3. RELATIVE DEGREE OF DESTRUCTIBILITY OF ORGANIC COMPOUND CLASSES

Compound class	Relative destructibility
Alcohols	Highest
Cellosolves/dioxane	
Aldehydes	
Aromatics	to
Ketones	
Acetates	
Alkanes	
Chlorinated hydrocarbons	Lowest

Because the oxidation temperature of a catalyst system is lower than comparable thermal systems, the formation of oxides of nitrogen are reduced. In addition, the heat required to complete the reactions is also reduced, which reduces the cost of auxiliary fuels.

Systems require preheating to reach the minimum temperatures at which catalytic oxidation occurs. Once this minimum temperature is achieved, heat liberated from the oxidation of the pollutant may be sufficient to support the reaction without auxiliary fuel. This is particularly true when heat recovery is used to preheat the inlet fume gas stream.

From a macroscopic view, the steps in a catalytic reaction are:

1. Transfer of reactants to, and products from, the outer catalyst surface.

2. Diffusion of reactants and products within the pore of the catalyst.

3. Active adsorption of reactants and the desorption of the products on the active centers of the catalyst.

4. Reaction(s) on active centers on the catalyst surface.

In addition, thermal activity occurs, which heats the catalyst and flue gas streams. These activities are:

1. Heat transfer to or from active centers to the catalyst particle surface.

2. Heat transfer to and from reactants and products within the catalyst particle.

3. Heat transfer to and from moving streams in the reactor.

4. Heat transfer from one catalyst particle to another within the reactor.

5. Heat transfer to or from the walls of the reactor.

Because the reactions are temperature dependent, a classic VOC conversion curve is produced as temperature is increased. Figure 7-10 is a typical curve for a VOC. Individual curves for specific VOC species may have a different slope.

To prevent thermal degrading (deactivation) of the catalyst, the concentration of VOC in the treated gas stream must be limited. In general, when the carrier gas is air (20.9% O_2), the heat value of the gas stream must be less than 10 Btu/scf. If the carrier gas is an inert gas (N_2, etc.), the heat value may be increased to 15 Btu/scf.

The space velocity (superficial velocity) through the catalyst bed is a limiting factor in the degree of destruction. This is comparable to residence time in a thermal treatment unit. Volume of treated gas, dilution air, and combustion gases from the preheat are used to calculate this velocity. For example, if the primary gas volume is 20,000 scfm and dilution air is 5000 scfm, the total volume is 25,000 scfm. For most noble metal catalysts the velocity to achieve 95 percent destruction is between 30,000 and 40,000 h^{-1}, and 10,000 and 15,000 h^{-1} for base metal catalysts. Therefore, the volume of the bed should be:

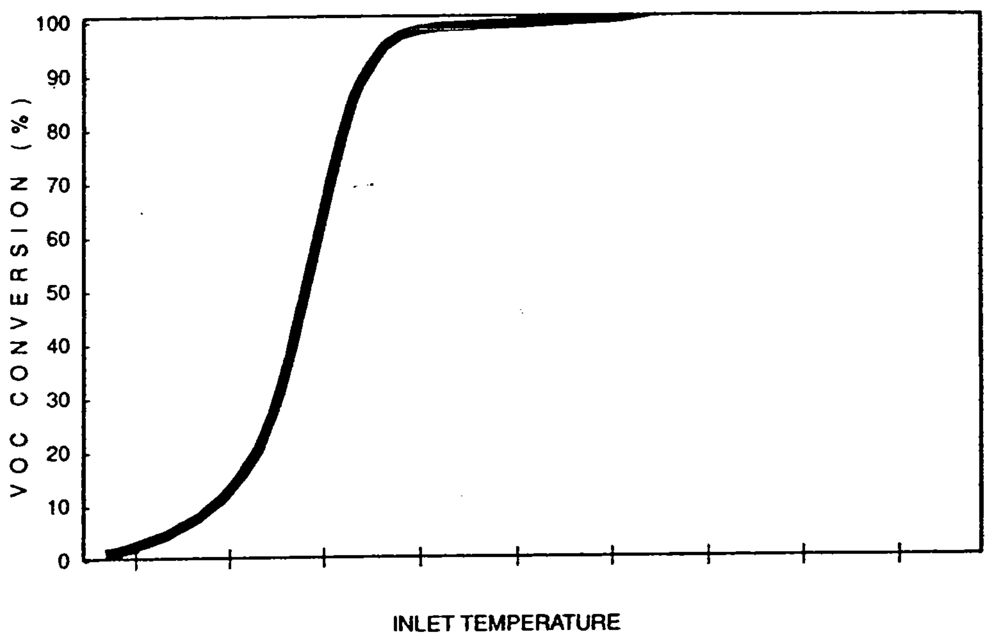

Figure 7-10. Relationship of percent conversion to temperature.

$$V_{bed} = \left(60\ \frac{min}{h}\right)\left(25{,}000\ \frac{ft^3}{min}\right)\left(\frac{h}{30{,}000}\right)$$

$$V_{bed} = 50\ ft^3 \textit{ for a noble metal catalyst}$$

7.2.3 Monitoring

The monitoring of catalytic incinerator performance (VOC destruction) is similar to that discussed under thermal systems in Section 7.1.3. There are certain specific concerns which are applicable to the catalyst system because of the potential for catalyst fouling and/or failure.

Monitoring of Gas Concentrations--

Direct monitoring of the outlet hydrocarbon concentration is costly, technically difficult, and is not necessarily required if other parameters are monitored (see below). The monitoring of this parameter, however, provides a direct indication that the incinerator is effectively destroying the hydrocarbons fed into the system. The measurement can be accomplished using a total hydrocarbon (THC) analyzer or a gas chromatograph (GC), which identifies individual hydrocarbon (HC) species. In complex gas systems, the destruction of multiple species is not equal at a given temperature. There is also the possibility of creation of species by recombination and/or incomplete combustion.

The use of a total hydrocarbon analyzer provides an indication of the relative overall destruction efficiency of the system. When the composition of the process gas stream changes, the response of the analyzer may be affected. For example, when multiple processes are captured for destruction and when process units cycle in and out of the system, both the rate and species may change. This may result in an increase or decrease in the measured outlet concentration. This change may be a true change in HC weight due to thermal destruction efficiency or simply a change in response of the instrument. Interpretation of the monitor output may be difficult and require a baseline and/or range of normal operation conditions to be determined to permit a comparison of measured values.

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The use of a GC may be appropriate to target a major species present in the input gas stream that is considered difficult to thermally degrade. This species can be the surrogate for monitoring the overall performance of the system. Because of the number of possible products of incomplete combustion, tracking of all species may not be technically feasible.

For most HC species the last product of incomplete combustion is carbon monoxide (CO). This species is considered difficult to oxidize and is a stable compound. If sufficient oxygen, temperature, and turbulence are provided to complete combustion to CO_2, a low level of CO may be expected (i.e., $\leq$ 30 ppm). CO may be monitored using a nondispersive infrared analyzer which is a good indicator of overall system performance.

Monitoring of the Temperature and Gas Flow--

Monitoring of the temperature and gas flow operating parameters provides an indication to insure that the incinerator achieves the required destruction efficiency. For example, if a stack test determines that a removal efficiency of 99 percent is achieved at 700°F, monitoring of the catalyst bed temperature and/or residence time may be appropriate. In general, residence time is not a measured variable and must be calculated from other measured variables (i.e., volume of the combustion chamber and gas flow rate). For most systems, continuous monitoring of the combustion temperature with a thermocouple is considered adequate to demonstrate performance.

There are several conditions, however, when temperature may be misleading:

1. If primary gas volume exceeds design values, residence time may decrease.

2. If the inlet concentration of pollutant decreases significantly and does not provide fuel for oxidation heating of the catalyst bed.

3. If the catalyst becomes poisoned.

7.2.4 Catalytic Incinerator Inspection and Maintenance

A catalytic incineration system has few moving parts and therefore has low maintenance requirements when properly operated. As with all mechanical systems, alignment and lubrication of bearings is necessary to prevent failure. Lubrication of mechanical linkages, slides, and other metal moving parts is required.

Filters and strainers for liquid fuels should be changed periodically to ensure even fuel flow. Parallel (duplicate) piping of strainers and filters is required for online service.

Prefilters used to prevent particulate matter entry to the oxidizer must be changed on a regular schedule to prevent draft losses and capacity limitation. Burner tips should be inspected and cleaned to ensure proper fuel mixing and efficient combustion.

Inspection of catalytic incinerators requires regular observation of monitoring devices (i.e., thermocouples, gas monitors, recorders, etc.). Most incinerators will have continuously recorded inlet and outlet incinerator temperature and auxiliary fuel input. Ideally, outlet carbon monoxide and oxygen will also be continuously recorded. Set points on each monitor are used to notify operator of incinerator malfunction between inspections.

A review of strip charts should be conducted once per operating shift to determine if operating conditions are typical of normal conditions and to note any trends. A more detailed physical inspection of the system should be made on at least a quarterly basis. This should include external and internal system components including refractory, heat exchangers, and electrical systems. Figures 7-11 and 7-12 are example inspection checklists for catalytic incineration systems on a per shift and quarterly frequency, respectively. Figure 7-5 shows an example maintenance report form that can be used for catalytic incinerator maintenance.

7.2.5 Common Problems or Malfunctions of Catalytic Incinerators

Many of the problems and malfunctions associated with catalytic incinerators are the same as to those associated with thermal fume incinerators discussed in Section 7.1.3 and are not repeated in this subsection. The following discussion of problems and malfunctions, therefore, focuses on problems and malfunctions that are only associated with catalytic incinerators.

Temperature of Oxidation--

The temperature of catalyst in the oxidizer is dictated by the total carrier gas volume, auxiliary fuel fired, and fume incinerated. Because all of these are variable, a feed back system is necessary to limit fuel rates to limit catalyst temperature. Typically a thermocouple is placed at the outlet of the catalyst bed to measure the average bed temperature. This sensor is connected to a programmable controller that sets auxiliary fuel flow to maintain the desired bed temperature. Because of the location of the thermocouple, a high failure rate is expected and dual sensors are recommended. Because a major portion of the flue gas heat input is supplied by the pollutants in the gas stream, a minimum fuel flow setting may not control bed temperature and higher temperatures may occur that may damage the catalyst.

SHIFT INCINERATOR INSPECTION FORM			
Facility Name:	Date of Inspection:		
Facility Location:	Time of Inspection:		
Process:	Name of Inspector (Print):		
Incinerator ID:	Signature of Inspector:		
INSPECTION ITEM	COMMENTS/CORRECTIVE ACTIONS		
1) Temperature alarms during shift: - High - Low			
2) Gas monitor alarms? - High CO - Low oxygen			
3) Fan operation - Abnormal sounds?			
4) Strip charts operational? Check paper and ink.			
Flue gas to incinerator	Range ________°F	Reading ________°F	
Combustion temperature	Range ________°F	Reading ________°F	
Catalyst temperature	Range ________°F	Reading ________°F	
Flue gas CO monitor	Range ________°F	Reading ________°F	
Flue gas oxygen monitor	Range ________°F	Reading ________°F	
Fan Current	______ amps		
Fuel rate	______scfm		
Heat Exchangers (for heat recovery)	IN	OUT	PRESSURE DROP
#1 Process gas	______°F	______°F	______ in. H_2O
Combustion gas	______°F	______°F	______ in. H_2O
#2 Process gas	______°F	______°F	______ in. H_2O
Combustion gas	______°F	______°F	______ in. H_2O

Figure 7-11. Example shift catalytic incinerator inspection form.

QUARTERLY CATALYTIC INCINERATOR INSPECTION FORM	
Facility Name:	Date of Inspection:
Facility Location:	Time of Inspection:
Process:	Name of Inspector (Print):
Incinerator ID:	Signature of Inspector:
INSPECTION ITEM	COMMENTS/CORRECTIVE ACTIONS
Refractory condition? (cracks, spalling, corrosion)	
Burner condition? (warpage, corrosion, fouling)	
Heat exchanger(s) and combustion chamber condition? (fouling, corrosion, leaks)	
Pressure seals condition? (check packing glands)	
Shell condition? (thermal shock, welds condition)	
Check auxiliary fuel piping train and note condition.	
Check interlocks, electrically operated valves, shutoff dampers, gauges, continuous recorders and thermocouples for proper operation. (calibrate where applicable)	
Catalyst cleaned (follow suppliers instructions) Date of last cleaning ____________	

Figure 7-12. Example quarterly catalytic incinerator inspection form.

Slaging/Fouling --

Because of the lower temperature in the bed oxidizer as compared to thermal units, the potential for fouling the chamber with foreign materials is reduced. Dusts and dirt not removed in prefilter systems or air pollution control equipment may, however, adhere to catalyst surfaces. These deposits (slags) may increase catalyst failure and reduce the destruction characteristics of the catalyst bed.

Auxiliary Burner Flame Safety--

Flame safety is an important aspect of all combustion processes. Failure to detect flame out may result in the continued introduction of fuel or fume into a hot combustion chamber in which ignition has ceased. A rich gas mixture is produced that spontaneously combusts with violence. The resulting explosion can destroy the incinerator and adjacent process equipment.

All components of the flame safety system must be inspected frequently and spare parts should be accessible for replacement. Under no circumstances should the flame safety be bypassed or disabled during normal operation. Only trained service personnel should be involved with disabling interlocks and safeties as part of troubleshooting or fault detection.

Catalyst Poisoning--

The most serious limitation to catalytic combustion systems is the destruction or deactivation of the catalyst due to poisoning by contaminants. This effect falls into two categories: irreversible and reversible.

Irreversible Catalyst Failure--

This failure mechanism is caused by coating or attachment of a poison to the noble metal used in the catalyst bed. Typical poisons are phosphorus, bismuth, lead, arsenic, antimony, mercury, iron oxides, tin, and silicon. Several of these elements are present in ambient air or process streams. Fumes having organic components containing these elements are not candidates for application of catalytic incineration systems. An engineering feasibility study is typically conducted to determine if the potential exists for incineration of these elements. Process changes between the design and operation of the incinerator may result in inclusion of forbidden substances. If poisoning occurs, the catalyst must be removed and returned to the supplier for remanufacture. Current research has been conducted to produce poison resistant catalyst for phosphorus and silicon applications.

High temperature can sinter the catalyst and reduce the active surface area. When this occurs the bed is destroyed and must be replaced.

Reversible Catalyst Failure--

Reversible catalyst poisoning occurs when compounds coat the bed surfaces, which temporarily blind the pores or oxidation sites. Typical reversible poisons are sulfur (reduced states), halogens, and carbon particles. These can be removed by oxidation through increasing bed temperature. Activation can also be restored by washing the bed to remove solid particles using detergents, acids, or caustic.

Low Oxygen--

A decrease in oxygen content of the fume may result in insufficient oxygen to complete the reaction. This condition can result in the formation of complex products of incomplete combustion.

Insufficient Preheat--

A minimum temperature of the bed is necessary to initiate catalytic oxidation. The preheat is typically established to provide the minimum temperature necessary to activate the catalytic reaction. The efficiency of reaction is also temperature dependent and a set temperature must be maintained to achieve design efficiency.

Poor Mixing--

Inadequate mixing of fume, preheat combustion gases and dilution air (oxygen) can result in stratifications in the bed which impede uniform oxidation and result in local heating of bed sections. Turbulence and mixing are equally important in catalytic as well as thermal systems.

Low Pollutant Concentration--

In general, the efficiency of the reaction increases with fume concentration. At low fume concentrations destruction efficiency may decrease by 30 to 40 percent. Application of a catalytic system to variable flow and pollutant rates may be unsuccessful. Engineering feasibility studies should be completed to determine the typical range of concentrations. If low fume rates are encountered, injection of fuel gas (propane, natural gas, etc.) may be required to maintain bed temperatures.

Poor Gas Distribution--

Partial fouling of the catalyst bed and/or poor gas distribution can result in local exceedance of face velocity. This can produce local heating and/or failure. Since bed temperature is measured as the average gas temperature exiting the system, it is important that minimum stratification occur and deviation from the average be minimized.

High Face Velocity--

Increased treatment volume decreases the specific volume of the catalyst bed and decreases efficiency. Limits on total gas volume are imposed to assure optimum destruction efficiency. High velocity can also erode the bed and decrease useful service life.

Table 7-4 summarizes the failure mechanisms, symptoms, and corrective actions associated with catalytic incinerators. The reader is also referred to Table 7-2 which contains failure mechanisms for thermal fume incinerators which are also applicable to catalytic incinerators.

7.3 Spare Parts

Spare parts should be maintained to replace fuses, sensors, relays, and key controllers in the flame safety circuits and monitoring instruments. Replacement burners and refractory should also be kept onsite. Experience based maintenance and

TABLE 7-4. SUMMARY OF FAILURE MECHANISMS, SYMPTOMS, AND CORRECTIVE ACTIONS FOR CATALYTIC INCINERATORS

Failure mechanism	Symptoms	Corrective actions
Catalyst failure (thermal)	Sintered surface Deactivation Low bed temperature	Replace bed
Catalyst failure (poison/reversible)	Deactivation	Increase bed temperature to burn out contaminant Prefilter carrier gases Use clean auxiliary fuels (n.g., propane) Change process streams; isolate poison
Catalyst failure (poison/irreversible)	Deactivation	Replace bed Isolate poison from process stream
Low oxygen	High CO Elevated PIC Low bed temperature	Increase dilution air Monitor fume O_2
Low preheat	High CO Elevated PIC Low bed temperature	Install auxiliary fuel burners Install feed back temperature control system Monitor preheat temperature
Poor mixing	High CO Bed failure	Increase turbulence or premix dilution air
Low pollutant concentration	Low destruction efficiency High CO/PIC Low bed temperature	Inject fuel HC to fume Increase temperature Replace with direct fired unit
Poor gas distribution	Low destruction efficiency High CO/PCC Local bed failure (thermal)	Improve gas flow distribution Improve mixing
High velocity	Bed erosion Low efficiency	Reduce gas volume Reduce temperature air inleakage Increase bed volume

Note: See Table 7-2 which contains failure mechanisms, symptoms, and corrective actions for thermal fume incinerators that are also applicable to catalytic incinerators.

parts replacement histories should be used to determine future needs. Each system is unique and a general maintenance program is only a starting point.

7.4 Operator Training

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

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

System training should be received from the incinerator manufacturer when a new system is commissioned. The manufacturer's start-up services will generally include introductory training for facility operators and maintenance personnel. The field service engineer involved in startup procedures will instruct plant personnel in the methods to ensure proper assembly and operation of the system components, check and reset system instrumentation and control, check for the proper operation of interlocks and temperature systems, and 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 incinerator installation will include manufacturer-recommended maintenance procedures. Annual in-house training should at a minimum include a review of these documents and confirmation of the original operating parameters. Training should include written instructions and practical experience sessions on safety, inspection procedures, system monitoring equipment and procedures, routine maintenance procedures, and recordkeeping. For plant personnel involved in taking incinerator opacity readings, U.S. EPA Reference Method 9 requires a semi-annual recertification in method procedures.

REFERENCES FOR SECTION 7

1. U.S. EPA. Parametric Evaluation of VOC/HAP Destruction Via Catalytic Incineration. EPA-600/2-85-041 (NTIS PB85-191187). April 1985.

2. U.S. EPA. VOC Control Effectiveness. EPA Contract No. 68-02-4285, WA 1/022. For Carlos Nunez, U.S. EPA, AEERL. February 1989.

3. Telecon. Sink, Michael, PES, with Yarrington, Robert, Englehard Corp., Edison, NJ. Space velocities for catalysts, and incinerator efficiency. April 1990.

4. Buonicore, A.J., and Theodore, L. Industrial Control Equipment for Gaseous Pollutants. Vol. 2, CRC Press, Inc., Boca Raton, Florida. 1975.

5. L. Theodore and J. Reynolds, Introduction to Hazardous Waste Incineration. Wiley-Interscience, New York. 1987.

6. J.P. Bilotti and T.K. Sutherland, in Air Pollution Control Equipment: Selection, Design, Operation and Maintenance. L. Theodore and A.J. Buonicore Eds., Prentice-Hall. Englewood Cliffs, NJ. 1982.

7. J.C. Summers, A.C. Frost, and J.E. Sawyer, "VOC Emission Control by Catalysts," presented at a STAPPA/ALAPCO Technical Briefing, New Orleans, Louisiana, October 1989.

8. B.A. Tichenor and M.A. Palazzolo, "Destruction of Volatile Organic Compounds Via Catalytic Incineration," Environmental progress, 6 (3), 172, 1987.

9. G.R. Lester and J.C. Summers, "Poison-Resistant Catalyst for Purification of Web Offset Exhaust," presented at APCA 81st Annual Meeting, Dallas, Texas, June 1988.

10. G.R. Lester, "Catalytic Destruction of Hazardous Halogenated Organic Chemicals," presented at AWMA 82nd Annual Meeting, Anaheim, California, June 1989.