THERMAL AND REGENERATIVE CATALYTIC OXIDIZERS

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1.0 SCOPE

This data sheet applies to thermal and catalytic oxidizers with fuel inputs (auxiliary fuel and process vapor) greater than 400,000 Btu/hr (117 kW), and to all oxidizers that are critical to a process. Thermal oxidizers are combustion-oxidation devices designed to thermally oxidize process exhaust vapor.

For many years, both direct flame and flameless catalytic oxidizers have been used to reduce vapor to acceptable exhaust products, such as carbon dioxide and water. The types of exhaust that are commonly incinerated come from baking, drying, curing, and chemical processes performed in ovens, dryers, kilns, stills, and reactors. Some process exhausts containing other than ordinary hydrocarbons, and oxygenated organics might require additional, special treatment, such as scrubbing and filtration, to remove particles, halogenated compounds, and oxides of sulfur and nitrogen.

Concentrated flammable vapor above its lower explosive limit (LEL) is often burned in flare stacks or as fuel in various heating equipment, and requires special design of the burners and combustion control safeguards. Such vapor streams should be treated as premixed flammable mixtures when supplied to an oxidizer because there may be times when the vapor passes through the explosive range.

Vapor that is delivered above the upper explosive limit (UEL) from the source is treated as normal gaseous fuel in this data sheet, and should be delivered to a typical burner fuel train with flame supervision.

Total fuel input includes burner fuel and process vapor. However, when a recommendation is related to a burner fuel input, only the amount of fuel delivered to the burner needs to be considered.

Vapor-air throughput is usually rated in terms of volumetric flow rate.

If national or local codes conflict with this data sheet, adhere to whichever guidance is more stringent.

1.1 Hazard

Refer to Understanding the Hazard (UTH): *Oven, Dryer, and Thermal Oxidizer Fires and Explosions* (P0246).

1.2 Changes

July 2018. Interim revision. Recommendation 2.2.3.2 was clarified, new definitions were added to Appendix A, Glossary of Terms.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

Provide controls and safeguards to all components of the thermal or catalytic oxidizer, related process equipment, and interconnecting ducts to ensure this equipment operates safely during startup, operation, and shutdown. In some installations, a wide range of vapor conditions might develop. The vapor collection and delivery to the oxidizer is a very important part of the total system. Completely investigate all aspects of the oxidizer and its associated equipment, including the appropriateness of its design and operating procedures. A process hazard analysis (PHA) should be performed to identify process conditions and potential upset. (See Data Sheet 7-43, *Process Safety,* for more information.)

FM recommends the use of FM Approved (see Appendix A for definition) equipment and devices such as fuel safety shutoff valves, fuel and air supervisory sensors/switches, temperature switches, combustibles analyzers, flame arrestors, flame scanners and supervisory combustion safeguards. Use FM Approved equipment whenever it is practical and compatible with the application.

If FM Approved equipment is not available to meet the size and arrangement of the installation or field operating conditions, choose equipment from a reliable manufacturer with proven field experience. In countries where FM Approved equipment is not available, use equipment listed by a local testing agency.

2.2 Equipment and Processes

2.2.1 Process Taps

2.2.1.1 Provide independent process taps for pressure sensors/switches, control devices, and interlocks in streams subject to fouling. Provide filters for pressure sensors or multiple sensors with voting logic to ensure reliable indication and control.

2.2.2 Combustion Safety Controls

2.2.2.1 Purge Permissives and Fan Interlocks

2.2.2.1.1 Design the system for a supervised, pre-ignition purge of the thermal oxidizer combustion chamber, the intake ducting, and the exhaust systems. Note that it might not be practical to purge the inlet duct to an oxidizer if there is a common duct feeding more than one oxidizer.

2.2.2.1.2 Provide an air flow of not less than 25% of the maximum oxidizer throughput, and of sufficient duration to produce at least four air volume changes during the purge. If there is a heat recovery system that recirculates products of combustion, ascertain that four volumes of fresh air are exhausted from the oxidizer; purge time will be longer.

2.2.2.1.3 Program the purge time into the combustion safeguard controller to prevent the ignition system and the fuel safety shutoff valves from energizing before the purge period is over. Once the time is programmed, the operator should not be able to make unauthorized changes.

2.2.2.1.4 Provide position sensors or interlock switches to ensure correct positioning of all dampers (including RTO flow control valves) during the purge period. Dampers may be cut away or provided with positive position stops to permit a minimum but adequate purge air flow; this should not be done on dampers that isolate supply vapor from the oxidizer (during purge cycles or emergency atmospheric venting).

2.2.2.1.5 A re-purge following a burner shutdown or flameout is not required if the combustion chamber temperature is higher than 1400°F (760°C) (note that 750°C is the guideline used in some countries) or if **all of** the following conditions are satisfied:

A. The burner is equipped with a flame scanner.

B. The fuel train is equipped with the required safety shutoff valves.

C. It can be demonstrated that the flammable concentration of the combustion chamber atmosphere cannot exceed 25% of the LEL.

2.2.2.1.6 Provide a fan interlock with redundant sensors/switches for all fans used for purging, supplying the vapor-air mixture and fresh air make-up, and recirculating and exhausting products of combustion.

2.2.2.1.7 Provide a flow/differential pressure sensor or switch for each fan wired into the safety control circuit *and at least one* of the following:

A. Mount a rotational switch on the fan's drive shaft and wire it into the safety control circuit.

B. Wire an auxiliary contact of an overcurrent-protected starter for the fan motor into the safety control circuit.

C. Wire a contact of a relay whose coil is energized from the load side of an overcurrent-protected starter for the fan motor into the safety control circuit.

D. Energize the safety control circuit directly (or through a transformer) from the load side of an overcurrent-protected starter for the fan motor.

Caution: The overcurrent protection of the starter should not exceed the convention rating required for the fan motor alone.

2.2.2.1.8 Do not use a negative pressure switch or controller as a safety interlock. Some systems maintain a certain pressure in the duct, and this might be a balance between the main fan and individual process exhaust fans. The control scheme might be set up so a process problem could cause the main fan inlet damper to close in, compounding the problem. Low flow should be indicated by some type of air flow measurement such as differential pressure rather than static pressure.

2.2.2.1.9 If loss of flow from any fan can present a hazard, the interlock should be arranged to automatically shut down all sources of fuel or flammables in the system, including shutdown of oxidizer burner fuel and process volatile organic compound (VOC) input. The main oxidizer exhaust fan should continue to run to provide whatever ventilation is possible, unless it is proven that the process exhaust flow has been totally interrupted (such as by a damper failure). An alternative means of emergency ventilation for the process should be considered as part of a process hazard analysis (PHA). Where vapor condensation could bind mechanical switching mechanisms, consider using non-mechanical sensors.

2.2.2.2 Fuel Interlocks

2.2.2.2.1 Provide high and low fuel pressure interlocks for gas-fired burners. Set switches at no more than 150% of normal operating pressure for high pressure, and no less than 50% of low fire operating pressure for low pressure. Have settings within the safe operating range of the burner. Burner turndown ratio and location of the switches should be considered when setting switches. Refer to Data Sheet 6-4, *Oil- and Gas-Fired Single-Burner Boilers,* for more details on pressure switches. See Figure 1 for a typical gas-fired fuel train arrangement.

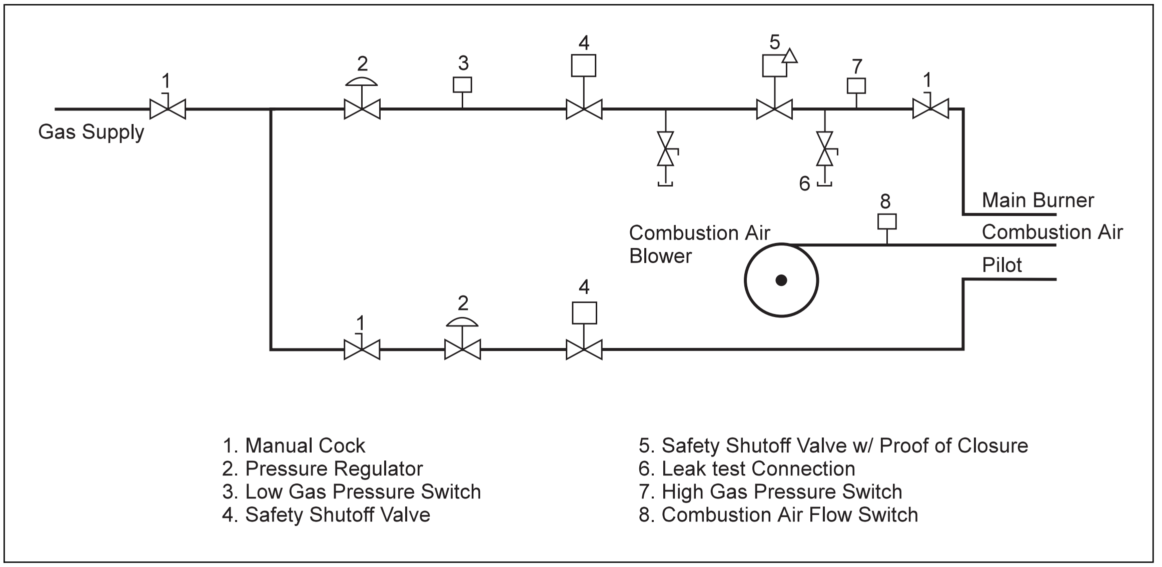

Fig. 1. Fuel train arrangement for gaseous fuel

2.2.2.2.2 Provide a low pressure switch for oil-fired burners except on oil burners where there is a fuel pump integral with the burner assembly.

2.2.2.2.3 Provide a low and high temperature interlock for oil that must be heated for proper atomization.

2.2.2.2.4 Provide an oil-atomizing medium low pressure or pressure differential interlock.

2.2.2.3 Combustion Safeguards

2.2.2.3.1 Provide combustion safeguard controllers to supervise the pilot and main burner flames (including concentrated process vapor above UEL), and to provide an acceptable sequence of operation during purge, ignition, firing, and shutdown. Arrange the combustion safeguard to shut off burner fuel supply and ignition sources whenever any interlock for a particular fuel train is not satisfied. For common interlocks such as fan flow or high temperature, all fuel supplies including process vapor input should be shut down.

2.2.2.3.2 Limit the pilot and main flame trial-for-ignition periods to 15 seconds for gaseous fuels, light oils, and concentrated process vapor above the UEL for units 2,500,000 Btu/hr (732 kW) or less, and 10 seconds for gaseous fuels, light oils and concentrated process vapor above the UEL for units greater than 2,500,000 Btu/hr (732 kW). Limit the trial-for-ignition period to 15 seconds for heavy oils. Limit the trial-for-ignition period to 4 seconds for direct spark ignition of main burner gaseous fuels and oil fuels.

2.2.2.3.3 A recycle type of controller with one attempt to reignite is permitted on automatic-lighted burners of units with a fuel input of 2,500,000 Btu/hr (732 KW) or less. Do not use recycle control if the system is expected to operate in excess of 25% of the LEL. Refer to Data Sheet 6-4, *Oil- and Gas-Fired Single-Burner Boilers,* for more information on combustion safeguard requirements.

2.2.2.3.4 For units that operate continuously for more than 24 hours, use self-checking UV flame scanners when UV scanners are used. Note that solid state UV scanners do not need to be self-checking.

2.2.3 Igniters

2.2.3.1 Locate the burner fuel input (including process vapor above the UEL) and the pilot such that the main fuel can be promptly ignited. Some burner designs may require a low fire start interlock to ensure an optimum fuel-air mix near the pilot flame.

2.2.3.2 Preferably, use an interrupted pilot, which is deenergized when the main-flame trial-for-ignition period is over (see Glossary of Terms). Direct spark ignition of the main flame is also acceptable for burners. However, since direct spark ignition is not directly proven, the trial-for-ignition period is reduced (see 2.2.2.3.2). For an intermittent pilot, provide separate flame supervision. Refer to Data Sheet 6-4, *Oil- and Gas-Fired Single-Burner Boilers,* for more detailed guidance on igniters.

2.2.4 Fuel Safety Shutoff Valves

2.2.4.1 For gaseous fuels, install two safety shutoff valves (SSOVs) for each main burner and pilot system. A system can be one burner (or pilot) or a group of burners (or pilots) that are controlled as one system.

For oil, install one safety shutoff valve (SSOV) for each main burner and pilot system. Install two safety shutoff valves if **any** of the following are true:

A. The pressure is greater than 125 psi (862 kPa).

B. The pump operates when oil is not being fired, regardless of pressure.

C. The pump operates during gas-firing for combination gas and oil burners.

2.2.4.2 If the system (oil or gas) is greater than 400,000 Btu/hr (117 kW), provide proof-of-closure on one of the safety shutoff valves if a second valve is required. An automatic leak detection device installed between safety shutoff valves satisfies the requirement for proof-of-closure. This type of device performs a pressure test at startup and shutdown by pumping gas above line pressure between the SSOVs and monitoring for pressure drop for a predetermined period of time.

2.2.4.3 For a multi-burner system, if it is desired to shut off an individual burner for process reasons or upon loss of flame, provide a common main safety shutoff valve and individual safety shutoff valves with proof-of-closure at each burner. The burner safety shutoff valve should be proved closed after shutdown. If it is not proved closed, all safety shutoff valves in the system should close.

2.2.4.4 Install a means to manually leak test each gas safety shutoff valve. Typically, a test port is installed downstream of each valve or is built into the valve.

2.2.5 Vapor Concentration Management

2.2.5.1 General

2.2.5.1.1 Provide bypass ducts installed directly to out-of-doors to prevent hazardous concentrations of vapor from reaching the oxidizer during startup, shutdown, and abnormal process or oxidizer operation.

2.2.5.1.1.1 Local regulations may prohibit the use of bypass ducts for environmental reasons. Where bypass is not permissible or available, the vapor concentration should be controlled using one of the following:

A. Introduce a dilution airstream to ensure vapor concentration is below 25% LEL prior to being introduced to an operating RTO.

B. Introduce airflow to the equipment being purged and slowly open the damper to the oxidizer, thereby controlling vapor concentration in the ductwork. The purge timer would then start when purge airflow rate is reached.

C. Use another engineered system specifically designed to prevent a slug of high-concentration gas flow from reaching the oxidizer.

In all circumstances, the oxidizer should be started and brought to operating temperature prior to introducing equipment process airflow.

2.2.5.1.1.2 Where provided, arrange bypass dampers to be automatically operated when any abnormal condition occurs that would lead to a process or oxidizer trip. An emergency vent fan might be needed to maintain air flow through the process equipment because it is possible that vapor will still be generated after a process trip.

2.2.5.2 Systems Operated Above the UEL

2.2.5.2.1 Supervise concentrated vapor that is above the upper explosive limit (UEL) with high and low pressure switches. Burner design should ensure the fuel velocity leaving the nozzles is always high enough to prevent air and flame from propagating back into the vapor supply line.

2.2.5.2.2 If the vapor concentration is normally maintained above the UEL, the vapor should be delivered in an inert atmosphere whenever passing through the explosive range, such as at startup and shutdown. Using an oxygen analyzer, verify that inerting has reduced oxygen concentration to less than 1% at startup.

2.2.5.3 Systems Operated Below the LEL

2.2.5.3.1 Operate the oxidizer and process equipment at a fixed rate of continuous safety ventilation. Do not exceed 25% of the LEL. Base safety ventilation calculations on the maximum loading of all potential sources. (Refer to Data Sheet 6-9, *Industrial Ovens and Dryers,* for safety ventilation recommendations.)

2.2.5.3.2 Use FM Approved detectors and combustibles analyzers where available. If FM Approved equipment is not available, use products listed in accordance with recognized performance standards.

2.2.5.3.3 If a dedicated exhaust fan is not installed, provide supply and exhaust flow interlocks to prove a minimum amount of fresh air is being provided. Arrange the interlocks to shut off supply of vapor and burner fuel.

2.2.5.3.4 Use continuous combustibles analyzers if normal operation will exceed 25% of the LEL. Arrange analyzers to alarm upon loss of signal or power. Flammable vapor concentration up to 50% of the LEL may be tolerated if continuous combustibles analyzers are used and properly maintained, provided **both** of the following are true:

A. The controller is arranged to do **all** of the following:

1. Sound an alarm before the concentration reaches 50%.

2. Shut down the vapor source and process burners when the concentration reaches 50% of the LEL.

3. Divert the vapor to a safe location out-of-doors when the concentration reaches 50% of the LEL if permitted by local environmental regulations. (Refer to 2.2.5.1.1 for recommendations where no bypass is permissible or available.) Use positive seating, fast-acting slide gates or dampers for isolation. See Section 2.2.7.3.

B. The entire combustibles sampling system, including the analyzer, is maintained at temperatures equal to or above the flash point of the least volatile component of the sampled mixture. This will prevent condensation, fouling, and inaccurate readings. Flash point is a well-defined property. The dew point will normally fall below this temperature at concentrations less than 50% of the LEL.

2.2.5.3.5 Gas analyzers should be selected to ensure that the response time characteristics of the analyzer are appropriate for the duct design and flow velocity. The analyzer should be capable of measuring, alarming, and initiating corrective or emergency action such that an unsafe condition will not be introduced in the oxidizer.

2.2.5.3.6 Install combustibles analyzers according to the manufacturer's instructions and the following:

A. Locate sampling lines close to the source of process vapor in the area where peak evaporation occurs, but not so close as to cause nuisance problems. (Note that sampling points should not be located too close to the surface of work being processed in an oven/dryer because the vapor concentration will be very high there. Locate in the oven area where evaporation is highest, but also where vapor is diluted with ventilation air. It is desirable to sample an average concentration, but also in a location where a concentration spike will be sensed the quickest.)

B. Locate the analyzer such that the response time of the LEL detection system and emergency damper actuator speed will minimize the potential for an unsafe condition, such as a sudden increase in vapor concentration, to be introduced to the oxidizer.

C. Where there is a hood, install a sampling point at the top of the hood or near the bottom of the exhaust duct.

D. Keep sampling lines as short as possible to minimize response time and condensation, which will reduce concentration at the analyzer.

E. Do not use sample line tubes larger in diameter than that recommended by the manufacturer.

F. Do not use multiple sampling points with one analyzer because this will considerably slow the response time. If multiple sampling points are needed (in separate zones, for example), dedicate one analyzer to each sampling point.

2.2.5.4 Design the oxidizer such that operation with the maximum possible vapor concentration will not result in overheating.

2.2.5.5 Supervise natural gas injection into the vapor supply stream so 25% of the LEL is not exceeded at maximum gas flow and minimum vapor-air flow. Gas injection can be used to increase oxidizer efficiency and control NOx. Do the following to help ensure gas injection does not create a hazardous condition:

A. Do not control injection gas flow by oxidizer temperature alone. It should also be dependent on vapor-air stream flow unless it can be shown that 25% of the LEL will not be exceeded at the minimum possible airflow and maximum possible gas flow.

B. Vapor flow measurement should be based on mass flow and therefore must be corrected for temperature.

C. Measure vapor-air flow upstream of the point of gas injection.

D. Meter injection gas flow.

E. Install a high injection gas flow switch/sensor.

F. Install a vapor-air stream low flow switch/sensor to further ensure the vapor-air injection gas stream remains below 25% of the LEL. Never use a negative pressure switch for this purpose because it will not detect a blocked air intake.

G. Interlock these devices with the injection gas safety shutoff valves.

H. Minimize the time delay between sensing a flow out-of-limits condition and tripping of the safety shutoff valves; 1 or 2 seconds maximum is preferred.

I. Install two safety shutoff valves, one having proof-of-closure.

J. Do not use a recycle-type controller if the injection gas input can exceed 2,500,000 Btu/hr (732 KW).

K. Verify the oxidizer is at its operating temperature before injection gas startup.

2.2.6 Temperature Interlocks

2.2.6.1 Design temperature control devices that regulate burner fuel input so failure of these devices does not cause unsafe conditions of abnormally high temperature or flammable concentrations within the oxidizer.

2.2.6.2 Provide high temperature interlocks in the combustion chamber and the exhaust duct, and arrange them to shut off the supply of fuel and vapor to the combustion chamber.

2.2.6.3 Provide a low temperature switch/sensor in the combustion chamber, independent of the operating controls. Interlock this switch to ensure the oxidizer, both direct flame and catalytic type, is at operating (“ready”) temperature and conditions before allowing introduction of solvent vapor into the vapor oxidizer supply. Provide sufficient heat and combustion air during operation to allow efficient and stable oxidation of the vapor.

2.2.6.4 Provide a high temperature interlock independent of the operating controls in the combustion chamber and the exhaust duct (applies to RTOs), arranged to shut down the supply of fuel and vapor and the process. (The process burner fuel supply should be shut down because an oxidizer high temperature condition can be caused by unburned fuel from the process.)

A. Arrange temperature sensors (thermocouples) to fail safe (upscale).

B. Locate the sensors so an air flow imbalance through the heat exchanger will not cause a false reading.

C. Set the temperature limits at no more than 20% over the normal operating temperature, and in no case should a safe operating temperature be exceeded.

2.2.6.5 As an alternative to 2.2.6.3 and 2.2.6.4, use **one** of the following methods of temperature interlocking when interlocking for low-temperature or high-temperature shutdown is included as part of an analog monitoring/measuring system:

A. Provide two temperature sensors. One signal can be used for control and indication, and the other signal can be used for interlocking with the safety shutoff valves (SSOVs) and indication. Alternatively, both signals can be used for all three functions, with either signal initiating the required interlocking action when the limit is reached. Monitor the temperature control loop for divergence and alarm when the difference between the two signals exceeds a predetermined set point.

B. Provide three temperature sensors. An auctioneering (voting) system with a divergence alarm selects the median signal to be used for control, interlocking, and indication. The signal should be sent to the safety interlock system (trip the SSOVs) first or in parallel to all systems.

2.2.6.6 Monitor the whole temperature control loop for malfunction. This can be accomplished by initiating a time delay period each time the heater control system calls for full heat, no heat, or minimum heat. If a predetermined temperature change is not detected within a specified time period, an alarm or trip should occur. This condition indicates that some component of the temperature control system is not functioning properly. The time delay should be built into the controller by the manufacturer.

2.2.6.7 A performance-based design evaluated in accordance with Data Sheet 7-45 is an acceptable alternative to the prescriptive requirements provided here.

2.2.6.8 Test temperature control/limit devices whenever replacement controls are installed or whenever any of these devices have been removed and replaced for any reason. Wiring, grounding, and selecting cable according to manufacturer's instructions are important.

2.2.6.9 Provide temperature sensors and extension wires that are rated for the expected environment and highest anticipated temperature.

2.2.6.10 For catalytic units, monitor the temperature differential across the catalytic bed. Measuring the temperature differential indicates the concentration of flammable vapor in the intake and the reactive qualities of the catalyst. Reduced efficiency of the catalyst due to poisoning, coating, or overheating will decrease the differential temperature and give a false indication of the quantity of content in the vapor. The temperature differential alone is not considered a reliable measurement of the flammable vapor concentration, but can be used for this purpose if a combustibles analyzer is not provided and normal operation is below 25% of the LEL. (See Section 2.2.5, Vapor Concentration Management.)

2.2.7 Duct Protection

2.2.7.1 Design the interconnecting ducts and chambers between the process unit and the oxidizer to prevent flammable deposits, vapor, and gas from accumulating. Providing drip-legs, traps, knockout pots, or scrubbers. In addition, insulating and heating the ducts and chambers will frequently be necessary. See Data Sheet 7-78, *Industrial Exhaust Systems, for more information.*

2.2.7.1.1 At the pulp and paper mills where liquids such as turpentine can spike and black liquor can blow back into noncondensible gas (NCG) lines, stabilize paper mill NCG sources to minimize rapid swings in NCG input.

2.2.7.1.2 Ensure sprinklers are accessible for inspection, maintenance, and replacement. Flexible sprinkler fittings allow for easier inspection. Ducts equipped with readily accessible access ports will increase the likelihood and frequency of duct interior inspections and cleaning.

2.2.7.1.3 Maintain duct temperature to prevent vapor from condensing on the inside surfaces of the duct.

2.2.7.2 Design damper and fan arrangements to prevent vapor from pocketing in the oxidizer, ducts, and auxiliary units. Maintain a slightly negative pressure in the main duct so vapor cannot backflow into stagnant branch lines or tees where emergency vents are connected. If vapor condenses in these areas when cold, a spike can occur after a startup when the areas are warmed up.

2.2.7.3 Install emergency or backblast dampers and oxidizer isolation dampers that fail in a safe manner (to the dump or bypass mode). Dampers should be fast-acting (one second maximum closing time if practical). See Section 2.2.7.6 for information on specially designed explosion protection isolation valves.

2.2.7.4 Arrange dampers to fail in the open position during power upsets to allow for natural ventilation; however, an oxidizer or process trip should bypass the oxidizer and vent to atmosphere.

2.2.7.5 Provide an adequately sized barometric vacuum relief damper if the negative pressure limit of the duct work can be exceeded. This damper will open automatically when atmospheric pressure exceeds the pressure inside the duct by a specified amount.

2.2.7.6 Where there is a high likelihood that the system may move into the explosive range due to a process upset, install explosion protection systems near the oxidizer and near any process systems that could be exposed to a flash back. The explosion protection systems could consist of quick-acting isolation valves, chemical blocking, or flame front diverters. Quick-acting isolation valves used in explosion protection systems will work much faster than isolation valves interlocked with combustibles analyzers as described in 2.2.7.3. Active explosion protection systems use pressure or flame sensors in the duct with response times of less than one millisecond. Installation guidelines for these systems can be found in Data Sheet 7-17, *Explosion Protection Systems.*

An alternative method of preventing a deflagration between an oxidizer and a process is to install FM Approved flame arrestors. Where flame arrestors are installed, adhere to the location and arrangement recommendations that address “manifolded vents” in Data Sheet 7-88, *Storage Tanks for Ignitable Liquids.* Do not use flame arrestors if fouling by a dirty vapor stream or condensed vapor will be a nuisance problem. Provide a means of cleaning the arrestor. If water is piped to the duct for cleaning purposes, provide a means to prevent admission when the oxidizer is in operation (such as a quick disconnect fitting, locked closed valve, etc.).

2.2.7.7 If there is a high likelihood that the system may move into the explosive range due to a process upset, protect vapor collection ductwork against explosions by doing **one of** the following:

A. Construct portions of the ductwork to intentionally fail in the event of an explosion, provided this would not cause significant property damage or injury to personnel.

B Install explosion vents in those portions of ducts that are too strong to burst.

2.2.7.8 Use noncombustible or FM Approved duct.

2.2.7.9 If a fire hazard is possible in the ducts between the process and the oxidizer, such as when combustible material may condense and accumulate inside the duct, provide automatic sprinkler protection or water spray in accordance with Data Sheet 7-78, *Industrial Exhaust Systems.* Duct insulation will not always prevent vapor condensation and should be installed on the outside of the duct. A dry system may be necessary in colder climates for out-of-doors ductwork installations. If water drainage back to the process must be prevented, install drains with traps. The traps can be filled with ethylene glycol (where permitted) or an equivalent substance to prevent freezing and evaporation. Design ducts to support the weight of the water while it is being drained.

2.2.8 Oxidizer Sizing

2.2.8.1 Size the oxidizer to prevent it from being overloaded, and air flow capacity from being exceeded. Account for all possible present or anticipated sources and process upsets.

2.2.8.1.1 Consider N+1 redundancy for RTOs serving high-value processes or where bypass is not permissible or available.

2.2.8.2 Size fans to match the system resistance.

2.2.8.3 Where a single oxidizer is used for multiple process units, consider the effect of the failure of part of the exhaust system and/or the oxidizer and the potential interruption to production and business. The introduction of an abnormally high concentration of flammable vapor from any one process exhaust could result in a fire or explosion, affecting part or all of the installation.

2.2.9 Heat Recovery

2.2.9.1 When oxidized combustion products are directly recirculated to the process for heat recovery, supervise the flammable gas and/or oxygen concentration. Combustible gas-oxygen analyzers, or oxidizer temperature differential together with supply/exhaust flow supervision may be used. Supervision may be omitted if air is recirculated through a heat exchanger, or a similar method of indirect heat recovery is used.

2.2.9.2 Refer to Data Sheet 7-99, *Heat Transfer Fluid Systems,* in cases where heat is exchanged in an oxidizer using a circulating system with oil or other organic or synthetic heat transfer fluid.

2.3 Operation and Maintenance

2.3.1 Investigate all emergency shutdowns and safety trips of thermal oxidizers to determine the cause and take necessary corrective action before restarting. Document cause and corrective actions for all emergency shutdowns and safety trips. [NOTE: Also see Data Sheet 10-8, *Operators*.]

2.3.2 Implement a formal management of change policy to address, at a minimum, any changes to the vapor concentration under normal operating conditions, vapor content, processes served, and number of supply streams.

2.3.3 Implement a formal documentation force/jumper system for lockout/bypass during testing, maintenance, and repair.

2.3.4 Provide adequate facilities for access to permit proper inspection, maintenance, and cleaning of both the oxidizer and ducts. (Refer to Data Sheet 7-78, *Industrial Exhaust Systems*.) Cleaning the vapor supply section of duct near the oxidizer, including any associated filters, is especially important because the oxidizer is a likely ignition source for a fire that can spread through the duct. The oxidizer exhaust fan blades may become coated with condensed process vapor and become unbalanced, causing excessive vibration. Establish a cleaning frequency that prevents this condition.

2.3.5 Adhere to the installation instructions and maintenance and inspection requirements of the manufacturer.

2.3.6 Have all safety interlocks tested at least annually by qualified personnel. Record and maintain all test results.

2.3.7 Perform manual leak testing of all fuel safety shutoff valves at least annually.

2.3.8 Inspect all belt-driven fans for worn belts. Establish the inspection frequency based on original equipment manufacturer (OEM) recommendations and modify as needed based on experience.

2.3.9 Monitor pressure differentials across catalyst beds to determine the need for maintenance, or follow manufacturer's instructions.

2.3.9.1 Isolate the heat exchanger beds from the process inlet during the burnout (bakeout) cycle. Using slide gates or dampers with air-purged seals, or removing duct sections and installing blanking plates can accomplish this. Tightly close recirculation dampers.

2.3.10 Calibrate all control/limit devices periodically as recommended by the manufacturer or as determined by local experience.

2.3.11 Inspect combustibles analyzers periodically as recommended by the manufacturer or as determined by operating experience.

2.3.12 Calibrate combustibles analyzers at least quarterly according to the manufacturer's instructions. The frequency of calibration can be adjusted depending on operating experience. In some cases, it is done daily. Unless adequate maintenance of vapor concentration controllers can be provided, do not operate at concentrations exceeding 25% of the LEL. Maintain calibration records and tag equipment due dates.

2.3.13 Inspect and clean recovery heat exchangers periodically. The interval between cleanings will depend on the character of the deposits and accumulation rate.

2.3.14 Document maintenance and inspection activities, including, at a minimum, the type of inspection or maintenance performed, the name of the technician, and the date.

2.3.15 Keep sample lines (when applicable) clean and airtight. Promptly renew filaments when necessary. Pressure test sampling lines annually with low-pressure compressed air to ensure tightness of the system. (When this is done, the air should be pumped up by hand and the instrument isolated from the sampling line). Any changes in the material being sampled require reevaluation of the controller calibration. A momentary bypass may be provided to allow online calibration. Sample line fouling and condensate buildup should be considered when laying out the system. Periodically drain condensate from the system low point, and keep sampling lines clean. Note that sampling lines should not be used with detectors that are not FM Approved to be aspirating. Some detectors, such as catalytic types, are only FM Approved as point detectors.

2.4 Protection

2.4.1 Design heat exchangers and vapor flow conditions to prevent accumulation of solids and condensation of vapor that could cause a fire or explosion hazard.

2.4.2 Provide sprinkler protection for ducts in accordance with 2.2.7.8.

2.5 Construction and Location

2.5.1 Locate oxidizers outside, preferably at ground level, and away from combustible construction. Smaller units, such as catalytic oxidizers, may be located above the process they serve or on the building roof. (Note that roof-mounted oxidizers may resemble HVAC units.)

2.5.2 Provide explosion-relief vents on direct-fired thermal oxidizers, if practical. It might be impractical to install explosion venting on oxidizers lined with heavy refractory and insulating materials.

For equipment capable of withstanding an internal pressure greater than 1.5 psig (0.1 barg), refer to Data Sheet 7-32, *Ignitable Liquid Operations,* Appendix D, for vent-sizing design methodology.

2.6 Ignition Source Control

2.6.1 Do not perform hot work on ductwork containing combustible deposits until the duct has been cleaned. Refer to Data Sheet 10-3, *Hot Work Management*.

3.0 SUPPORT FOR RECOMMENDATION

3.1 Loss History

In FM client losses for which information is available, the primary contributing factors to regenerative thermal oxidizer (RTO) fires and explosions were process upset, lack of maintenance, and lack of operator training (human element).

Upset of the process served by the oxidizer, or the oxidizer itself, was a contributing factor in 26% of fire and explosion incidents. Upset of the process served by the RTO often resulted in a higher concentration of VOCs entering the RTO, causing explosion or uncontrolled ignition. Process upset of the RTO was associated with loss of power to the RTO in several reported cases.

Maintenance and lack of operator training contributed to 29% of losses where contributing factors were reported. Maintenance issues included accumulation of combustible deposits, valve failure, damper failure, and plugged filters. Combustible deposits, valve failure, and damper failure often resulted in higher concentrations of VOCs entering the RTO and contributed to fire spread. In one incident, a plugged filter allowed ignitable liquid carryover into the RTO, resulting in a fire.

Finally, lack of operator training, and specifically lack of operator action under abnormal operating conditions, contributed to several losses. In a number of incidents, operators attempted to reset local alarms at the RTO controls without determining the cause of the alarm.

3.2 Illustrative Losses

3.2.1 Explosion Loss Examples

3.2.1.1 RTO Explosion at Chemical Plant

An RTO at a chemical plant processed two vapor streams: a diluted stream operating at less than the LEL and an inert stream operating at greater than the UEL. These streams were combined upstream of the RTO, where a fresh air stream was admitted to maintain the flammable vapor concentration at the RTO inlet under the LEL. An operator error resulted in a spike in concentration of VOCs in the inert stream leading to the RTO. Operators in a process control room received a high LEL alarm from the RTO. An operator proceeded to the RTO control panel, located at the RTO, and verified the high LEL alarm. The operator observed that the fresh air damper upstream of the RTO was open and attempted to reset the LEL device twice. The operator observed white vapor exiting the dilution air intake, followed by an explosion inside the RTO.

It is probable that operator action to reset the LEL device caused the LEL indicator to briefly reset to zero, allowing dampers upstream of the RTO to open and admit high VOC-content gas to enter the system. The presence of gas scrubbers onsite as a backup to the RTO allowed the facility to continue to operate without interruption.

3.2.1.2 Lack of RTO Bypass Leads to Explosion at Printing Blanket Manufacturer

A printing blanket is a synthetic rubber blanket used in the offset printing process to transfer an image from a metal plate to the paper. An RTO at a printing blanket manufacturer was used to process flammable solvent vapor. Approximately 10 minutes before the explosion, the RTO lost all power. The RTO was provided with appropriate alarms; however, all alarms were taken offline when the RTO lost power. There was no bypass around the RTO for the solvent stream, nor was there an independent LEL detector in the inlet ductwork to the RTO. The RTO fan stopped due to the loss of power, but the process did not receive an alarm or automatically shut down as flammable solvent vapor accumulated in the ductwork. The solvent vapor ultimately found an ignition source, causing an explosion in the ductwork and the process building.

3.2.2 Fire Loss Examples

3.2.2.1 Operator Error Leads to RTO Fire at a Carbon Products Plant

An RTO processed exhaust vapor from a specialty carbon products manufacturing plant. During a routine maintenance procedure on the RTO, a technician mistakenly disconnected the thermocouple that controls the temperature of the oxidizer. It was later determined that the high-temperature limit switch was inoperable. The disconnected thermocouple caused the controls for the oxidizer to continuously call for more heat. The RTO ultimately overheated, melting the tubes in the heat exchanger, causing molten metal to drip onto and through the oxidizer floor and ultimately onto and through the roof, igniting the fibrous glass insulation vapor barrier.

3.2.2.2 Combustible Deposits lead to RTO Fire at a Steel Products Manufacturer

An RTO processed paint and solvent vapor at a steel products manufacturing plant. Condensate deposits had built up in the RTO and associated ductwork over a period of approximately 4 years. At the time of the incident, one of the flow control valves used to control the exhaust stream flow through the RTO heat recovery canisters failed. This caused the exhaust temperature to increase, ultimately igniting the combustible deposits in the RTO. Additionally, the residue buildup in the associated ducts allowed the fire to spread throughout the exterior facility ductwork. Local firefighters were able to extinguish the fire before it spread to the branch ductwork leading back to the booths and ovens. Plant production was transferred to other facilities, limiting the business impact of the incident.

3.3 Supplemental Information

3.3.1 Direct-Flame Oxidizers

Direct-flame oxidizers can be applied to many types of organic solvent vapor, organic dust, and combustible gas. For combustion, the vapor must be heated to its autoignition temperature and have sufficient oxygen with adequate mixing to complete the chemical reaction. Quenching of the burner flame can occur when the capacity of the burner is not sufficient or the flame pattern and mixing is inadequate. The vapor must be retained at the autoignition temperature to permit sufficient time (dwell time) for the chemical reaction to be completed. The dwell time is usually 0.4 to 0.8 sec. Ample oxygen, more than 16% of total flow, is normally available for complete combustion because the process safety ventilation requirements do not permit exceeding 25% of the lower explosive limit (LEL) or 50% of the LEL with adequate combustible gas analyzers and interlocks. (See Figure 2.) Operating temperatures of the combustion chamber may range from 1400°F (538°C) to 2000°F (1093°C).

Special precautions must be taken where the concentrated vapor between 25% and 50% of the LEL are exhausted from the process. For safety, the vapor is usually diluted with air to below 50% LEL for transfer to the oxidizer. The fuel content of the vapor will generate heat when oxidized. The resulting temperature increase is usually several hundred degrees over the inlet temperature, giving a final temperature of 1000°F (538°C) to 1300°F (704°C) where the vapor-air mixture is 25% LEL or less.

If the vapor-air stream to the oxidizer could pass through the flammable range or above the UEL, special care must be taken to prevent propagation of a flame front and possible explosion pressure wave from

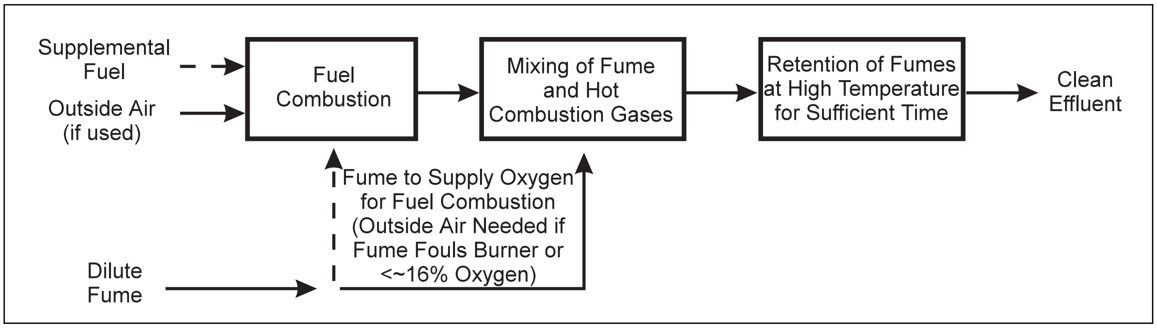

Fig. 2. Steps required for successful incineration of dilute vapor

damaging duct work or interconnected equipment. In flammable vapor-air mixtures, a combustion flame front can change from deflagration to detonation velocities. Deflagration isolation devices, such as chemical blocking systems, fast-acting valves and flame front diverters, may be unreliable. Protection against flame propagation can be achieved with FM Approved detonation arresters.

3.3.2 Catalytic Oxidation

Catalytic oxidizers can be used to reduce compatible vapor-gas air mixtures at relatively low temperatures. The oxidation reaction of the mixture is accelerated when the mixture contacts the heated surface of the catalyst.

The mixture may have such a low energy content that it would not burn with a self-sustaining flame. The use of catalytic units is limited to organic liquid, vapor, and gas of low residual ash content that will not clog or coat the catalyst and its support media. Compounds of arsenic, mercury, tin, silicon, sulphur, zinc, halogens, and similar materials will poison or suppress the catalyst.

Exposure of the catalytic element to the environment of the oxidizer will, in time, decrease the ability of the catalyst to promote oxidation. This aging process is accelerated very rapidly by excessively high temperatures. A three- to five-year service life may be expected for operating temperatures of 1100°F (593°C) or less, but when operating at above 1300°F (704°C) the service life may decrease to about one year. Malfunction of thermocouples and control instruments, and sudden surges in the combustible concentration can rapidly deactivate the catalyst due to overheating. When unheated solvents are passed, the catalyst can become coated; a special cleaning reaction is required to restore efficiency.

The catalyst and the vapor-gas air mixture must be preheated to promote an efficient oxidation reaction. Preheat temperatures should be between 600°F (316°C) and 900°F (482°C) for 90% conversion. The degree of preheat necessary will depend on the type and concentration of the vapor-gas air mixture.

3.4 Combustible Gas Analyzers

There are two types of combustibles detectors that can be used in the ductwork between a process and a thermal or catalytic oxidizer: a sample draw system and a duct-mount system. Each should be investigated to ensure the response time and sampling type is appropriate for the application and installed location of the detector.

When selecting a sample draw system, both the travel time of the vapor in the tubing and the response time of the controller should be considered. FM Approved detectors will have both travel and response times published in their manuals so the total response time can be calculated. The sample draw system is acceptable if the detector is located far enough from the oxidizer that appropriate actions can be taken to either prevent the development of an explosive atmosphere in the ductwork prior to the oxidizer or bypass the oxidizer.

The other type of combustibles detector is the duct-mounted type, and there are two subcategories. Duct-mounted combustibles analyzers usually have faster response times than sample draw systems, and should be considered where the distance between the process and the oxidizer is short.

The first sub-group uses a point detector installed inside the ductwork. The point detector utilizes a sensing element located in the duct. This will provide a much faster reaction time than the sample draw system, but will either only measure the concentration at the edge of the duct or may have a longer nose to reach into the duct. The longer nose design may cause a restriction of flow depending on the ratio of the sensor diameter to the duct size. The sensor nose is typically from 2 to 6 in. (5 to 15 cm) in diameter.

The second type of duct-mounted combustibles detector is the open path type, consisting of optical sensors installed on each side of a duct, projecting an infrared beam across the vapor flow. The open-path type has the fastest response time of the three combustibles detectors.

Whichever detector is used, the potential for fouling at the sampling points and the potential for the detector or sampling tube to restrict flow should be considered when selecting a combustibles detector. Regular inspection and maintenance should be established to ensure accurate and timely measurements.

3.5 Bypass Operation

Thermal and catalytic oxidizers are subject to fires and explosions similar to other heating equipment. They are also subject to overheating due to their high operating temperatures.

Oxidizer losses are often related to the processes they serve. If vapor concentration is not managed properly between a process and an oxidizer, then it is likely that the oxidizer will serve as the ignition source for a duct explosion once vapor concentration reaches the flammable range. A bypass duct and combustibles analyzers can prevent an explosive concentration of vapor from reaching an ignition source by diverting the exhaust stream directly to the outdoors. However, environmental regulations and other operating factors may prohibit or discourage the use of a bypass.

4.0 REFERENCES

4.1 FM

Data Sheet 6-4, *Oil- and Gas-Fired Single-Burner Boilers*
Data Sheet 6-9, *Industrial Ovens and Dryers*
Data Sheet 6-10, *Process Furnaces*
Data Sheet 6-13, *Waste Fuel-Fired Facilities*
Data Sheet 6-17, *Rotary Kilns and Dryers*
Data Sheet 7-2, *Waste Solvent Recovery*
Data Sheet 7-7, *Semiconductor Fabrication Facilities*
Data Sheet 7-9, *Dip Tanks, Flow Coaters and Roll Coaters*
Data Sheet 7-17, *Explosion Protection Systems*
Data Sheet 7-27, *Spray Application of Flammable and Combustible Materials*
Data Sheet 7-32, *Ignitable Liquid Operations*
Data Sheet 7-43, *Process Safety*
Data Sheet 7-45, *Instrumentation and Control in Safety Applications*
Data Sheet 7-78, *Industrial Exhaust Systems*
Data Sheet 7-88, *Storage Tanks for Itnitable Lilqluids*
Data Sheet 7-96, *Printing Plants*
Data Sheet 7-99, *Heat Transfer Fluid Systems*
Data Sheet 10-3, *Hot Work Management*
Data Sheet 10-8, *Operators*

Understanding the Hazard (UTH): *Oven, Dryer, and Thermal Oxidizer Fires and Explosions* (P0246).

4.2 Other

National Fire Protection Agency (NFPA). NFPA 86, *Ovens and Furnaces.*

APPENDIX A GLOSSARY OF TERMS

FM Approved: Products and services that have satisfied the criteria for FM Approval. Refer to the *Approval Guide*, www.approvalguide.com, an online resource of FM Approvals, for a complete listing of products and services that are FM Approved.

Intermittent igniter: An igniter that is in operation at the completion of the igniter trial-for-ignition and remains in operation through the mail burner trial-for-ignition. It may, but does not have to, remain in operation for all or part of the normal operating cycle of the main burner. (No equivalent definition exists in ASME CSD-1.)

Interrupted igniter: An igniter that is in operation at the completion of the igniter trial-for ignition and remains in operation through the main burner trial-for-ignition. It may not be placed in service during the normal operating cycle of the main burner.

LEL: Lower explosive limit.

NCG: Noncondensible gas.

PHA: Process Hazard Analysis.

PLC: Programmable logic controller.

RCO: Regenerative catalytic oxidizers.

RTO: Regenerative thermal oxidizers.

SSOV: Safety shutoff valve.

UEL: Upper explosive limit.

VOC: Volatile organic compound.

APPENDIX B DOCUMENT REVISION HISTORY

July 2018. Interim revision. Recommendation 2.2.3.2 was clarified, new definitions were added to Appendix A, Glossary of Terms.

January 2017. This document has been completely revised. The following major changes were made:

A. Changed the term “fume incinerator” to “thermal oxidizer” throughout the document to be consistent with current industry terminology.

B. Added a recommendation for redundancy on airflow switches/sensors, and specified the types of switches/sensors.

C. Revised vapor concentration management recommendations to address bypass and locations in which bypass is not available or allowed.

D. Added guidance on selecting gas analyzers appropriate to application, sample location, response time, and flow velocity.

E. Added a recommendation to provide high-temperature interlocks in the combustion chamber and the exhaust duct arranged to shut off the supply of fuel and vapor to the combustion chamber.

F .Added an option for performance-based design for temperature control.

G. Revised recommendations for explosion venting in ductwork to remove specific references to vent sizing and location.

H. Added a recommendation for redundancy in new construction.

I. Added a recommendation to investigate all trips before restarting.

J. Added a recommendation to implement management of change procedures.

K. Added a recommendation to use lockout/bypass during maintenance and testing.

L. Added guidance on isolating the catalyst heat exchanger beds from the process inlet during the burnout (bakeout) cycle.

M. Added a recommendation to document all maintenance activities.

N. Deleted recommendations specific to printing plants and transferred them to the appropriate data sheet.

April 2012. Terminology related to ignitable liquids has been revised to provide increased clarity and consistency with regard to FM Global’s loss prevention recommendations for ignitable liquid hazards.

September 2004. Minor editorial change has been made to the recommendation 2.2.5.3.

May 2003. Editorial changes have been made to the recommendations 2.3.1 and 2.2.5.5.

January 2003. Clarification on the use of LEL detectors was made (see recommendations 2.2.4.3 and 2.2.4.4). Loss experience information has been revised.

September 2002. Clarification was made to recommendation 2.2.4.1 and minor editorial changes.

May 2002. Clarification was added to recommendation 2.2.4.4 regarding location of sampling lines.

September 2001. The following changes were made:

1. A warning has been added to section 2.2.1.1.2 regarding the use of pressure switches in place of airflow switches.

2. A recommendation has been added for checking fan belts (2.2.1.1.4).

3. It has been stated that concentrated fumes should be treated similar to a normal fuel (2.2.1.3.2).

4. A recommendation for self-checking UV flame scanners has been added (2.2.1.3.4).

5. Clarifications have been made regarding automatic safety shutoff valve leak testing systems (2.2.3.1 and 2.2.3.2).

6. A recommendation has been added regarding safety shutoff valves in multi-burner systems (2.2.3.1).

7. Recommendations have been added to Section 2.2.4.4 regarding LEL analyzer sampling lines.

8. Changes have been made in Section 2.2.5 regarding temperature control systems.

9. Some changes have been made to Section 2.2.6.1 related to prevention of fume condensation.

10. In Section 2.2.6.2, it has been stated to maintain a slightly negative pressure in the main duct to prevent any back-flow.

11. In Sections 2.2.6.5 and 2.2.6.6, extensive changes have been made regarding explosion protection.

January 2000. This revision of the document has been reorganized to provide a consistent format.