INDUSTRIAL OVENS AND DRYERS

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1.0 SCOPE

This data sheet addresses the inherent fire and explosion hazards in industrial ovens and dryers from fuel, process combustibles, and flammable volatiles.

When appropriate, references to data sheets concerning ancillary equipment and processes have been included. The terms “oven” and “dryer” are used interchangeably in this data sheet.

Special types of ovens, dryers, and kilns and associated processes are addressed in other data sheets (Section 4.0, References).

1.1 Changes

October 2026. Interim revision. Significant changes include the following:

A. Minor editorial changes were made.

B. Improved guidance for protection options in ovens and dryers.

1.2 Hazard

The primary hazards associated with ovens and dryers are fires and explosions. Many ovens process combustible products or products that emit flammable vapor during drying or curing. Special atmosphere ovens can use flammable gas in concentrations above the upper explosive limit (UEL) to aid in processing or curing. Buildup of combustible deposits or accumulation of flammable gases in any portion of the oven, dryer, or ductwork can lead to a serious fire or explosion. Operation, ventilation, protection, and housekeeping recommendations in this data sheet are developed to address the loss experiences of FM clients. See 3.2 Fuel Explosions on page 34 and 3.3 Process Vapor Explosions on page 35 for more information on fuel and process vapor explosions.

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

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 FM Approved Equipment

2.1.1 Use FM Approved equipment, materials, and services whenever they are applicable. For a list of products and services that are FM Approved, see the *Approval Guide*, an online resource of FM Approvals.

2.2 Construction and Location

2.2.1 Oven Location

2.2.1.1 Locate ovens and dryers on the ground floor in buildings of noncombustible construction.

2.2.1.2 Do not locate ovens, dryers, or associated equipment in below-grade areas due to restricted ventilation and accessibility.

2.2.1.3 Where liquid fuels are used, locate and arrange the fuel system components (other than those directly associated with the fuel train) in accordance with FM Property Loss Prevention Data Sheet 7-32, *Ignitable Liquid Operations*; FM Property Loss Prevention Data Sheet 7-88, *Outdoor Ignitable Liquid Storage Tanks*; and other applicable data sheets.

2.2.1.4 Where hazardous equipment, such as a dip tank or drainboard, is located near the oven entrance, design and arrange the equipment in accordance with FM Property Loss Prevention Data Sheet 7-9, *Dip Tanks, Flow Coaters and Roll Coaters.*

2.2.1.5 Keep any necessary storage of cloth, paper, or other combustible materials in process at least 10 ft (3 m) from the oven and its burners, heaters, etc.

2.2.2 Oven Construction and Insulation

2.2.2.1 Construct ovens and dryers as follows:

A. Use noncombustible construction throughout.

B. Arrange interiors with smooth surfaces to permit easy and complete cleaning.

C. Do not permit inaccessible spaces.

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D. Use noncombustible racks, trays, spacers, and containers (where needed), and place them inside ovens so they can be easily cleaned.

E. Make joints between sections of insulated metal panels tight to minimize the leakage of condensable vapor into the interiors of the panels.

F. Provide hazardous location rated electrical equipment in the interior of ovens where flammable vapor is or may be present in accordance with FM Property Loss Prevention Data Sheet 5-1, *Electrical Equipment in Hazardous Locations*.

2.2.2.2 Insulate floors of ovens that operate above 300°F (150°C) to the same degree as the oven walls and roof, and protect against physical damage. Insulation may consist, for example, of a smoothly troweled layer of insulating concrete, applied after the side walls are erected. For the aggregates in the insulating concrete, use perlite, vermiculite, diatomaceous earth, or the equivalent. Use a layer 2 in. (50 mm) thick for 300°F (150°C) oven heat, 3 in. (76 mm) for 400°F (205°C), etc., adding 1 in. (25 mm) for each 100°F (38°C) increase.

2.2.2.3 For outdoor ovens, use special construction to withstand damage from windstorms. See FM Property Loss Prevention Data Sheet 1-28, *Wind Design*.

2.2.3 Ducts

2.2.3.1 Design and install ducts in accordance with FM Property Loss Prevention Data Sheet 7-78, *Industrial Exhaust Systems.*

2.2.3.2 Insulate ducts and ventilate the space around them to keep temperatures of combustible construction below 160°F (71°C).

2.2.3.3 Locate the exhaust duct inlet in the zone or area where the concentration of flammable vapor inside the oven or dryer is greater.

2.2.3.4 Pitch ducts in which flammable vapor condenses so they drain to suitable traps or other safe locations.

2.2.3.5 Avoid the use of a common manifold exhaust duct from multiple ovens or with other equipment. This increases the fire and explosion exposure from one to the other. However, common exhaust ducts may be necessary where ovens are connected to solvent recovery systems and certain fume disposal or cleaning equipment. See FM Property Loss Prevention Data Sheet 6-11, *Thermal and Regenerative Catalytic Oxidizers.*

2.2.3.6 Local regulations may prohibit the use of bypass ducts for environmental reasons. If bypass ducts are prohibited by local regulations, ensure vapor concentration in the ductwork is controlled in accordance with Data Sheet 6-11.

2.2.4 Low-Oxygen Atmosphere Ovens

2.2.4.1 Minimize air infiltration and loss of atmosphere by ensuring that the oven and ducts are essentially gas-tight. Provide gaskets on service doors to minimize leakage.

2.2.4.2 Design the end openings for the product transfer to minimize air and inert atmosphere movement through the entrance and exit openings.

2.3 Protection

2.3.1 Building Fire Protection

2.3.1.1 Provide sprinklers at the ceiling level based on the surrounding occupancy.

2.3.1.2 In addition to sprinklers at the ceiling, provide automatic sprinklers in accordance with FM Property Loss Prevention Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers,* underneath any obstruction where combustible deposits can accumulate.

2.3.1.3 Protect conveyors, including transfer systems between ovens or dryers, in accordance with FM Property Loss Prevention Data Sheet 7-11, *Conveyors*.

2.3.1.4 Protect exhaust systems in accordance with Data Sheet 7-78, *Industrial Exhaust Systems.*

2.3.2 Oven/Dryer Fire Protection

2.3.2.1 Provide protection inside ovens and dryers that meet any of the following criteria:

A. The material being processed or dried is combustible.

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B. The oven / dryer is of combustible construction, including the materials inside the enclosure such as insulation, cabling, ductwork or other combustible components.

C. The oven / dryer is of noncombustible construction but contains process vapors with flammable or ignitable components such as volatile organic compounds (VOC's) or other combustible constituents.

2.3.2.2 Conduct a study to identify the appropriate response of critical equipment (e.g., fuel supply/heating system, conveyors, fans, dampers) upon actuation of the sprinkler system. Factors for determining the proper response include the design of the oven or dryer, the source(s) of combustible materials, the ability to isolate combustible sources, the impact of fresh air, and the consequences of shutting the equipment down or keeping it in operation. Provide interlocks to automatically perform these actions, as determined by the study. See other data sheets for more detailed information on appropriate actions for specific equipment, processes, and/or occupancies.

2.3.3 Automatic Protection Options and Designs

2.3.3.1 Automatic Protection System Options

2.3.3.1.1 Install one of the following automatic protection options for the oven or dryer:

A. Automatic or deluge sprinklers. For operating temperatures above 650°F (343°C), use deluge sprinklers.

B. Deluge water spray nozzles

2.3.3.1.2 When an automatic sprinkler system is provided to protect the oven or dryer, design the system as follows:

2.3.3.1.2.1 Install the system in accordance with Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*.

2.3.3.1.2.2 Locate piping on the outside of the oven, with the sprinklers nipple-down in a pendant position by inverted U bends. If there is not room for the sprinklers themselves, place them in dome-shaped recesses at least 10 in. (254 mm) in diameter.

2.3.3.1.2.3 Use automatic sprinklers with a temperature rating approximately 50°F (28°C) higher than the high temperature limit setting.

2.3.3.1.2.4 Arrange the sprinklers on a maximum spacing of 8 ft by 8 ft (2.4 m by 2.4 m).

2.3.3.1.2.5 Design sprinklers to discharge at least 20 gpm (76 L / min) at the most remote sprinkler with 12 sprinklers flowing simultaneously. Ensure a minimum discharge pressure of 7 psi (0.5 bar) is maintained from all sprinklers. For heavy festooned materials such as plastic and linoleum, increase the sprinkler flow to 30 gpm (110 L / min).

As a general rule, the footprint of the oven / dryer can be used as the sprinkler operating area for smaller equipment. For larger ovens or dryers (see Figures 2.3.3.2.1 and 2.3.3.3.1), accounting for 12 sprinklers to operate is sufficient.

2.3.3.1.2.6 Where duct and oven sprinklers share a common supply, the design must accommodate simultaneous operation.

2.3.3.1.3 When deluge water spray nozzles are provided to protect the oven or dryer, design the system as follows:

2.3.3.1.3.1 Follow the manufacturer specifications for the installation of FM Approved deluge water spray nozzles.

2.3.3.1.3.2 Arrange the deluge water spray nozzles to provide complete coverage of the oven or dryer, including any obstructed areas.

2.3.3.1.3.3 Design the deluge water spray nozzles to provide a minimum 0.15 gpm / ft^2 (6 mm / min) density over the oven / dryer area.

2.3.3.2 Festooned Cloth Dryers

2.3.3.2.1 Install automatic standard sprinklers in festooned cloth dryers, as shown in Figure 2.3.3.2.1 For protection within the festoons, install pendent standard or sidewall sprinklers in a staggered arrangement.

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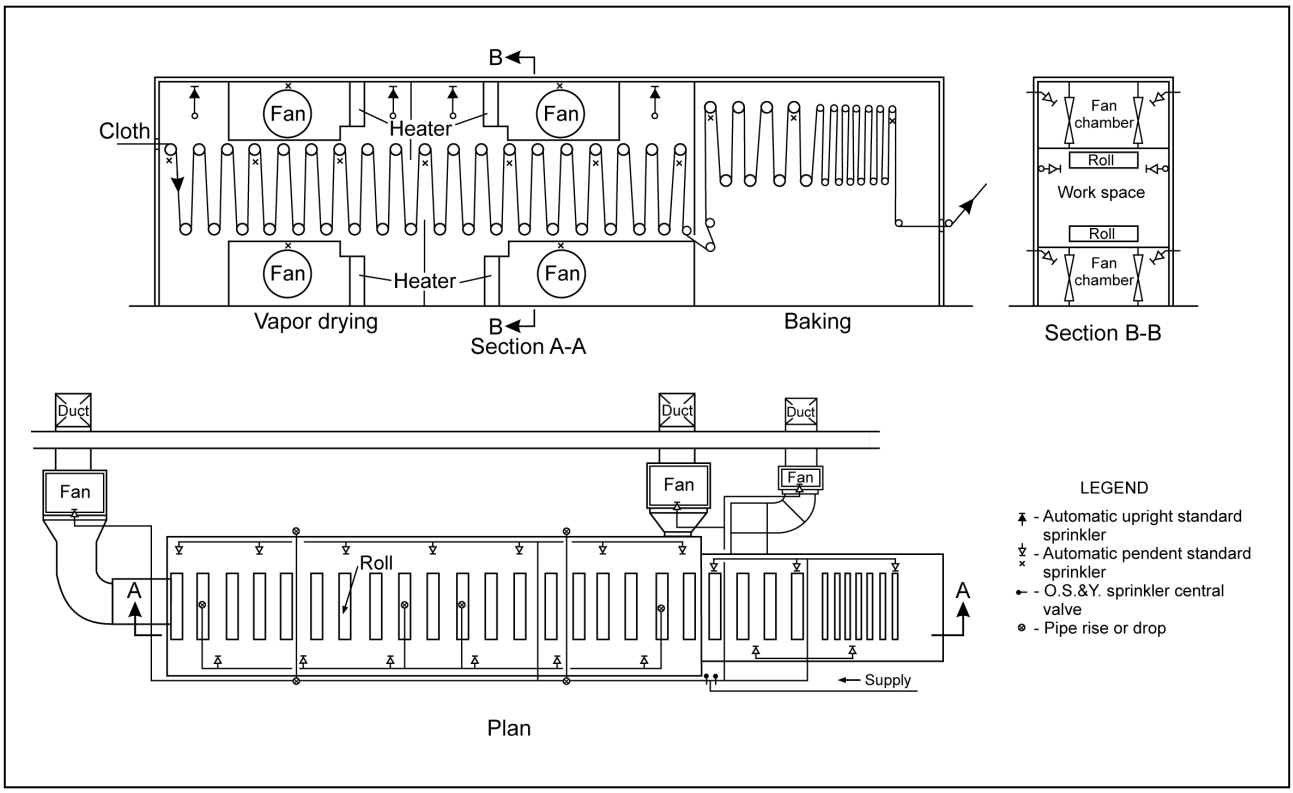


Fig. 2.3.3.2.1 Typical sprinkler arrangement for a festooned cloth dryer.

2.3.3.3 Carpet Dryers

2.3.3.3.1 If carpet cloth makes a single pass between closely spaced hot air ducts, install automatic standard sprinklers as shown in Fig. 2.3.3.3.1.

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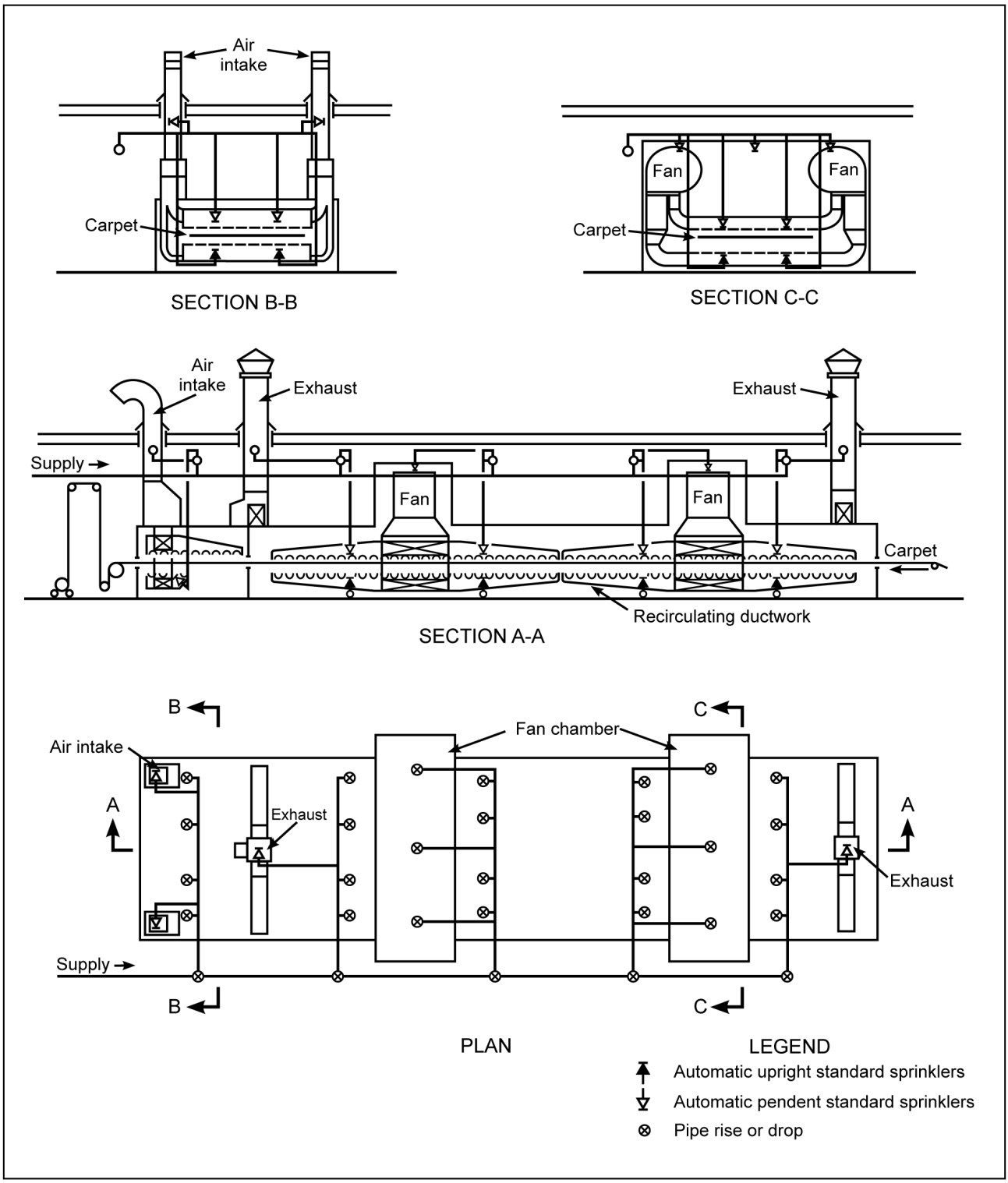


Fig. 2.3.3.3.1 Typical sprinkler arrangement for a single-pass carpet dryer.

2.3.3.4 Festooned Paper, Linoleum, and Plastic Dryers

2.3.3.4.1 Provide automatic sprinkler protection in accordance with Figure 2.3.3.3.1. Provide a minimum clearance of 18 in. (450 mm) between sprinklers and the top of paper festoons.

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2.3.3.5 Heat Transfer Fluid Systems

2.3.3.5.1 For ovens or dryers associated with heat transfer fluid systems, provide automatic fire protection in accordance with FM Property Loss Prevention Data Sheet 7-99, *Heat Transfer Fluid Systems*.

2.3.3.6 Ovens, Dryers, and Lumber Dry Kilns for Wood Processing

2.3.3.6.1 For ovens or dryers associated with wood processing and woodworking operations, provide automatic fire protection in accordance with FM Property Loss Prevention Data Sheet 7-10, *Wood Processing and Woodworking Facilities.*

2.3.4 Spray Dryers Handling Combustible Products

2.3.4.1 Install sprinklers in spray dryers handling combustible products (see Figure 2.3.4.1) as follows:

A. Locate the sprinklers or water spray nozzles around the periphery of the dryer at the top. For dryers having an air-diffuser plate above the product spray head, locate the sprinklers or spray nozzles beneath the diffuser plate; no protection is needed in the space above. Space sprinklers 8 ft (2.4 m) apart around the periphery.

B. In spray dryers having a skirt, install a second set of sprinklers or water spray nozzles beneath the skirt, using the same arrangement and spacing as at the top of the dryer.

C. Make sure automatic sprinklers, if used, have temperature ratings appropriate for the maximum operating temperature of the equipment. For operating temperatures above 650°F (343°C), use open-head deluge systems.

D. Actuate deluge systems, if used, by fixed-temperature heat-responsive devices having temperature settings from 100°F to 125°F (38°C to 52°C) above the maximum operating temperature of the equipment. Locate the devices at the top of the dryer. Alternatively, if there is an air-diffuser plate, locate the devices immediately below the diffuser plate. Do not use rate-of-rise detection devices because of rapid temperature changes during startup.

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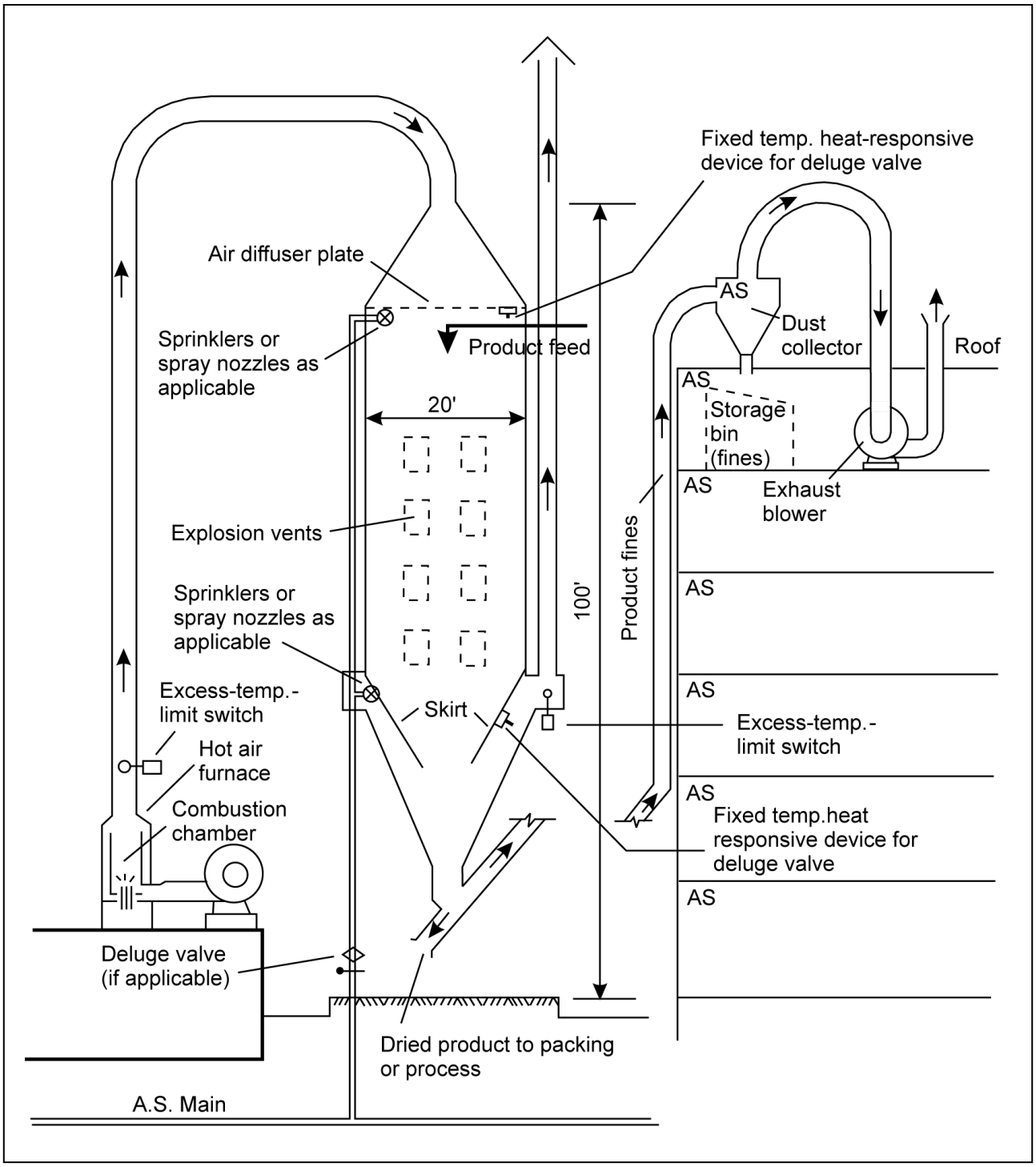


Fig. 2.3.4.1 Typical large spray-drying unit.

2.4 Equipment and Processes

2.4.1 Oven Wiring

2.4.1.1 Install wiring in accordance with locally or nationally recognized applicable code requirements. Use wiring insulation suitable for the maximum temperatures employed.

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2.4.2 Piping Systems

2.4.2.1 For gas-fired or oil-fired ovens or dryers, arrange fuel supply, transfer, and piping systems safely as outlined in Data Sheet 7-32; Data Sheet 7-88*;* FM Property Loss Prevention Data Sheet 7-54, *Natural Gas and Gas Piping;* and other FM recommended practices for handling, piping, and storing gas and oil.

2.4.2.2 For oil-fired ovens or dryers, install emergency shutoff valves or equivalent interlocks in the oil supply piping system to ensure the prompt shutdown of oil flow in the event of a fire. Install these valves in addition to safety shutoff valves installed in the combustion safeguard system (see Section 2.4.8.11). The number and location of emergency shutoff valves will vary depending on the piping system size, complexity, and the potential exposure created by a release. See Data Sheet 7-32, for additional information on these devices and their appropriate placement in the piping system.

2.4.3 Manually Operated Fuel Shutoff Valves

2.4.3.1 Provide each gas-fired or oil-fired oven with a manually operated emergency fuel shutoff valve. Locate these valves so they are prominent and accessible preferably outside the area of the oven.

2.4.4 Air Supply, Oven Ventilation, and Exhaust

2.4.4.1 For ovens and dryers located in a building, provide sufficient make-up air to the room / building containing the oven or dryer to ensure all air required for combustion and safety ventilation is available. This is in addition to the air required for room / building ventilation and any other equipment that uses air.

2.4.4.2 When air is provided by dampers or louvers, provide interlocks to prevent oven and dryer operation unless the dampers / louvers are proved in the open position.

2.4.4.3 Provide interlocks for any fans / blowers required for room air supply, combustion air, safety ventilation in the oven or dryer, air circulation within the oven or dryer, and exhaust from the oven or dryer in accordance with Sections 2.4.4 and 2.4.9.

2.4.4.4 Select oven recirculation and exhaust fans compatible with the maximum exhaust temperature, the material, and the vapor present during operation.

2.4.5 Explosion Vents

2.4.5.1 General

2.4.5.1.1 Recommendations in this section are applicable to the design of explosion vents and latches for ovens and dryers other than spray dryers. For explosion protection of spray dryers, see FM Property Loss Prevention Data Sheet 7-76, *Combustible Dusts*.

2.4.5.1.2 For protection of buildings and other structures, see FM Property Loss Prevention Data Sheet 1-44, *Damage-Limiting Construction*; Data Sheet 7-76; and other applicable data sheets.

2.4.5.1.3 Provide explosion vents for ovens where there are fuel or process vapor explosion hazards.

2.4.5.1.4 Design explosion vents in accordance with the following, as applicable:

A. For weak construction (structure/equipment designed to withstand internal pressures less than 1.5 psi [0.1 bar]), size explosion vents in accordance with Data Sheet 1-44.

B. For strong construction (structure/equipment designed to withstand internal pressures greater than 1.5 psi [0.1 bar]), size explosion vents in accordance with Data Sheet 7-32.

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C. For installations with multiple zones, treat each zone separately when calculating explosion venting.

D. For ovens having horizontal conveyors nearly as wide as the oven, with a relatively large volume below the conveyor where the flammable mixtures could accumulate, locate vents on the oven wall both above and below the plane of the conveyor.

E. Distribute vents evenly along the length of the oven so the maximum distance between vents does not exceed five times the width or height of the oven, whichever is smaller.

F. Locate vents as close as possible to ignition sources. If the oven is compartmentalized, install as much venting as practical near ignition sources.

G. Provide a distance of at least two explosion vent diameters between an explosion vent outlet and any large, flat obstruction (e.g., a wall). Use hydraulic diameter for vents that have a cross section other than circular.

H. Preferably, vent outdoors. For ovens located indoors, a vent pipe or duct may sometimes be needed to direct discharge to a safe outdoor location. Vent pipes and ducts will, however, increase the vented explosive pressure experienced by the equipment. Vent pipes and ducts with a length-to-diameter ratio (L / D) of 1 or less can usually be installed on either high-strength or low-strength equipment if there are no obstructions in the discharge. Do not vent indoors unless the building room volume is at least ten times the vented volume of the oven.

I. Use square or circular vents whenever possible. Where rectangular vents are unavoidable, ensure the longer side is not more than 3 times the shorter side.

J. Use lightweight vent panels, preferably not more than 2.5 lb/ft^2 (12 kg/m^2).

K. Ensure there are no combustibles exposed to the flame jet that would exit the vent. If possible, allow for a distance of 50 ft (15 m) between vents and combustibles that are easily ignited by a short-duration fire exposure.

2.4.5.2 Vent Panel or Door

2.4.5.2.1 If vent doors are hinged on one side and held by latches on the other side, secure the vent doors as follows:

A. Use FM Approved oven door latches for explosion venting.

B. Use the following formula to calculate the maximum allowable release force per latch. Because of the effect of the hinge restraint, only consider one half of the force on the door surface in the calculations for the latch settings and selection.

HINGED DOOR FORMULA:

$$\frac{A}{2} \times Pr = F \times L$$

Or

$$\frac{A}{2} \times \frac{Pr}{L} = F$$

A = Panel area, ft^2 (m^2)
Pr = Release pressure, lb / ft^2 (Pa)
F = Latch release force, lb (N)
L = Number of latches

Example A

Hinged door area	(A) 8 ft^2 (0.74 m^2)
Design release pressure	(Pr) 20 lb / ft^2 (957.6 Pa)
Number of latches	(L) 3

U.S. Customary Units

$$\frac{8}{2}\text{ft}^2 \times \frac{20 \text{ lb/ft}^2}{3} = F = 26.7 \text{ lb maximum allowable release force per latch}$$

Metric

$$\frac{0.74}{2}\text{m}^2 \times \frac{957.6 \text{ Pa}}{3} = F = 118.1 \text{ N maximum allowable release force per latch}$$

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Note: 118.1 N × 0.1020 kg/N = 12.0 kg

C. Obtain the latch release force from the manufacturer's literature and its listing in the *Approval Guide*.

D. Select and install the hinges to resist at least 200% of the total latch release force.

E. Secure or restrain vent panels and doors at the bottom or on one side as necessary to prevent flying missile damage. Do not hinge panels at the top, as the panel weight will impede the discharge of gas through the vent opening. Additionally, the panel may close due to gravity following its operation.

F. Arrange vent doors so they do not close by themselves after opening, thus creating a vacuum inside the oven after an explosion.

2.4.5.2.2 If vent wall panels are secured by latches on two or four sides, with no hinges, secure the panels as follows:

A. Use FM Approved explosion-relieving fasteners.

B. Roof panels may be secured by the panel weight alone.

C. Both wall and roof panels may be secured by shear pins of specific shear strength that will break at the designed panel-oven release pressure.

D. Use the following formula to calculate the maximum allowable release force per latch. Deduct the weight of the roof panels from the design release pressure before calculating the fasteners or latch forces.

UNHINGED PANEL FORMULA:

$A \times Pr = F \times L$

Or

$$\frac{A \times Pr}{L} = F$$

Example B

Panel Area	(A) 8 ft^2 (0.74 m^2)
Design release pressure	(Pr) 20 lb / ft^2 (957.6 Pa)
Number of latches	(L) 4

U.S. Customary Units

$$\frac{8 \text{ ft}^2 \times 20 \text{ lb/ft}^2}{4} = F = 40 \text{ lb maximum allowable release force per latch}$$

Metric

$$0.74 \times \frac{957.6}{4} = F = 177.2 \text{ N maximum allowable release force per latch}$$

Note: 177.2 N × 0.1020 kg/N = 18.1 kg

2.4.5.2.3 Explosion vents need not be provided on low-oxygen atmosphere ovens due to the difficulty of maintaining the oven gas tight. The inert atmosphere and the emergency inert system provide appropriate explosion prevention.

2.4.6 Temperature Controls

2.4.6.1 Never exceed the safe operating temperature of the dryer or oven.

2.4.6.2 Provide an excess temperature limit control (requiring manual reset) that is independent of any automatic or manual temperature control. Arrange the interlock to activate an audible / visual alarm and automatically shutdown the fuel supply or source of heat. Ensure the excess temperature limit controller indicates the temperature and is marked with the set point.

2.4.6.3 If combustible materials are processed in the oven, set the limit at least 100°F (38°C) below the autoignition temperature of the material being processed.

2.4.6.4 Locate the sensor for the excess temperature limit control in accordance with a risk assessment to determine the optimal location for hazard mitigation.

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2.4.6.5 For gas-fired or oil-fired ovens and dryers, interlock the excess temperature limit control with the safety shutoff valves.

2.4.6.6 For steam-heated ovens and dryers, interlock the excess temperature limit control with a self-closing valve in the steam supply line.

2.4.6.7 For electrically heated ovens and dryers, interlock the excess temperature limit control with a contactor in the main supply circuit to the heating units. Do not use the contactor that is used for temperature control.

2.4.6.8 Only use components for the excess temperature control that will fail safe (i.e., cause the same response as an excess temperature condition).

2.4.6.9 For zoned ovens, provide separate excess temperature limit controls in each zone.

2.4.6.10 For zoned ovens, provide an audible / visual low temperature alarm in a zone if a low temperature condition will result in evaporation of a flammable vapor in a downstream zone exceeding the level that can be exhausted by the exhaust ventilation system.

2.4.7 Electric Heater Safeguards

2.4.7.1 Protect electric heating units and infrared lamps from physical damage or contact with the work by guards or baffles.

2.4.7.2 Provide a high temperature interlock, arranged to audibly alarm and shut down the heating system.

2.4.8 Combustion Safeguards

2.4.8.1 General

2.4.8.1.1 This section provides guidelines for burner system sequencing, combustion safeguards and interlocks for the prevention of fuel explosions in industrial ovens and dryers.

2.4.8.2 Burner Safeguards

2.4.8.2.1 Basic safeguards for oven and dryer burner systems include:

A. Proof of adequate combustion air and ventilation air.

B. A reliable ignition source before fuel can reach the main burner.

C. A limited trial-for-ignition of the main burner flame.

D. Shutoff of fuel on flame failure. Flame outage is the ultimate effect of undesirable existing conditions in the fuel-air supplies and fuel-air mixing and ignition-system equipment.

E. At least one hardwired manual emergency shutdown switch through which the operator can shut down all fuel and ignition energy to the oven or dryer. Locate the emergency shutdown switch to permit operator access during upset or fire conditions.

F. Safety interlock trips. When an oven or dryer operates automatically without constant operator attendance, all trip interlocks require manual reset unless the interlock system includes a high-high (or low-low) redundant interlock. In those cases, operation of the high (or low) interlock may not require a manual reset provided the control system is designed to automatically restart the oven or dryer when the trip condition clears. Operation of the high-high or low-low interlock means its associated high or low interlock did not function and safety shutdown requiring a manual reset is required. All trips require operator intervention and manual reset for ovens and dryers not designed for unattended automatic operation.

2.4.8.3 Interlocks

2.4.8.3.1 The proper combination of interlocks and flame-supervisory combustion safeguards is essential. Supervision of fuel pressures, airflow, essential air-damper positions, fans, purging, oil temperatures, and oil-atomizing medium is important for anticipating the development of unsafe conditions and for initiating a safety shutdown even though flame outage has not yet occurred. This supervision gives further protection by preventing improper sequences of operation that could result in a hazardous condition.

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2.4.8.4 Purge Ventilation

2.4.8.4.1 At gas-fired and oil-fired ovens, provide an automatic pre-ignition ventilation period to purge the work chambers and / or combustion chambers of fuel vapor and flammable gases that may have accumulated during shutdown before fuel safety shutoff valves and electric ignition can be energized.

2.4.8.4.2 For indirect-fired ovens, an automatic purge for the work chambers may be omitted. A manually controlled purge by the best available means is acceptable provided no flammable vapor is given off by the materials processed.

2.4.8.4.3 For direct-fired ovens, manually controlled purge by the best available means is acceptable, provided the following criteria are met:

A. The volume of the oven, based on external dimensions, is less than 350 ft^3 (10 m^3).

B. No flammable vapor is given off by the work processed.

C. Interlocks are provided and their contacts wired into the oven's safety control circuit.

2.4.8.4.4 This will ensure opening of oven doors and fresh-air inlet dampers and operation of fans before the fuel safety shutoff valve(s) can be energized and opened and electric ignition activated.

2.4.8.4.5 For both mechanical and natural-draft ventilation systems, it may be necessary to open doors and have the fresh-air inlet and exhaust dampers in the open position to provide sufficient purge air. Provide interlocks to prove the dampers and doors in the correct position or use mechanical stops and cutaway dampers.

2.4.8.4.6 Provide a purge of at least four volume changes with fresh air by operating the recirculating and ventilating fans.

2.4.8.5 Purge Relighting

2.4.8.5.1 In the event of a safety shutdown, a relight may be attempted without a timed re-purge provided there is sufficient mechanical ventilation to prevent the accumulation of a flammable atmosphere. Continued operation of the fans (supply, exhaust, and recirculation) may maintain the purged condition.

2.4.8.5.2 Where sufficient mechanical ventilation is not available, provide purge ventilation as outlined in Section 2.4.8.4.

2.4.8.5.3 Reignite burners having pilots with the pilots. Do not attempt to ignite burners from the hot refractory. Reignite burners individually in accordance with the normal lighting sequence.

2.4.8.6 Combustion-Air Blower and Products-of-Combustion Ventilating Fan Interlocks

2.4.8.6.1. Interlock each fan / blower to ensure that they are placed in operation before the fuel safety shutoff valves and electric ignition can be energized. This also ensures that the oven control system will automatically close the safety shutoff valves and deactivate the ignition system, if either the fan / blower stops or the flame is stopped during an upset condition. Ensure fans and blowers are multi-belt driven unless a direct coupling drive is used. The following are acceptable interlocking methods:

A. Mount a rotational switch on the fan's drive shaft and wire it into the safety control circuit. The switch closes when the fan reaches the predetermined speed for adequate ventilation.

B. Wire the 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.

2.4.8.6.2 Do not provide starter protection with a rating that exceeds the conventional rating required for the fan motor alone.

2.4.8.6.3 Provide an airflow or differential pressure switch for each fan wired into the safety control circuit. This is not needed for oil burners where there is a direct shaft connection between the fuel pump and combustion air fan.

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2.4.8.7 Fuel Pressure Interlocks

2.4.8.7.1 Provide fuel pressure interlocks, low and high gas pressure switches for gas burners, low oil pressure switches for oil burners, and low atomizing medium pressure switches (air or steam) for oil burners.

2.4.8.8 Oil Preheating Equipment and Low-Oil-Temperature Interlocks

2.4.8.8.1 Provide oil-temperature interlocks for heavy-oil burners that require preheated oil. Configure the interlocks to prevent burner light-off when the oil temperature is below the burner manufacturer's recommended minimum and to shut off all fuel, including closure of the oil safety shutoff valves, if the oil temperature falls outside the recommended range during firing.

2.4.8.9 Proved Low-Fire-Start Interlock

2.4.8.9.1 Provide a low-fire-start interlock where the burner must be started at a low fire setting.

2.4.8.10 Individual Burner Valves and Observation Ports

2.4.8.10.1 At manually operated ovens, provide a separate, manually operated quarter-turn valve for each burner whenever practical. Use valve handles that are constructed of metal and visually indicate the ON and OFF positions.

2.4.8.10.2 At manually operated ovens, provide observation ports for each of the burners so pilots, electric igniters and flame-sensing elements of combustion safeguards can be easily observed.

2.4.8.10.3 Locate observation ports for burners fueled through individual valves so that the ignition sources can be positively observed before and while the operator opens the valve to light the burner.

2.4.8.11 Safety Shutoff Valves

2.4.8.11.1 For gas-fired burners, provide two safety shutoff valves for each pilot and main burner system, a system being one or more burners operated as a unit. If the pilot or burner system input exceeds 400,000 Btu / hr (117 kW), provide proof-of-closure on one of the safety shutoff valves.

Exception: If an explosion-resistant (including heat recovery system) radiant tube-type of heating system is used, a single safety shutoff valve is adequate.

2.4.8.11.2 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 valve with proof-of-closure at each burner. Verify the burner safety shutoff valve is closed after shutdown. If it is not proved closed, ensure all safety shutoff valves in the system are closed.

2.4.8.11.3 For oil-fired burners, provide a single safety shutoff valve. Or, provide two safety shutoff valves, one having proof-of-closure, if (a) the oil pressure is greater than 125 psi (8.6 bar), (b) the oil pump is independent of the burner, or (c) the oil pump operates during gas-firing for combination oil / gas burners.

Exceptions:

A. If an oil burner using No. 4 or lighter oil includes an individual control unit within the burner assembly (e.g., pump, pressure regulators, and shutoff valve), an external safety shutoff valve is not needed. Configure the control unit to shut off fuel within 5 seconds after the oil-burner motor is de-energized.

B. If an oil burner using No. 4 or lighter fuel oil includes an individual motor-driven blower within the burner assembly and the blower air is used to aspirate and deliver fuel oil to the burner, an external safety shutoff valve is not needed. Configure the system to shut off fuel within 5 seconds after the combustion air blower motor is de-energized.

C. If an oil burner using No. 4 or lighter fuel oil is of the aspirating type and uses compressed air to draw oil from a reservoir, applying a fuel-oil safety shutoff valve is generally impractical. Install a gas safety shutoff valve in the aspirating air line to the burner and configure it to stop fuel delivery within 5 seconds after the valve is de-energized.

2.4.8.11.4 Provide a permanent and ready means to periodically check the tightness of the main gas burner’s safety shutoff valves. See FM Property Loss Prevention Data Sheet 6-0, *Elements of Industrial Heating Equipment*.

2.4.8.11.5 Inspect and test safety controls at least annually, whenever maintenance involving the safety controls is performed and after any modification to the safety controls. Conduct inspection and testing in accordance with manufacturer's instructions.

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2.4.8.12 Fuel-Air Mixers

2.4.8.12.1 Do not use low-pressure (below 1 psi [0.069 bar]) atmospheric inspirators. A gas-air mixer with a blower or compressor is preferable to a high-pressure atmospheric inspirator.

2.4.8.13 Limiting Burner Turndown

2.4.8.13.1 Limit burner turndown at gas and oil burner systems so stable flames and complete combustion are obtained at the low firing rate. Gas-fired oven heaters, for example, may have burners using zero governor inspirator mixers where the heater pressure is highly negative with respect to room pressure. Limit turndown so the proportion of air at the mixer does not fall below 85% of the amount needed for complete combustion. Where the desired turndown would reduce the air below 85%, the diaphragm of the zero governor may be specially loaded by connecting the space in the housing above the diaphragm (which is normally vented outdoors or other safe location) to the combustion heater chamber.

2.4.8.13.2 At gas-fired heaters that have burners using low-pressure atmospheric inspirator mixers, install the burner only for constant firing at a fixed rate or on / off firing. It may be used for high-low or modulated firing, provided the low firing is 50% or more of rated burner input.

2.4.8.14 Combustion Air Piping Systems

2.4.8.14.1 Interlock the combustion air and fuel supplies so failure of either will shut off and lock out the fuel. Fuel gas usually leaks through zero governors if gas cocks have not been closed after blower shutdown. The mixture in the combustion air piping may be ignited by a flashback through the burner started by hot furnace refractory. Even with furnaces under 100 ft^3 (2.8 m^3) in volume, provide interlocking where two or more furnaces are supplied by one blower.

2.4.8.14.2 If the combustion air blower can aspirate fuel, provide an interlock to prevent blower operation during the purge period to minimize possible leakage from the aspirating effect.

2.4.8.15 Automatic Fire Checks and Safety Blowouts

2.4.8.15.1 Provide automatic fire checks and safety blowouts (sometimes called “backfire preventers”) in piping systems that distribute flammable air-gas mixtures from gas mixing machines to protect the piping and the machines in the event of an explosion. (Note: Automatic fire checks and safety blowouts cannot be installed in burner systems using blower mixers that do not permit valves to be located in piping downstream from their outlets.)

Install automatic fire checks and safety blowouts in accordance with the following recommendations:

A. Install the automatic fire checks upstream, as close as practicable to the burner inlets. Be certain to follow the fire check manufacturer’s instructions. Either install a separate fire check at each burner or at each group of burners. The second method is generally more practical if a system consists of many closely spaced burners.

B. Provide a separate, manually-operated gas cock at each automatic fire check to shut off the flow of the air-gas mixture after a flashback has occurred. Locate the cocks upstream, as close as practical to the inlets of the automatic fire checks.

C. Never reopen any of these cocks after a flashback has occurred until the fire check has cooled sufficiently to prevent reignition of the flammable mixture and it has been properly reset.

D. Provide a safety blowout device (backfire preventer) near the outlet of each gas mixing machine where the piping is larger than 2.5 in. (64 mm) NPS or equivalent to protect the machine if an explosion passes through an automatic fire check.

2.4.8.15.2 Follow the manufacturer’s instructions in installing these devices. Acceptable safety blowouts are available from some manufacturers of gas-mixing machines. They incorporate the following components and design features:

- a flame arrestor
- a blowout disk
- a provision for automatically shutting off the supply of the air-gas mixture to the burners in the event of a flashback passing through an automatic fire check

2.4.8.16 Pilots and Ignitors

2.4.8.16.1 For the main burners of gas-fired and oil-fired ovens, use premixed pilots with sufficiently large capacities to ensure ignition of the main burners.

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2.4.8.16.2 External oven heaters can be provided with pilots with low-pressure (gas pressure below 1.0 psi [69 mbar]) atmospheric inspirator mixers supplied with undiluted gas, if the heater chambers into which the pilots fire are continuously maintained sufficiently negative (at least -0.20 in. water column [0.5 mbar]) with respect to room-air pressure. To ensure this negative pressure, induce the proper amount of fresh air for complete combustion using motor-driven fans.

2.4.8.16.3 The main burners of gas-fired and oil-fired automatic and semi-automatic-lighted ovens can be ignited by normal gas-fired or oil-fired pilots. Provide combustion safeguards wired into the safety control circuit as described in Section 2.4.8.18, unless the ovens are indirect-fired and have explosion-resistant heating systems.

2.4.8.16.4 Gas and light (No. 4 or lighter) oil-fired ovens can be provided with direct electric ignition if the design of the burners renders gas pilots impractical.

2.4.8.16.5 Ensure the pilot flame is stable, even during substantial fluctuations in draft or back pressure.

2.4.8.16.6 Ruggedly design each pilot mounting assembly and install securely so the pilot cannot be moved out of the position where it will furnish reliable ignition for the burner.

2.4.8.17 Direct Electric Ignition

2.4.8.17.1 At gas or light-oil burners, including multi-nozzle power burners and continuous-line burners having direct electric ignition, automatically limit the trial-for-ignition periods to 5 seconds. Do not use direct electric ignition for main burners with a fuel input greater than 2,500,000 Btu / hr (730 kW / h) unless a low-fire start is provided using a slow-opening valve or a modulating motor with interlock.

2.4.8.17.2 If more than 5 seconds is needed to reliably ignite the burner due to time needed for fuel to reach the burner, the trial-for-ignition period can be extended if it can be demonstrated that 25% of the LEL cannot be exceeded during the extended time.

2.4.8.18 Combustion Safeguards

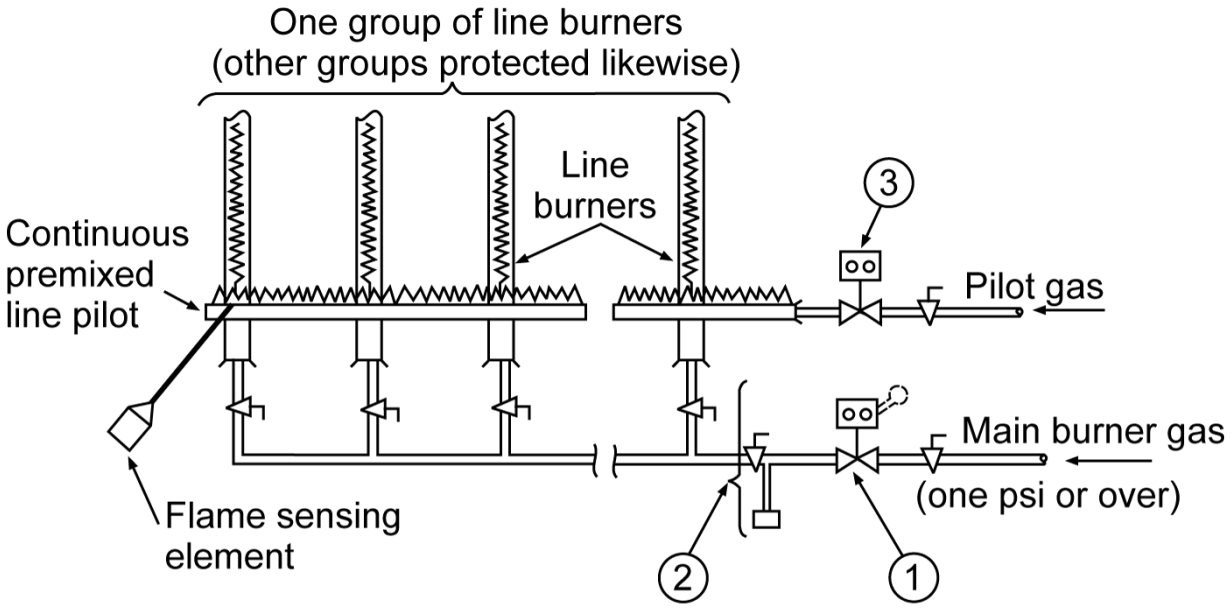
2.4.8.18.1 Install FM Approved combustion safeguards at gas-fired and oil-fired ovens to supervise burner flames. It is acceptable to supervise the flames of two adjacent main burners with a single combustion safeguard if the burners will ignite one from the other at all firing rates. The maximum flame failure response time is 4 seconds.

2.4.8.18.2 Supervise the main burner flame alone rather than supervising the pilot and main burner flames simultaneously. With the former system, the main burner’s trial-for-ignition periods can be automatically limited.

2.4.8.18.3 Install flame-sensing elements in accordance with the manufacturer’s instructions, and ensure they are securely mounted so their position in respect to the pilot and main burner flames will not change.

Combustion safeguards are usually practical for line burners if they are arranged in groups so that a combustion safeguard for each group may supervise a continuous line pilot during light-off and firing (see Figure 2.4.8.18-1). Combustion safeguards are also usually practical if continuous line burners (including radiant-cup burners or line-burner sections attached consecutively to a common burner manifold and having a reliable flame propagation characteristic from one to the other) are arranged in groups so that a combustion safeguard for each group will supervise a pilot during lighting-off and main flame alone during firing (see Figure 2.4.8.18-2).

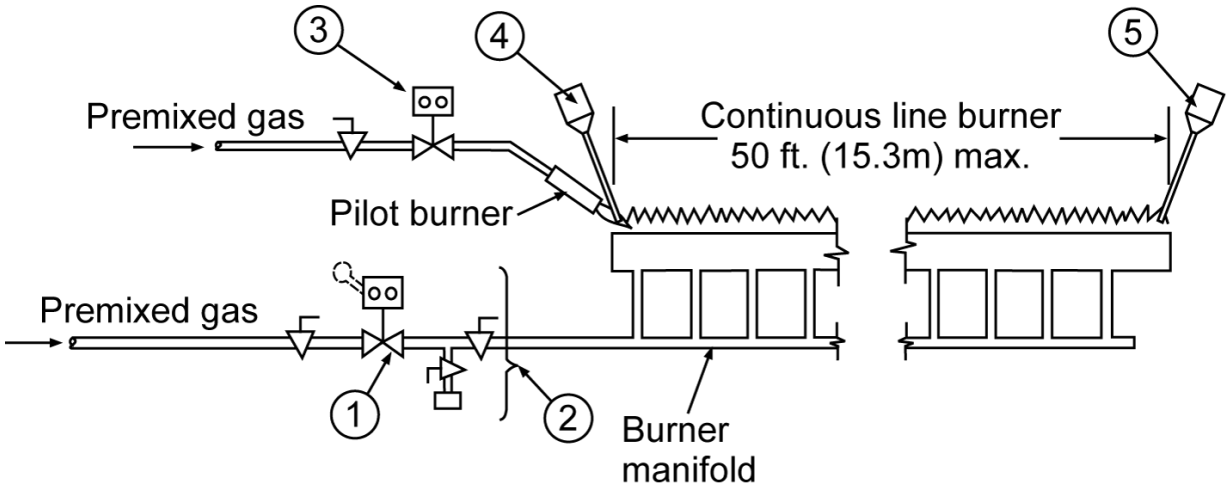
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1. Approved main gas safety shutoff valve. Manual-opening, automatic-closing valve or automatic-opening and closing valve, to suit firing method used.
2. Permanent and ready means for making periodic tightness checks of main gas safety shutoff valve.
3. Approved pilot gas safety shutoff valve.

Fig. 2.4.8.18-1. Example of application of a combustion safeguard supervising a continuous line pilot for a group of line burners during lighting-off and firing

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1. Approved main gas safety shutoff valve. Manual-opening, automatic-closing valve or automatic-opening and closing valve, to suit firing method used.
2. Permanent and ready means for making periodic checks of main gas safety shutoff valve.
3. Approved pilot gas safety shutoff valve.
4. Pilot flame sensing element. Wired into safety control circuit so that it is automatically cut out of combustion safeguard's flame detecting circuit at end of trial-for-ignition period. (Flame rod shown, but a photoconductive cell, infrared or ultraviolet scanner may be used.)
5. Main flame sensing element. Wired into combustion safeguard's flame detecting circuit, unlike pilot flame sensing element 4, it is not cut out but remains in the flame detecting circuit during light-off and firing. (Flame rod shown, but a photoconductive cell, infrared or ultraviolet scanner may be used.)

Fig. 2.4.8.18-2. Example of application of a combustion safeguard supervising a pilot for a continuous line burner during lighting-off and the main flame alone during firing

2.4.8.19 Operation Sequencing

2.4.8.19.1 For gas and oil pilots and main burners, automatically limit the trial-for-ignition (interrupted pilots) and main flame establishing periods to 15 seconds.

2.4.8.19.2 Limit automatic recycling to one attempt to relight after accidental flame failure during firing. Do not use automatic recycling except for automatically lighted ovens having pilots.

2.4.8.19.3 At continuous-line gas burners, the total length of burner supervised by a single FM Approved combustion safeguard is limited to 50 ft (15.2 m). At burners where the total length exceeds 20 ft (6.1 m), the trial-for-ignition periods are automatically limited to not more than 15 seconds (see Figure 2.4.8.18-2). This includes those consisting of a limited number of individual radiant-cup burners or line-burner sections that are supplied from a common burner manifold, have reliable flame propagation between consecutive burners without special external flame-propagation devices, and are located directly adjacent to one another.

2.4.9 Safety Ventilation

2.4.9.1 General

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2.4.9.1.1 Dilute the vapor evaporated at the peak rate to a concentration not exceeding 25% of the LEL using safety ventilation. Flammable vapor concentrations up to 50% of LEL are permitted if continuous vapor concentration indicators and controllers are used as recommended in Section 2.4.9.2.5.

2.4.9.1.2 Provide an automatic pre-ignition ventilation period for each oven startup at gas-, oil-, steam- or electric-heated ovens to purge the work chamber of any flammable vapor before the heating or electric ignition systems can be activated and the conveyor placed in operation.

2.4.9.1.3 Provide a purge consisting of at least four volume changes with fresh air.

2.4.9.1.4 If closure or incorrect positioning of any door or damper will prevent proper purging of the entire oven work chamber, interlock it with the safety-control circuit to ensure proper positioning before and during the purge period.

2.4.9.1.5 Design throttling dampers so the system will handle at least the minimum ventilation rate required for safety at normal operation when they are set in their maximum throttling position. This can be done by cutting away part of the dampers or permanently stopping them partially open to produce the necessary ventilation rate as proved by airflow tests. This does not apply to any dampers that may be required in connection with special extinguishing systems.

2.4.9.1.6 In ovens where dampers and variable-speed fans control the safety ventilation or temperature by modulating airflow, design the system so that reducing the volume of air cannot reduce the safety ventilation rate below that required for safe operation. If LEL detectors are used, provide a fast-acting continuous LEL detector interlocked to shut down the source of heat and solvent or product feed, and bypass the exhaust to atmosphere where an oxidizer is used, at no more than 50% of the LEL. See Section 2.4.9.2.5.

2.4.9.1.7 Provide a positive safety ventilation system using one or more motor-driven centrifugal fans to safely dilute and discharge vapor given off by the work to oxidizers / solvent recovery systems or out-of-doors. Do not return atmosphere containing flammable vapor to the heated work chamber through the fans (see Figure 2.4.9.1.7) unless the system is designed to prevent excessive concentrations. See Section 2.4.9.2 and Data Sheet 6-11.

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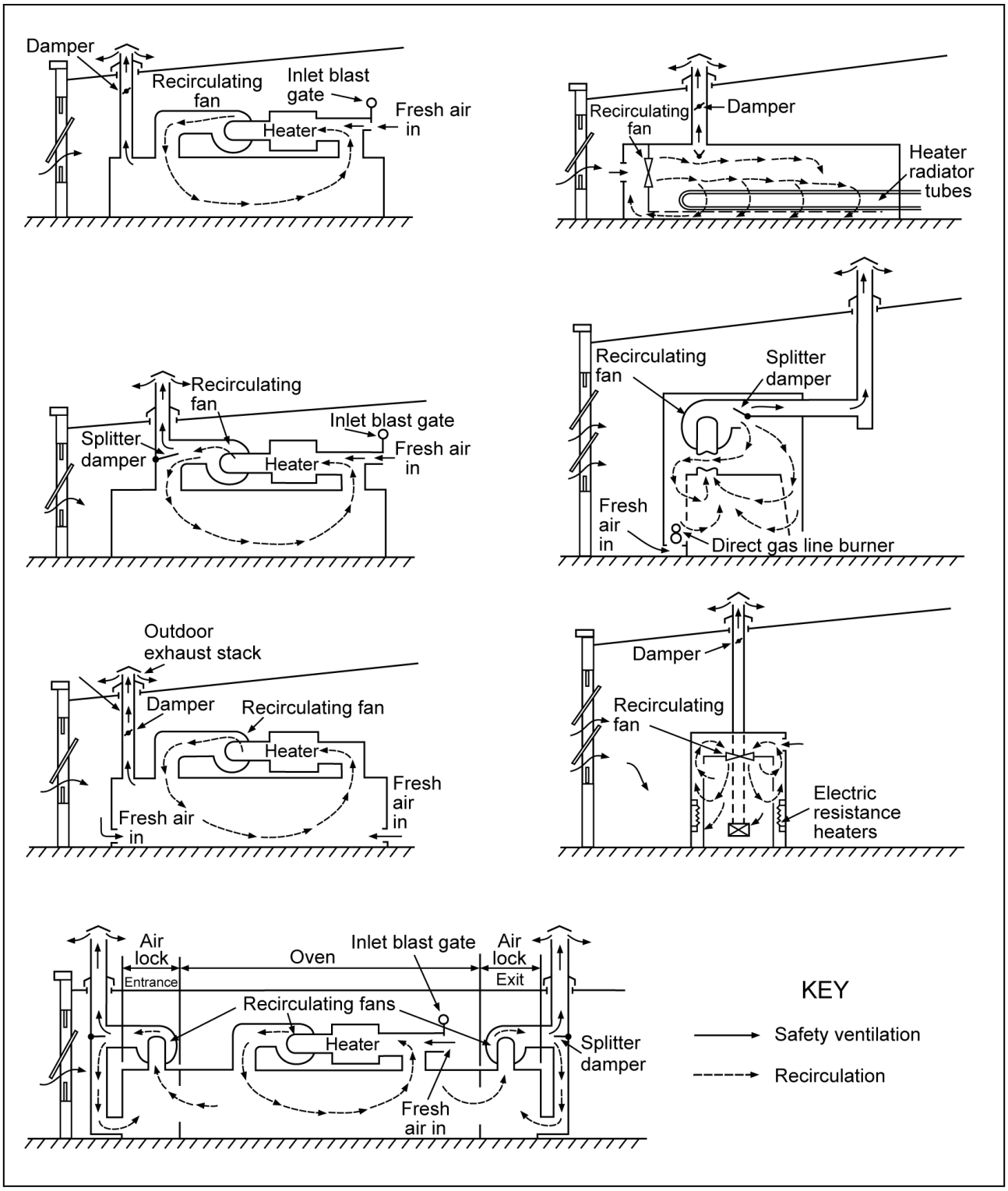


Fig. 2.4.9.1.7 Typical unacceptable safety ventilation systems using dual purpose fans alone (recirculation combined with spill exhaust)

2.4.9.1.8 Circulate the fresh air within the oven to all parts of the work chamber and around the material being heated. This is best done by motor-driven circulating or recirculating fans so arranged that there are no pockets where solvent vapor can accumulate.

2.4.9.1.9 Provide interlocks for fans, conveyors, and heating systems to ensure the following:

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A. All fans whose failure would adversely affect the safety ventilation rate or flow pattern are placed in operation before the conveyor can be started.

B. Failure of any fan will automatically stop the conveyor, close the safety shutoff valves, and deactivate the ignition (of gas-fired or oil-fired ovens) or de-energize electrically heated ovens. If stopping the conveyor is likely to result in the work igniting, provide interlocks to ensure the following:

1. The conveyor is in operation before the safety shutoff valves can be energized and opened and the electric ignition system activated (for gas-fired and oil-fired ovens), or the heating system energized (for electric-heated ovens).

2. Failure of the conveyor will automatically close the safety shutoff valves, deactivate the ignition system, or (for electric-heated ovens) open the contactor in the main power supply.

It is acceptable to move the conveyor semi-automatically to remove work from the oven in the event of a conveyor stoppage due to fan failure. This may be controlled by a pushbutton switch.

Where an automatic material feeding system supplies a conveyor at a point adjoining the oven entrance (as with a lithograph oven coater) the feeding system may be interlocked with the fans instead of the conveyor.

2.4.9.1.10 Connect safety ventilating fans to their motors by direct coupling or V-belt drive using two or more belts.

2.4.9.1.11 Select each fan so that, under field conditions, its operating point will fall in the steep portion of the characteristic curve of volume versus static pressure with fan speed constant (see Figure 2.4.9.1.11-1). Increased resistance in the system at ducts and inlets, the effect of outdoor wind conditions or fans drawing from the same room, etc., will produce the minimum reduction in the safety ventilation rate. To ensure each fan will have an adequate pressure characteristic for normal safety ventilation duty, select the fan with the following blade-tip speeds in operating condition:

- At least 7,500 ft/min (2,286 m/min) for fans having backward inclined blades (see Figure 2.4.9.1.11-2, Group 1)
- At least 6,800 ft/min (2,072 m/min) for fans having radial tip blades (see Figure 2.4.9.1.11-2, Group 2)
- At least 5,000 ft/min (1,524 m/min) for fans having forward curved blades (see Figure 2.4.9.1.11-2, Group 3)

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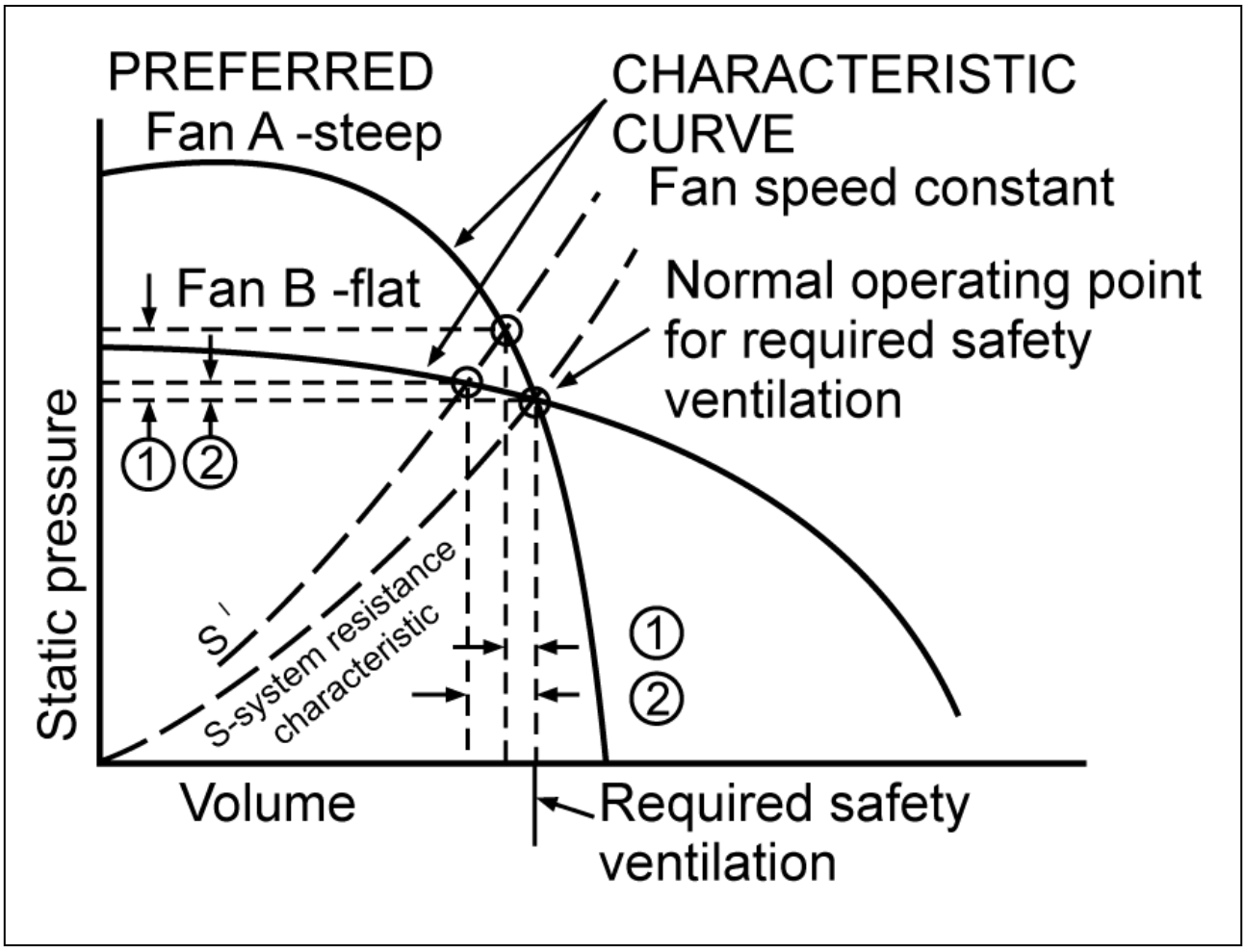
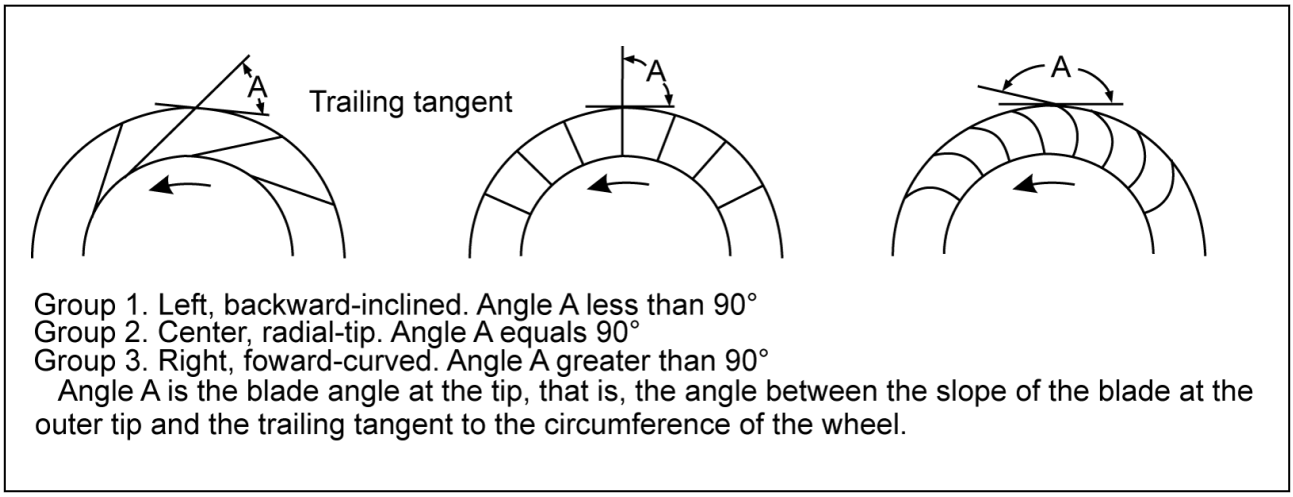


Fig. 2.4.9.1.11-1. Selection of a safety ventilating fan. The reduction of volume for fan B exceeds that of fan A for a given increase in system resistance



Group 1. Left, backward-inclined. Angle A less than 90°
Group 2. Center, radial-tip. Angle A equals 90°
Group 3. Right, foward-curved. Angle A greater than 90°
Angle A is the blade angle at the tip, that is, the angle between the slope of the blade at the outer tip and the trailing tangent to the circumference of the wheel.

Fig. 2.4.9.1.11-2. Centrifugal fans; divided into three groups according to blade shape

2.4.9.1.12 Provide a fan interlock in the oven safety-control circuit for each fan whose failure would adversely affect the safety ventilation rate or flow pattern. There are four acceptable methods:

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

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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 dirirectly (or through a transformer) from the load side of an overcurrent-protected starter for the fan motor.

Do not provide starter overcurrent protection with a rating that exceeds the conventional rating required for the fan motor alone.

2.4.9.1.13 Provide an airflow or differential pressure switch for each fan wired into the safety control circuit.

2.4.9.2 Rate Determination

2.4.9.2.1 Safety Ventilation Rate

2.4.9.2.1.1 Determine the necessary safety ventilation rate for batch, continuous, and powder curing ovens using the calculations in Appendix C.1.

2.4.9.2.2 Fuel Correction

2.4.9.2.2.1 For direct-fired ovens, add the volume of combustion products to the volume calculated for safety ventilation to obtain the total safety ventilation. The volume of combustion products may be calculated as follows:

US Customary Units:

Total Burner Rating (Btu / hr) / (95 x 60) = ft^3 / min at 70°F

Metric:

Total Burner Rating (kW) x 60 / 3600 = m^3 / min at 20°C

2.4.9.2.3 Temperature Correction

2.4.9.2.3.1 Consider temperature correction factors when selecting the size of exhaust fan needed to move the required volume of fresh air referred to 70°F (21°C) into an oven operating at "t" degrees. For example, to move a volume of 1000 cfm (28.3 m^3 / min) of fresh air referred to 70°F (21°C) into an oven operating at 300°F (149°C), it is necessary to exhaust:

US Customary Units:

$$V_t = V_{70} \times \frac{460 + t}{530} \text{ or } V_t = V_{70} \times \frac{460 + t}{460 + 70}$$

$$\frac{460 + 300°F}{460 + 70°F} \times 1000 \text{ cfm} = 1434 \text{ cfm of exhaust at } 300°F$$

Metric:

$$V_t = V_{21} \times \frac{273 + t}{294} \text{ or } V_t = V_{21} \times \frac{273 + t}{273 + 21}$$

$$\frac{273 + 149°C}{273 + 21°C} \times 28.3 \text{ m}^3/\text{min} = 40.6 \text{ m}^3/\text{min at } 149°C$$

Where V_t = Fan size (volume) at temperature t

2.4.9.2.4 Altitude Correction

2.4.9.2.4.1 If the altitude of the process exceeds 1000 ft (305 m), apply a correction factor to the necessary ventilation rate in accordance with Table 2.4.9.2.4.

Table 2.4.9.2.4. Altitude Correction Factors

Altitude, ft (m)	*Correction Factor*
0 (0)	1.00
1000 (305)	1.04
2000 (610)	1.08

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***Table 2.4.9.2.4. Altitude Correction Factors* (continued)**

Altitude, ft (m)	*Correction Factor*
3000 (915)	1.12
4000 (1220)	1.16
5000 (1524)	1.20
6000 (1829)	1.25
7000 (2134)	1.30
8000 (2438)	1.25
9000 (2743)	1.40
10,000 (3048)	1.45

2.4.9.2.5 Vapor Concentration Detectors/Controllers

2.4.9.2.5.1 Provide continuous-type, vapor-concentration detectors / controllers at ovens that (because of special process demands) are operated at vapor concentrations above 25% of the lower explosive limit. See FM Property Loss Prevention Data Sheet 5-49, *Gas and Vapor Detectors and Analysis Systems,* and Data Sheet 6-11. These detectors / controllers are occasionally used with continuous-process ovens where large amounts of ignitable liquids are evaporated.

2.4.9.2.5.2 Arrange the vapor-concentration detector to alarm at no more than 45% of the LEL. Automatically shut down the process at no more than 50% of the LEL.

2.4.9.2.5.3 In multi-zone ovens, sample the atmosphere in each zone, except where it has been determined that the atmosphere in that zone cannot exceed 25% of the lower explosive limit (LEL).

2.4.9.2.5.4 Select the sample point location to represent the average vapor concentration within the oven. Ensure oven atmosphere circulation is adequate to prevent localized areas of high vapor concentration that could compromise the effectiveness of the sample point. Do not locate the sample point near the evaporation surface, where vapor concentrations are significantly higher than the oven average.

2.4.9.2.5.5 Use FM Approved gas detectors mounted directly on the oven or dryer to minimize system response time. Configure the detection system and to complete the associated protective actions within 5 seconds of gas detection.

2.4.9.2.5.6 Install the vapor-concentration detector according to the manufacturer’s instructions and have them serviced periodically by the manufacturer or qualified personnel.

2.4.9.2.5.7 Calibrate the detector appropriately for the solvents being used. Obtain correction factors from the manufacturer for the solvents being used.

2.4.9.2.5.8 Correct the actuation settings for the maximum anticipated oven temperature. Lower explosive limit (LEL) values decrease with higher oven temperatures (see Table 2.4.9.2.5.8).

Table 2.4.9.2.5.8 Lower Explosive Limit Correction Factors for Elevated Oven Temperatures

Oven Temperature	*LEL Correction Factor*
77°F (25°C)	1.00
212°F (100°C)	0.94
300°F (149°C)	0.90
400°F (204°C)	0.86
500°F (260°C)	0.82

Note: These values were derived from data presented in US Bureau of Mines Bulletin 627.

To determine the exact LEL corrected for temperature, use the following equation from US Bureau of Mines Bulletin 627:

$LEL_t = LEL_{77°F}$ [1 - 0.000436 (t°F - 77°F)] [US Customary Units]

$LEL_t = LEL_{25°C}$ [1 - 0.000784 (t°C - 25°C)] [Metric]

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2.4.10 Low-Oxygen Atmosphere Ovens

2.4.10.1 Perform a process hazard analysis in accordance with FM Property Loss Prevention Data Sheet 7-45, *Safety Controls, Alarms, and Interlocks*, to determine allowable oxygen content of the oven atmosphere based on the flammability level of the solvent to ensure the atmosphere cannot reach flammable limits under normal operating conditions. See Table 2.4.10.1.

Table 2.4.10.1 Limiting Oxidant Concentrations for Flammable Gases When Nitrogen or Carbon Dioxide are Used as Diluents

	Updated or Adjusted Data		*Original Data*	
	N_2-Air Mixture	CO_2-Air Mixture	N_2-Air Mixture	CO_2-Air Mixture
Gas / Vapor	LOC	LOC	LOC	LOC
Paraffins (alkanes)				
Methane	11.1[a]	(13.1)[b]	12.1[b]	14.6[b]
Ethane	(9.5)[b]	(11.9)[b]	11.0[b]	13.4[b]
Propane	10.7[a]	(12.8)[b]	11.4[b]	14.3[b]
n-Butane	(10.6)[b]	(13.0)[b]	12.1[b]	14.5[b]
Isobutane (methylpropane)	(10.5)[b]	(13.3)[b]	12.0[b]	14.8[b]
n-Pentane	(10.6)[b]	(12.9)[b]	12.1[b]	14.4[b]
Isopentane (2-methylbutane)	(10.5)[c]	(13.0)[c]	12.0[c]	14.5[c]
n-Hexane	(10.4)[b]	(13.0)[b]	11.9[b]	14.5[b]
n-Heptane	(10.0)[c]	(13.0)[c]	11.5[c]	14.5
Cycloparaffins (cycloalkanes, naphthenes)				
Cyclopropane	(10.2)[b]	(12.4)[b]	11.7[b]	13.9[b]
Olefins (alkenes)				
Ethylene (ethene)	8.5[a]	(10.2)[b]	10.0[b]	11.7[b]
Propylene (propene)	(10.0)[b]	(12.6)[b]	11.5[b]	14.1[b]
α-butylene (1-butene)	(10.1)[b]	(12.5)[b]	11.6[b]	14.0[b]
Isobutylene (2-methylpropene)	(10.5)[c]	(13.5)[c]	12.0[c]	15.0[c]
Isopentene (2-methyl-1-butene)	(10.0)[c]	(12.5)[c]	11.5[c]	14.0[c]
Diolefins (dienes)				
1,3-Butadiene	(8.9)[b]	(11.6)[b]	10.4[b]	13.1[b]
Aromatics				
Benzene	(11.4)[d]	(12.4)[b]	11.4[d]	13.9[b]
Ethylbenzene	9.0[d,e]	-	9.0[d,e]	-
Diethylbenzene	8.5[d,f]	-	8.5[d,f]	-
Divinylbenzene	8.5[d,f]	-	8.5[d,f]	-
Toluene	9.5[g,h]	-	9.5[g,h]	-
Vinyltoluene	9.0[d,i]	-	9.0[d,i]	-
Styrene (phenylethene)	9.0[d,j]	-	9.0[d,j]	-
Alcohols				
Methyl aclohol (methanol)	(8.5)[c]	(10.5)[c]	10.0[c]	12.0[c]
Ethyl alcohol (ethanol)	(9.0)[c]	(11.5)[c]	10.5[c]	13.0[c]
Ethyl alcohol (ethanol)	8.7[g,h]	-	8.7[g,h]	-
n-Propyl alcohol (n-propanol)	8.6[g,h]	-	8.6[g,h]	-

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***Table 2.4.10.1 Limiting Oxidant Concentrations for Flammable Gases When Nitrogen or Carbon Dioxide are Used as Diluents* (continued)**

	Updated or Adjusted Data		*Original Data*	
	N_2-Air Mixture	**CO_2-Air Mixture**	**N_2-Air Mixture**	**CO_2-Air Mixture**
Gas / Vapor	**LOC**	**LOC**	**LOC**	**LOC**
Isopropyl alcohol (2-propanol)	9.5[k,h]	-	9.5[k,h]	-
t-Butyl alcohol (t-butanol)	-	(15.0)[c,l]	-	16.5[c,l]
Isobutyl alcohol (2-methyl-1-propanol)	9.1[g,h]	-	9.1[g,h]	-
Isohexyl alcohol (2-ethyl-1-butanol)	(7.9)[c,l]	-	9.3[c,l]	-
Esters				
Methyl Formate	(8.5)[c]	(11.0)[c]	10.0[c]	12.5[c]
Methyl acetate	(9.5)[c]	(12.0)[c]	11.0[c]	13.5[c]
n-Propyl acetate	10.1[k,h]	-	10.1[k,h]	-
Isopropyl acetate	8.8[g,h]	-	8.8[g,h]	-
n-Butyl acetate	9.0[g,h]	-	9.0[g,h]	-
Isobutyl acetate	9.1[g,h]	-	9.1[g,h]	-
Isobutyl formate	(11.0)[c]	(13.5)[c]	12.5[c]	15.0[c]
Ethers				
Methyl ether	(9.0)[c]	(11.5)[c]	10.5[c]	13.0[c]
Ethyl ether	(9.0)[c]	(11.5)[c]	10.5[c]	13.0[c]
Propylene oxide	(6.6)[m]	-	7.8[m]	-
Ketones				
Acetone	(10.0)[c]	(12.5)[c]	11.5[c]	14.0[c]
Methyl ethyl ketone	(9.5)[c]	(12.0)[c]	11.0[c]	13.5[c]
Organo-chlorides				
n-butyl chloride	(12.5)[c]	-	14.0[c]	-
	(10.5)[b,n]	-	12.0[b,n]	-
Methylene chloride	(17.5)[b,o]	-	19.0[b,o]	-
	(15.5)[c,n]	-	17.0[c,n]	-
Ethylene dichloride	(11.5)[c]	-	13.0	-
	(10.0)[b,n]	(15.0)[b,n]	11.5[b,n]	16.5[b,n]
1,1,1-Trichloroethane	(12.5)[c]	-	14.0[c]	-
Tricholoroethane	(7.7)[c,n]	-	9.0[c,n]	-
Vinyl Chloride	13.4[d,h]	-	13.4[d,h]	-
Vinylidene chloride	15.0[d]	-	15.0[d]	-
Inorganic Compounds				
Carbon disulfide	(4.3)[c]	(6.4)[c]	5.0[c]	7.5[c]
Carbon monoxide (in air)	5.1[a]	(5.1)[c]	5.5[c]	5.5[c]
Hydrogen (in air)	4.6[a]	(4.6)[c]	5.0[c]	5.2[c]
Hydrogen sulfide (in air)	(6.4)[c]	(10.0)[c]	7.5[c]	11.5[c]
Miscellaneous nitrogen-containing compounds				
UDMH (1,1-dimethyl hydrazine)	(6.0)[c]	-	7.0[c]	-
Commercial fuels				

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***Table 2.4.10.1 Limiting Oxidant Concentrations for Flammable Gases When Nitrogen or Carbon Dioxide are Used as Diluents* (continued)**

	Updated or Adjusted Data		*Original Data*	
	N_2-Air Mixture	**CO_2-Air Mixture**	**N_2-Air Mixture**	**CO_2-Air Mixture**
Gas / Vapor	**LOC**	**LOC**	**LOC**	**LOC**
Motor Gasolines				
(70/100)	(10.5)[c]	(13.5)[c]	12.0[c]	15.0[c]
(100/130)	(10.5)[c]	(13.5)[c]	12.0[c]	15.0[c]
(115/145)	(10.5)[c]	(13.0)[c]	12.0[c]	14.5[c]
Aviation fuels				
Kerosene	(8.5)[c,l]	(11.5)[c,l]	10.0[c,l]	13.0[c,l]
JP-1 fuel	(9.0)[c,l]	(12.5)[c,l]	10.5[c,l]	14.0[c,l]
JP-3 fuel	(10.5)[c]	(13.0)[c]	12.0[c]	15.5[c]
JP-4 fuel	(10.0)[c]	(13.0)[c]	11.5[c]	14.5[c]
Natural gas				
(Pittsburgh natural gas)	(10.5)[b]	(12.9)[b]	12.0[b]	14.4[b]

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All experiments performed at 25° C (77° F) unless otherwise indicated.

[a] 120 L (31.7 gal) apparatus — I. A. Zlochower and G. M. Green, “Mining Publication: The Limiting Oxygen Concentration and Flammability of Gases and Gas Mixtures” (June 2009).

[b] Flammability tube — Table 44 of Bureau of Mines Bulletin 503, “Limits of Flammability of Gases and Vapors” (1952).

[c] Flammability tube — Table 11 of J. M. Kuchta, A. L. Furno, A. Bartkowiak, and G. H. Martindill, “Effect of Pressure and Temperature on Flammability Limits of Chlorinated Combustibles in Oxygen-Nitrogen and Nitrogen Tetroxide-Nitrogen Atmospheres” (1968).

[d] ~5 L (1.3 gal) vessel, ASTM E681, Standard Test Method for Concentration Limits of Flammability of Chemicals (Vapors and Gases) (2015). – The Dow Chemical Company (Unpublished).

[e] Experiments performed at 70°C (160°F).

[f] Experiments performed at 114°C (237°F).

[g] ~5 L (1.3 gal) vessel, ASTM E2079, Standard Test Methods for Limiting Oxygen (Oxidant) Concentration in Gases and Vapors (2013); — L. G. Britton, “Using Heats of Oxidation to Evaluate Flammability Hazards,” Process Safety Progress (2002).

[h] Experiments performed at 60°C (140°F).

[i] Experiments performed at 105°C (221°F).

[j] Experiments performed at 73°C (163°F).

[k] ~5 L (1.3 gal) vessel, ASTM E2079, Standard Test Methods for Limiting Oxygen (Oxidant) Concentration in Gases and Vapors (2013) — L. G. Britton, The Dow Chemical Company, 1999 (Unpublished Report).

[l] Experiments performed at 150°C (300°F).

[m] R. M. Jones, “Reducing the Inflammability of Fumigants with Carbon Dioxide,” Industrial & Engineering Chemistry Research (1933).

[n] Experiments performed at 100°C (210°F).

[o] Experiments performed at 30°C (86°F).

2.4.10.2 Provide an oxygen analyzer for each oven zone to control the oxygen content. Provide a second analyzer system to actuate an inert gas emergency purge. Connect this analyzer directly to the emergency purge system bypassing all process control devices.

2.4.10.3 Provide metering and control with the inert gas flow control. Equip the system with an automatic emergency inerting mode using a manually-operated switch.

2.4.10.4 Provide emergency standby power for the fans and safety controls.

2.4.10.5 Provide for the availability of an emergency purge in the event of a power failure.

2.4.10.6 Design the inert and emergency gas system to prevent over-pressurization of the piping and (glass tube) flow meters.

2.4.10.7 Protect the oven from over-pressure because of the emergency inerting. An emergency vent actuated during the emergency purge may be provided.

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2.4.10.8 Design the inert gas system including any vaporizers to provide the maximum flow rates for all demand conditions.

2.4.10.9 Design vaporizers, when provided, to provide 150% of the highest purge-gas flows. Consider loss of power.

2.4.10.10 Size inert gas storage for process and emergency purge to have at least a minimum of five oven volumes for oven purge.

2.4.10.11 Provide a visual or audible alarm arranged to alarm if inert gas flow can be interrupted due to low temperature or low flow from the vaporizer.

2.4.11 Autoclaves and Vacuformers Used for Bonding and Curing

2.4.11.1 Use one or more of the following safeguards depending on the value of the work load, the amount of damage to the load by interruption of the curing cycle, and the cost of the safeguard in relation to the value of the load:

A. Cut-off valves on the vacuum line to each platen, arranged to close automatically if vacuum is lost within the plastic bag.

B. Use of an inert gas such as nitrogen, carbon dioxide, or waste off-gas as the pressurizing medium, reducing the oxygen content to 10% or less

C. A water spray protection system in the autoclave (water spray, where provided for cooling the load at the end of the curing cycle, may also be used for fire protection)

D. High-temperature cutout

E. High chilled water temperature alarm or cutout (heat supply)

2.5 Operation and Maintenance

2.5.1 Human Factors

2.5.1.1 Safety Control Bypass Management

2.5.1.1.1 Develop and implement a program to document and track safety interlock bypasses (jumpers) installed by operations personnel. Include the reason for the bypass, the personnel authorizing it, the expected reinstatement date and time, and the procedure for restoring the safety control to service in the documentation.

2.5.1.1.2 Substitute alternate means to supervise the interlock being bypassed in accordance with operating procedures.

2.5.1.1.3 Minimize the amount of time the safety control is out of service.

2.5.1.2 Safety Shutdown Investigation

2.5.1.2.1 Following any safety shutdown, determine the cause of the shutdown prior to restarting equipment.

2.5.1.2.2 Include operating procedures to delay restart of equipment based on cool-down or purge time to prevent a flammable atmosphere from developing in the oven or dryer.

2.5.1.2.3 Include operating procedures to identify equipment operating outside of normal parameters following a safety shutdown, and remove it from service prior to restarting equipment.

2.5.2 Operating Parameters

2.5.2.1 Develop and implement a plan for deviating from normal operating conditions, including, but not limited to:

- Conveyor speed, where applicable
- Oven/dryer temperature
- Materials being processed
- Ventilation rate/fan speed
- Structural alterations to the enclosure

Several oven and dryer losses involved materials being overheated due to changes in the conveyor and / or oven / dryer setpoints without evaluating the impact of the changes.

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2.5.3 Commissioning

2.5.3.1 Installation Tests

2.5.3.1.1 Before an oven is placed in service, measure the minimum ventilation rate provided by the safety ventilation system. At the same time, check the evaporation rate to ensure the safety ventilation system capacity will be adequate. Tests have often shown wide variance between design capacity and actual measurements taken in the field.

2.5.3.1.2 Measure the ventilation rate before making any process changes that would affect the rate of ventilation required. These include changing the character of the work or solvent (or the percentage by weight of solvent), increasing batch loads or conveyor speeds, shortening pre-drying periods, and increasing oven / dryer temperatures or ramp rates. Moreover, before making such changes, determine the evaporation rate and recalculate safety ventilation. Never operate an oven with its safety ventilation system impaired or overburdened.

2.5.3.1.3 Special hazards are introduced when ovens are connected to solvent recovery or fume incineration systems, so make frequent checks of the safety ventilation's adequacy. Include determination of the evaporation rate and airflow.

If oxidizers are not sized properly, they may not be able to maintain the required temperature at full airflow. Cutting back on the ventilation to increase temperature is hazardous. If this condition exists, increase the burner size.

2.5.4 Burnouts and Fires in Indirect Air Heaters

2.5.4.1 If heat exchangers in indirect gas-fired or oil-fired air heaters can be seriously damaged by burnouts or fire from carbon or soot deposits, take the following precautions:

A. Maintain burner-mixer adjustments to provide for complete combustion. Do not permit flame impingement on heat exchanger tubes.

B. Follow a rigid cleaning schedule to prevent accumulation of soot or carbon.

C. Keep heater and oven fans running after burners are shut down to prevent abnormal temperature buildup in the heat exchanger from residual heat in the combustion chamber.

D. Allow no dampers or other obstructions in the hot air ducts that would affect the free flow of air through the heat exchanger.

E. Provide an excess temperature limit switch at each discharge duct for products of combustion leaving the heat exchanger, arranged to shut off all fuel to the burners if temperature of the products of combustion rises 50°F (10°C) above the normal maximum.

2.5.5 Oven Maintenance

2.5.5.1 Maintain all oven and dryer equipment, and components in good condition, per manufacturers' recommendations.

2.5.5.2 If present, perform inspection, testing and maintenance of all fans, blowers, motors, and controllers per FM Property Loss Prevention Data Sheet 13-24, *Fans and Blowers*.

2.5.5.3 Inspect and test safety controls at least annually and in accordance with the manufacturer's instructions.

2.5.5.4 Clean ovens and ducts at regular intervals if they are subject to buildups of flammable deposits of condensed solvent or oil vapor, or accumulations of combustible lint, dust, or other material. In general, do not allow combustible deposits in ducts for paint, varnish, and core-baking ovens to accumulate to more than 1 / 8 in. (3 mm) thickness between cleanings. The rate at which deposits build varies considerably with different ovens and processes; no specific schedule can cover all ovens. Clean new ovens on a weekly schedule until sufficient experience is obtained to establish the necessary frequency.

2.5.5.5 Clean deposits and drips from racks, trays, and conveyors regularly. Use metal (or other noncombustible material) trays to collect drippings from ovens and drainboards. Use trays that can be removed for cleaning.

2.5.5.6 Pay particular attention to cleanliness at heaters with steam coils, housings, and ductwork since these are the hottest spots where charring and eventual ignition are most likely. Remove fuel oil leakage or condensed oil vapor in the vicinity of oven heaters frequently, and tighten piping to prevent further leakage. Also pay particular attention to the end of ducts supplying fume incinerators since these incinerators are a likely ignition source.

The method of cleaning varies with the nature of the deposits. Scraping with non-sparking tools is probably the most widely used method for soft or easily removed deposits. Exceptionally hard deposits may have to be melted by steam, or the ducts dismantled and scraped. Even burning out dismantled ducts at a safe location in the yard is a method that has been used. Remove lint and dust by vacuum cleaning. Do not blow with compressed air or steam because of the possibility of explosion from a combustible dust cloud.

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2.5.6 Explosion Vent Maintenance and Tests

2.5.6.1 Visually inspect explosion vents at least daily to ensure the vents are not obstructed.

2.5.6.2 Visually inspect explosion vents at least quarterly for signs of corrosion or other damage.

2.5.6.3 Conduct and document pull / push tests of hinged or latched explosion vents with pressure release measurement at least annually.

2.5.7 Electrical and Mechanical Maintenance

2.5.7.1 Perform maintenance on a complete and rigid schedule, specific for each device (see FM Property Loss Prevention Data Sheet 5-20, *Electrical Testing*). Keep complete records of the preventive maintenance program.

2.5.8 Inspection of Safety Controls

2.5.8.1 Function-test safety controls on a regular schedule, but at least in accordance with Table 2.5.8.1.

Table 2.5.8.1. Test Frequency for Functionality Tests of Safety Controls

Interlock	*Test Frequency*
Igniter and burner components	Semiannual[1]
Combustion air supply system	Semiannual[1]
Piping, wiring, and connections of all interlocks and shutoff valves	Semiannual[1]
Combustion control system	Semiannual[1]
Calibration of indication and recording instruments	Semiannual[1]
Automatic fire checks	Semiannual[1]
Operating sequence tests, all components	Semiannual[1]
Combustible gas analysis automatic interlocks (calibrate as needed)	Semiannual[1]
Gas cleaner and drip leg	Semiannual[1]
Explosion venting latches	Semiannual[1]
Conveyor interlocks	Semiannual[1]
Fuel safety shutoff valve(s) for leakage	Annual
Fan and airflow interlocks	Annual
Purge interlocks	Annual
Flame failure system components	Annual
High-temperature limit switch	Annual
Door-and-damper limit switches	Annual
Oil pressure and temperature interlocks	Annual
Oil Atomizing media interlocks	Annual
High and low gas fuel pressure interlocks	Annual

[1] Semiannual or annual, as required by manufacturer's instructions or operating history

2.6 Training

2.6.1 Develop and implement an operator training program in accordance with FM Property Loss Prevention Data Sheet 10-8, *Operators*. Include normal operation and emergency response in the training program.

2.6.2 Train operators in relighting procedures following accidental flame failure. Procedures will vary with the individual oven.

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2.7 Ignition Source Control

2.7.1 Hot Work

2.7.1.1 Develop and implement a hot work management program in accordance with FM Property Loss Prevention Data Sheet 10-3, *Hot Work Management*, to strictly control all hot work operations.

3.0 SUPPORT FOR RECOMMENDATIONS

Most oven / dryer losses are due to fires and explosions. The following sections describe many of the typical causes of fire and explosion. Burner management, temperature control, safety ventilation, control of solvent feed, explosion venting, and cleaning of internal deposits are all very important safeguards. Installation and testing of safety devices, control of ignition sources, good housekeeping, and the installation of automatic sprinklers are equally important loss prevention practices. If an LEL detection system is installed, it is critical that it be properly designed and have a fast response time. Losses have occurred where these detection systems did not respond due to improper installation.

3.1 Fire

Fires have occurred at dryers and ovens of practically every type. The following types of ovens have been most frequently involved in fire:

- Coated metal (paint) ovens
- Textile, fiberboard, and paper dryers
- Ovens for impregnated electric coils
- Core ovens
- Dryers for evaporating low-flash-point solvents used in rubber coating

3.1.1 Paint Ovens

Spontaneous heating and autoignition of deposits in ovens or ducts cause one out of three paint oven fires. Paint drippings or coated parts coming in contact with burner flames or electric heaters are another leading cause.

In batch ovens, overheating due to failure of thermostatic controls and the use of combustible racks, trays, or spacers account for more than half of the fire losses. Flammable deposits of condensed vapor in exhaust ducts are the second most important defect.

Most duct fires occur at ovens using lacquer or other finishes whose deposits are subject to spontaneous ignition. Occasionally, serious fires occur in oil-fired oven heaters, usually involving soot deposits in heat exchanger tubes.

3.1.2 Textile Dryers

Most fires in dryers for textile fibers are caused by ignition of lint that has accumulated on high-pressure steam coils. To avoid excessive temperatures, pressure at coils is limited to 100 psi (6.9 bar) (steam temperature 338°F [170°C]) and is preferably kept below 75 psi (5.2 bar) (steam temperature 320°F [160°C]). Ignition has occurred in carbonized stock from wool dryers that was either improperly neutralized or packed too tightly while still hot from the dryer.

3.1.3 Fiberboard Dryers

Fires usually start in broken bits of board and dust that accumulate in the bottom of a fiberboard dryer or in heating ducts. Ignition is usually by continued heating of these accumulations at hot spots, or abnormally high dryer temperatures.

3.1.4 Electric Coil Baking Ovens

Overheating of coils or deposits, following the failure of thermostatic controls, emphasizes the importance of providing separate excessive temperature alarms or cutoff switches. Drippings or coils in contact with heaters and heating elements are the second leading fire cause, showing the need for safe location and guards. Broken bulbs have caused fires at ovens using infrared lamps.

3.1.5 Core Ovens

Deposits of condensed core-oil vapor is responsible for most fires in core ovens. The deposits are subject to spontaneous ignition, build up rapidly and are difficult to remove. Deposits several inches thick have been reported in exhaust ducts that were not regularly cleaned.

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3.1.6 Rubber and Plastic Coating Dryers

At coating machines, printing presses and similar dryers evaporating large quantities of solvents, most fires were caused by condensed deposits in either the ducts or dryers. Ignition was most frequently by spontaneous heating, but static sparks caused many fires at the coater. See Data Sheet 7-96.

3.1.7 Coffee, Cocoa, and Peanut Roasters

Overheating in the roaster and ignition of chaff or dust in the exhaust system are the two most prevalent causes of fire in coffee, cocoa and peanut roasters. The roasting operation depends on the operators because the food products are heated close to their ignition points. Inattention by the operator will likely result in overheating. Mechanical or power supply failures also may cause roaster contents to overheat. This can go undetected until the finish material is discharged into the cooling pan where it may burst into flames.

3.1.8 Heat Transfer Fluids

Some ovens and dryers use an heat transfer media instead of steam or hot water. Data Sheet 7-99, describes various fluids, fluid heating systems and the recommended safeguards for the installations. The fluids are generally high-flash-point ignitable liquids. If the fluid escapes from the system and is ignited, a severe fire can result. The fluid filled heat exchangers usually operate at temperatures that can result in spontaneous heating and ignition of synthetic or natural fibers and materials.

3.1.9 Autoclaves Used for Bonding and Curing

Commercial autoclaves are widely used for bonding and curing processes. For bonding, the components to be fabricated are coated with an adhesive and clamped together. They are then wrapped in a woven asbestos or fire retardant cloth blanket, sealed inside a high strength chemically inert plastic “bag” having vacuum connectors, placed on metal frames or platens, and put into the autoclave. A vacuum is drawn within the plastic bag. The autoclave is then pressurized and heated. After several hours at curing temperature, the bonded material is cooled by air or water spray. Pressurizing is usually by air. Heating is most commonly by steam coils although electrical resistance heaters and direct-fired gas heaters are sometimes used.

For curing, layers of the material are coated with adhesive or resin and wrapped around the mandrel. After covering with a plastic or silicone rubber bag, the whole is placed in the autoclave, the bag evacuated, and the same procedure followed as for bonding.

There have been many fires in autoclaves, usually during the curing cycle. Most reported losses have occurred in autoclaves fabricating aircraft and missile components. They have been attributed to spontaneous heating of the cloth blanket or the plastic bag, or of waste paper or other foreign material accidentally introduced into the autoclave. In addition, because fires are consistently preceded by loss of vacuum, it has been theorized that pin hole leaks develop in the evacuated bag, permitting air to rush in. This may heat the plastic bag and generate static electricity that ignites the bag or the mixture of air and solvent vapor from the adhesive.

Although autoclave fires usually do not cause serious fire damage, the frequency has been high. They interrupt the curing cycle so that the entire work load often must be scrapped, and the autoclave must be shut down for clean up and testing before it can be restarted.

3.2 Fuel Explosions

Fuel explosions may occur from the ignition of unburned fuel or flammable products of incomplete combustion during lighting-off, firing, or relighting. Explosions can also occur after shutdown if fuel leaks into the combustion chamber.

The loss experience emphasizes the importance of providing suitable combustion safeguards and interlocks, and assigning competent operators to carry out all lighting-off, relighting, and shutdown operations. Thorough inspection, testing and maintenance programs must be established and maintained.

The usual response is to shut down the oven fuel supply / heating system, conveyors, and fans. However, each installation should be evaluated to determine if alternative responses are appropriate, such as interrupting product feed and putting conveyors at maximum speed to remove product from the oven, keeping the fans on to prevent the accumulation of an explosive mixture, etc.

In gas-fired ovens and dryers, lighting-off explosions have occurred because of gas leakage during shutdowns, by operators who failed to close all main burner valves before opening the main gas safety shutoff valve, and because of unreliable pilots.

Firing explosions have occurred after accidental flame failures at ovens where burner flames were not supervised by combustion safeguards. The most important cause was operation of burners with insufficient air for complete combustion, resulting in the formation of dangerous mixtures of carbon monoxide, hydrogen, and air.

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Relighting explosions were caused by operators who, after accidental flame failure, did not properly purge with fresh air before they activated electric ignition or introduced a lighting torch.

In oil-fired ovens, there were few fuel explosions reported because of the smaller number of these units in service. Lighting-off explosions were caused by operators who failed to properly purge with fresh air between unsuccessful repeated attempts to ignite burners.

Firing explosions have occurred after accidental flame failures at ovens where burner flames were not supervised by combustion safeguards. The remainder was due to the operation of burners with insufficient air for complete combustion, which resulted in the formation of dangerous mixtures of carbon monoxide, hydrogen and air.

3.3 Process Vapor Explosions

An explosion hazard exists in any oven or dryer where at least one of the following conditions is found:

A. The work space temperature level exceeds the flash point of any ignitable liquids in the work space.

B. The work space is subjected to combustion products (e.g., direct-fired ovens).

It is impractical to eliminate all ignition sources at ovens used for processing materials that emit flammable vapor during the heating cycle. Primary dependence for prevention of a vapor explosion must be placed on diluting the vapor with fresh air to well below the lower explosive limit and discharging them outdoors by a positive and dependable system. This is known as “safety ventilation.” Safety ventilation is typically designed to maintain a continuous oven or dryer atmosphere below 25% of the lower explosive limit (LEL).

The majority of the oven vapor explosions were due to failure to determine the solvent evaporation rate or measure the rate of safety ventilation provided before making process changes. These include unusual operational conditions not foreseen for inclusion in the safety control system design or operational procedures. Some of these critical changes involved different solvents, increased batch loads and speeding up conveyors. High speed coating or print dryers using flammable vapor indicator / controllers had explosive vapor concentrations develop before the system could react. Errors by personnel, such as operating with the ventilation throttling dampers improperly set and equipment defects account for the remainder. Sometimes the fresh air is reduced to save energy or because the oxidizer burner is not large enough.

Batch ovens are inherently more hazardous than continuous (conveyor) ovens because the work load is introduced all at once, causing the evaporation rates to peak and then fall (see Figure 3.3-1).

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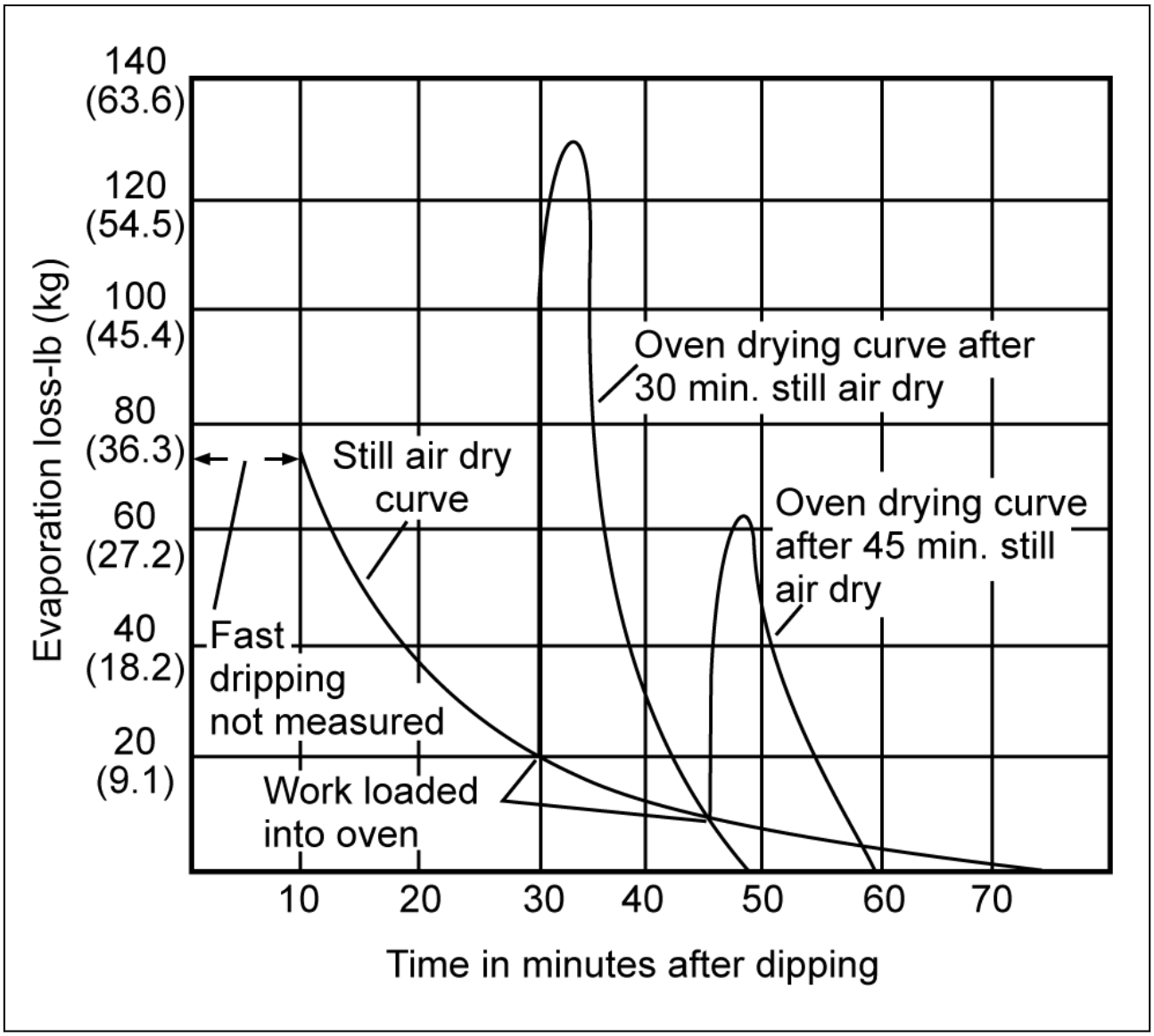


Fig. 3.3-1 Example of solvent evaporation-rate curve for a batch oven

It is usually practical to dilute vapor to below or barely below the lower explosive limit (LEL) when flammable volatiles are being evaporated at the peak evaporation rate. During the rest of the heating cycle, with a fixed ventilation rate, the ventilation is excessive and the oven wastes heat. For work carrying the same amount of flammable volatiles, the batch oven requires a much higher safety ventilation rate than the continuous type. With large batch ovens, safety ventilation requirements become uneconomically high, and there is a strong incentive for users to make unsafe reductions.

In continuous ovens, the work and the amount of flammable volatiles enter at a nearly constant rate so that the evaporation rate is also nearly constant. This makes it practical to dilute the flammable vapor to 25% or less of the lower explosive limit at all times. Also, the continuous oven is inherently more economical to heat.

Two design deficiencies have caused process safety ventilation explosions. Most oven manufacturers now recognize the solutions:

A. Forced safety ventilation systems using dual purpose fans alone (recirculation combined with spill exhaust) are also not sufficiently dependable. Such systems usually develop only a slight pressure and are affected by the same variables as natural draft systems (see Figure 3.3-2). Typical acceptable safety ventilation systems using safety ventilating fans, with no recirculation through the fans are shown in Figure 3.3-3.

B. Safety ventilation systems using natural draft alone are not dependable. The intended upward flow in the exhaust duct and stack is too easily reduced or even reversed. Temperature changes, outdoor winds, residue deposits or other obstructions in the exhaust duct or stack, restrictions at fresh air inlets and other fans drawing from the same

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room are variables that can too easily affect the slight pressure usually developed in such systems for producing the ventilation rate required for safety. The increased safety afforded by forced ventilation is now recognized by oven manufacturers.

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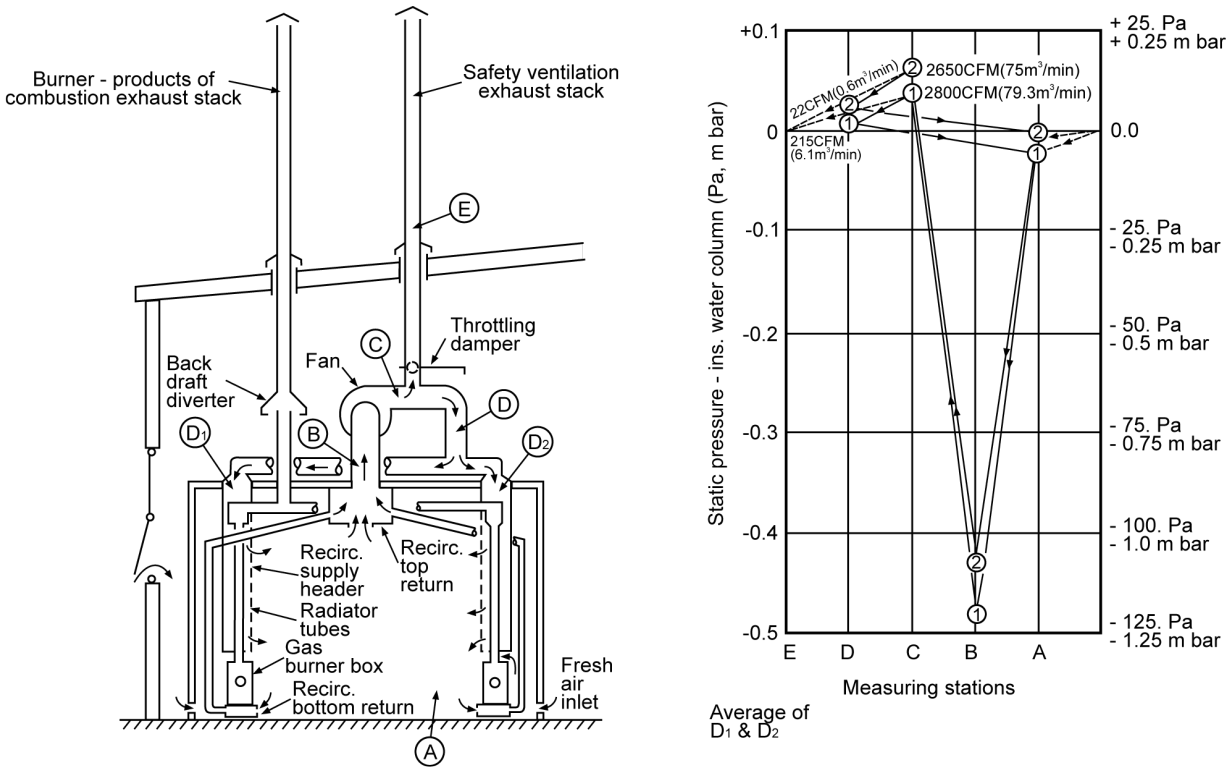


Table 3.3-2 Airflow test illustrating undesirable characteristics usually present in an oven safety ventilation system using dual purpose fans alone

	Test No. 1 Throttling Damper Wide Open		*Test No. 2 Throttling Damper Closed*	
Amount of fresh air drawn into oven by fan, measured at station E	215 cfm	6.1 m^3/min	22 cfm	0.6 m^3/min
Amount of air recirculated through fan, measured at station D	2.585 cfm	73.2 m^3/min	2.628 cfm	74.4 m^3/min
Total flow of air through fan, measured at station C	2.800 cfm	79.3 m^3/min	2.650 cfm	75.0 m^3/min
Static pressure measured at fan inlet, station B	-0.48 in. WC	-1.2 mbar	-0.43 in. WC	-1.07 mbar
Static pressure measured at fan outlet, station C	+0.04 in. WC	+0.1 mbar	+0.06 in. WC	+0.15 mbar
Numerical sum of fan inlet and outlet pressures (sum of static pressures measured at stations B and C)	0.52 in. WC	1.3 mbar	0.49 in. WC	1.22 mbar

Note: The dual-purpose fan system is undesirable because it develops practically no change in the static pressure rise through the fan even when the throttling damper is moved from open to closed.

Fig. 3.3-2 Airflow test illustrating undesirable characteristics usually present in an oven safety ventilation system using dual purpose fans alone

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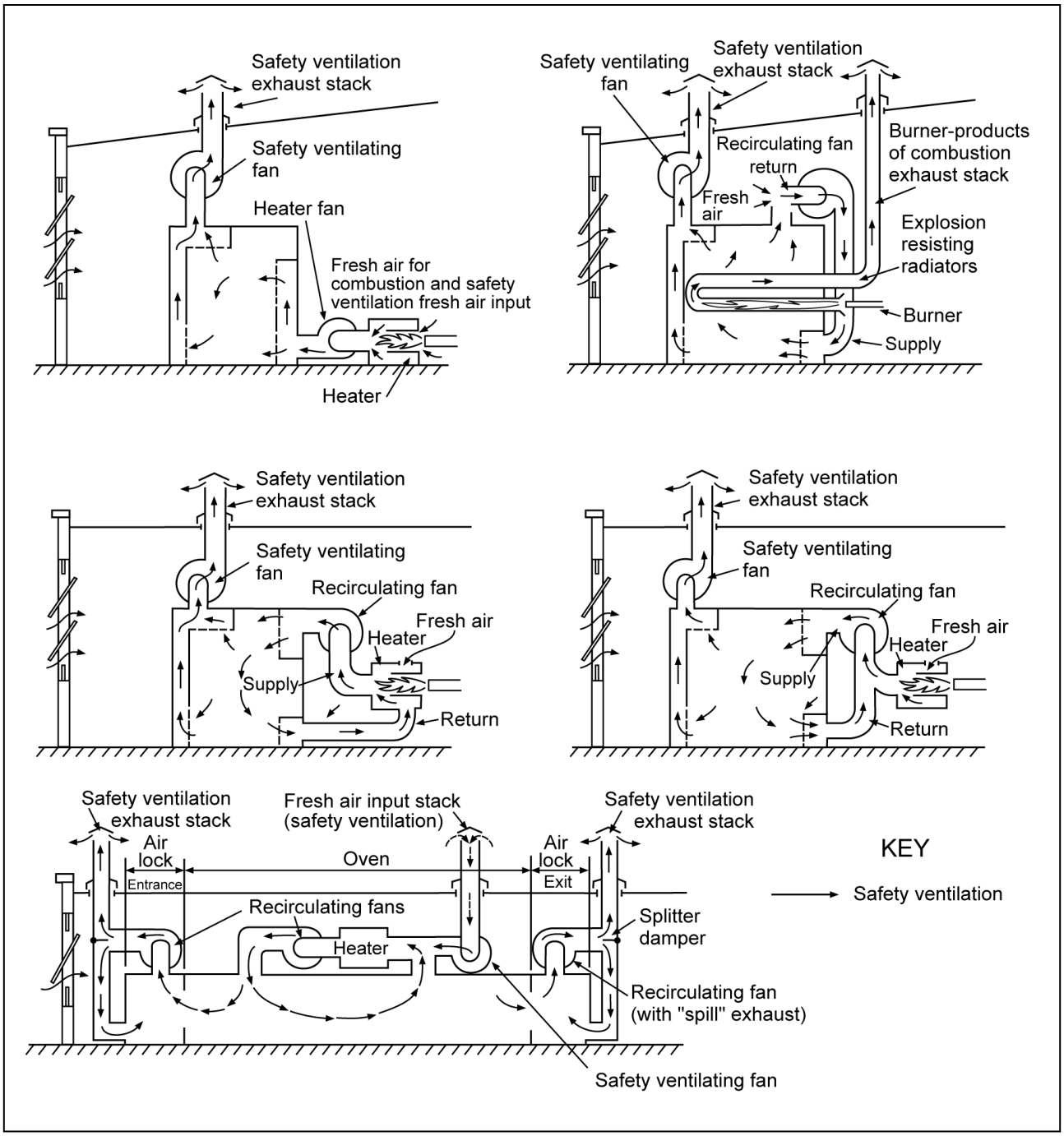


Fig. 3.3-3 Typical acceptable safety ventilation systems using safety ventilating fans, with no recirculation through fans

3.3.1 Low Oxygen Atmosphere Ovens

Low-oxygen atmosphere ovens and dryers are designed to operate with elevated vapor concentrations by limiting the oxygen concentration with an inert gas atmosphere. While conventional ovens typically minimize explosion potential by maintaining flammable vapor concentrations below 25% LEL, low-oxygen atmosphere systems control the oxidant concentration rather than the fuel concentration, allowing operation at significantly higher solvent vapor levels.

These systems are typically found in solvent-intensive, high-value or emission-constrained processes where conventional dilution ventilation is impractical due to solvent losses, environmental limitations or other factors.

Low-oxygen atmosphere ovens are generally associated with solvent recovery systems, such as vapor condensers or carbon bed absorbers, and operate in a closed-loop configuration. A portion of the solvent vapor-laden atmosphere,

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typically on the order of 1% to 3%, is diverted to the solvent recovery unit for treatment (see Figure 3.3.1-1). The cleaned gas stream is then recombined with the recirculation flow and returned to the oven.

See FM Property Loss Prevention Data Sheet 7-2, *Waste Solvent Recovery*.

Part of the solvent vapor-laden oven atmosphere, 1% to 3%, is cleaned at the solvent recovery unit (see Figure 3.3.1-1). The cleaned atmosphere is recombined with the recirculation stream and passed back through the oven.

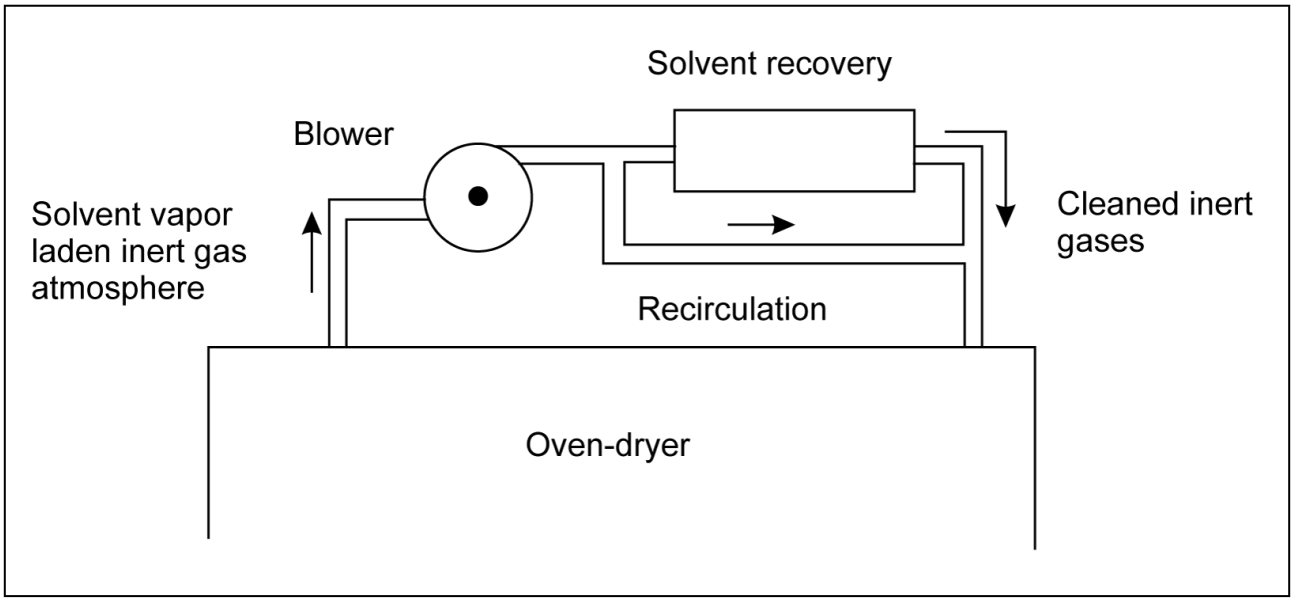


Fig. 3.3.1-1 Schematic of a low oxygen atmosphere oven and solvent recovery system

3.4 Loss History

3.4.1 Introduction

Table 3.4.1 shows the oven and dryer losses reported to FM for the period from 2009 to 2019. Two thirds of all oven and dryer losses were fires, with property damage driving fire losses.

Table 3.4.1. Reported Losses, 2009-2019

Reported Peril	*% of Total Losses by Value*	*% of Loss Due to Property Damage*	*% of Loss Due to Time Element*
Fire	55.4%	65%	35%
Explosion	41.4%	33%	67%
Mechanical Breakdown	1.7%	37%	63%
Temperature Change	0.7%	2%	98%
Sprinkler Leakage	0.7%	100%	0%
Electrical Breakdown	0.1%	56%	44%
Collapse	0.1%	92%	8%

3.4.2 Contributing Factors

3.4.2.1 Lack of Automatic Sprinklers

Lack of sprinkler protection where needed was cited as a negative contributing factor in approximately one-third of reported losses. Automatic sprinklers installed as recommended in this data sheet can minimize the consequences / severity of a fire involving an oven or dryer by preventing the fire from spreading to adjacent combustible construction and other equipment.

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3.4.2.2 Adequacy and Maintenance/Inspection of Safety Devices

There were many different safety devices in losses where adequacy and / or maintenance of safety devices was cited as a negative loss factor. Some examples include lack of calibration on gas detectors resulting in oven atmospheres exceeding LEL, a lack of gas detectors in a batch oven, failure of heat detector / high temperature limits, and conveyor speed interlocks.

3.4.2.3 Equipment Restarted Without Corrective Action

In approximately 5% of oven and dryer losses, equipment that had previously shutdown on a safety interlock was restarted without corrective action being taken by operators. In these cases, 94% were reported as explosion losses.

3.4.2.4 Inadequate Operating Procedures

Operating procedures were cited as a negative loss factor in approximately 8% of losses reported to FM. Although there is significant overlap between this category and 3.4.2.3, there are a significant number of unique losses when inadequate operating procedures contributed to the severity of the loss.

3.4.3 Illustrative Losses

3.4.3.1 Unsprinklered Bakery Oven Fire Spreads to Combustible Construction, Destroys Building

A fire occurred in a bakery oven, most likely due to combustible deposits stuck to the oven conveyor. Automatic sprinklers were not provided in the oven or in the production area of the facility. The oven and facility were provided with high-temperature and flame detection interlocks arranged to stop the conveyor system. These interlocks failed, resulting in ignited material transferring from the oven to a plastic spiral conveyor cooling belt. The plastic conveyor then caught fire, which developed sufficient heat to ignite combustible building construction materials. It reportedly took approximately 40 minutes for the local fire department to arrive at the facility. By that time, the entire building was involved in the fire. The building ultimately collapsed, destroying the building and all contents.

3.4.3.2 Bakery Oven Fire Spreads to Exhaust Duct Chase and Roof

A fire occurred in the last zone of a bakery production oven as the oven was being shut down for cleaning. The oven was provided with a manually-activated fire protection system. However, employees attempted to fight the fire with portable fire extinguishers instead of activating the fire protection system in the oven. The fire then spread to the exhaust ductwork, which had not been cleaned in approximately one week. The resulting temperatures ignited the walls of the exhaust chase, and eventually spread to the roof. The majority of the property damage was thermal damage to approximately 9,000 ft^2 (840 m^2) of the roof covering and rooftop equipment. Time element (TE) was negligible as the production from the impacted oven was shifted to other areas of the plant.

3.4.3.3 Faulty Gas Control Valve, Operator Error Lead to Rotary Dryer Explosion

A rotary dryer in a corn ethanol plant was equipped with a problematic fuel gas control valve, requiring frequent manual resets. On the day of the incident, the fuel control valve was manually reset by plant personnel following a safety shutdown for an unrelated cause. At that time, operators noted that the reported gas control valve position was not consistent with the gas flow rate reported by the flow meter. The valve position reported 0% open while the meter reported increasing gas flow to the burners. An initial explosion resulted in three of four explosion vents relieving. These vents were replaced, and the dryer was successfully restarted even though the gas control valve did not appear to be operating within design parameters. A second explosion occurred in the dryer, followed by two subsequent explosions in the associated cyclones.

3.4.3.4 Malfunctioning Interlock, Operator Error lead to Extensive Fire Damage

A radiant processing oven used to process plastic sheets was provided with an optical sensor interlocked to shut down the conveyor in the event that a plastic sheet was overheated and sagged below the conveyor level. On the day of the incident, a plastic sheet was jammed in the oven, became overheated and eventually ignited. The optical sensor failed to initiate the interlock, so additional plastic sheets continued to enter the oven, fueling the fire. The operator noticed the fire but did not press the manual emergency stop button. The operator left the area to obtain a manual fire extinguisher. Other nearby employees also gathered manual fire extinguishers and began attempting to extinguish the fire. In total, 40 manual fire extinguishers were discharged onto the fire in a 10 minute period, but did not extinguish the fire. The emergency stop button was reportedly pressed after manual firefighting efforts were abandoned and sprinklers activated. The fire spread above the suspended ceiling to other parts of the facility. The fire was extinguished by the automatic sprinklers before local firefighters arrived on scene. Firefighters cut multiple holes in the roof to assist with smoke control and to confirm the fire above the suspended ceiling had been extinguished. The oven and associated equipment were destroyed, and at least 90 gaylords of food-grade plastic pellets were discarded due to contamination.

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4.0 REFERENCES

4.1 FM

Data Sheet 1-28, *Wind Design*
Data Sheet 1-44, *Damage-Limiting Construction*
Data Sheet 1-57, *Plastics in Construction*.
Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*.
Data Sheet 5-1, *Electrical Equipment in Hazardous Locations*
Data Sheet 5-20, *Electrical Testing*
Data Sheet 5-49, *Gas and Vapor Detectors and Analysis Systems*
Data Sheet 6-0, *Elements of Industrial Heating Equipment*
Data Sheet 6-11, *Thermal and Regenerative Catalylic Oxidizers*
Data Sheet 7-2, *Waste Solvent Recovery*
Data Sheet 7-9, *Dip Tanks, Flow Coaters and Roll Coaters*
Data Sheet 7-10, *Wood Processing and Woodworking Facilities*
Data Sheet *7-20, Oil Cookers*
Data Sheet 7-32, *Ignitable Liquid Operations*
Data Sheet 7-45, *Safety Controls, Alarms, and Interlocks*
Data Sheet 7-54, *Natural Gas and Gas Piping*
Data Sheet 7-76, *Combustible Dusts*
Data Sheet 7-78, *Industrial Exhaust Systems*
Data Sheet 7-88, *Outdoor Ignitable Liquid Storage Tanks*
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*

FM *Approval Guide*, an online resource of FM Approvals, see “Explosion Venting Wall Systems”

4.2 NFPA Standards

National Fire Protection Association (NFPA). *Standard for Ovens and Furnaces.* NFPA 86.

National Fire Protection Association (NFPA). *Venting of Deflagrations. NFPA 68.*

APPENDIX A GLOSSARY OF TERMS

Autoclave: A heated pressure vessel used to treat materials. Refer to Section 3.1.9 for additional information.

Autoignition: Spontaneous ignition of material without a source of ignition or internal reaction.

Automatic fire check: A check valve that closes when a fusible link is heated by a flame.

Batch oven: An oven that does not have a continuous feed of material into it. Temperature ramps up at a specified rate to a temperature that then remains constant for a certain amount of time (soak time) before a cooling cycle begins. Material is inserted and removed only before and after the heating cycle.

Combustion safeguard: A safety controller and flame scanner that responds directly to flame properties. It senses the presence of flame and causes fuel to be shut off in the event of flame failure. A combustion safeguard will typically also monitor other safety devices such as fuel pressure and airflow switches.

Deflagration: A rapid combustion or explosion that travels at a velocity less than the speed of sound and therefore does not detonate. A pressure wave precedes the flame front. Pressure can increase by about a factor of 10. Detonation can be several orders of magnitude greater. For an explosion to occur, confinement is also needed.

Explosion vent: A light-weight, explosion-relieving panel or membrane that is lightly fitted on the top or side of an oven. Vents are designed to open at a low pressure so pressure will be quickly relieved inside the oven. Doors fitted with FM Approved explosion latches may also provide explosion relief.

Explosive range: In between the lower and upper explosive (flammable) limits of a flammable material. A flammable material can ignite if a mixture of air (or other oxidizer) and the material in a gaseous state falls in this range. For example, if a mixture of toluene and air contains between 1.1 and 7.1% toluene by volume, it can ignite. Temperature, pressure and oxygen concentration can change the explosive range.

Festooned: Material processed in an oven that is hanged or draped between a series of points.

FM Approved: References to “FM Approved” in this data sheet mean the product or service described has satisfied the criteria for FM Approval. See the *Approval Guide,* an online resource of FM Approvals, for a complete listing of products and services that are FM Approved.

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Fume incinerator: A thermal oxidizer used to destroy pollutants exhausted from ovens that use solvents for the process. Regenerative thermal oxidizers (RTO) and regenerative catalytic oxidizers (RCO) also perform this function.

Inerting gas: A nonflammable gas, such as argon or nitrogen, that is used to displace air and make the atmosphere nonflammable.

Ignitable liquid: Any liquid or liquid mixture capable of fueling a fire, including flammable liquids, combustible liquids, inflammable liquids, or any other term for a liquid that will burn. An ignitable liquid is one that has a fire point.

Igniter: A source of ignition for a burner. Can be electric or fuel-fired.

LEL detector: A combustibles analyzer that gives a reading in terms of percent of LEL for the sampled atmosphere.

Lower explosive limit: The minimum concentration of a flammable vapor in air at which ignition can occur.

Pilot: A fuel-fired igniter.

Plenum: A chamber from which a fan draws air. May be fitted with heating / cooling coils and damper vanes.

Purge: To flush a combustion chamber with fresh air, usually 4 volumes.

Safety blowout device: Used in a premixed fuel line to protect equipment such as a compressor from a flareback. Consists of a flame arrestor, fire check valve, and rupture disk.

Safety ventilation: Ventilation of an oven with fresh air to keep solvent vapor diluted well below the LEL. Normally measured and calculated using the exhaust flow rate.

Standard cubic feet (scf): Air quantity, referenced to dry air at 70°F (21°C) and 29.92 inch Hg (1 bar) pressure. This measurement is often used for fan capacity ratings. If referenced in determining ventilation capacity, standard cubic feet must be converted to actual cubic feet by accounting for site-specific temperature and altitude conditions.

Solvent recovery system: An unfired system used to remove solvent vapor from the exhaust stream.

Trial-for-ignition: The maximum amount of time fuel can be admitted to a pilot or burner at startup if flame is not detected.

Turndown: The operating range of a burner, or the ratio of the maximum firing rate to the lowest firing rate (e.g., 10 to 1).

Upper explosive limit: The maximum concentration of a flammable vapor in air at which ignition can occur.

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

October 2026. Interim revision. Significant changes include the following:

A. Minor editorial changes were made.

B. Improved guidance for protection options in ovens and dryers.

April 2021. This document has been completely revised. The following significant changes were made:

A. Added a recommendation to install classified electrical equipment in the interior of ovens if flammable vapor may be present.

B. Added a recommendation to use Data Sheet 6-11 for control of volatile vapor concentration in ducts if bypass ducts are prohibited by environmental regulations.

C. Added a recommendation to size water supply for simultaneous operation of duct and oven sprinklers supplied by a common water source.

D. Deleted recommendation for portable extinguishing equipment.

E. Deleted recommendation related to electrical disconnects for electric heaters.

F. Clarified gas detector recommendation to open path IR-type detectors because other technologies are FM Approved only up to 200°C [392°F].

G. Added recommendation to conduct process hazard analysis for low-oxygen atmosphere ovens to ensure the atmosphere cannot reach flammable limits under normal operating conditions.

H. Added a recommendation to establish a documented program for safety interlock bypass management.

I. Added recommendation to establish a documented program to address changes in operating parameters, including conveyor speed to address loss history.

J. Added recommendation to conduct daily visual inspection of explosion vents to check for obstructions.

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K. Revised test frequency for some combustion safety devices to annual.

L. Updated loss history.

July 2014. The following major changes were made:

A. Revised terminology and guidance related to ignitable liquids to provide increased clarity and consistency. This includes replacement of references to “flammable” and “combustible” liquid with “ignitable” liquid throughout the document.

B. Reorganized the document to provide a format that is consistent with other data sheets.

C. Provided additional information relative to the construction and proper location of ovens and dryers.

D. Modified recommendations related to explosion vents.

E. Provided guidance on the proper design of fuel supply, transfer, and piping systems for gas-fired and oil-fired ovens and dryers, including reference to other applicable data sheets.

F. Revised the oven and dryer ventilation system design guidance to meet current industry practices. This includes accounting for the impact of altitude on the necessary ventilation rates, and the elimination of the use of nominal (i.e., estimated) solvent rate data for continuous ovens.

G. Revised Appendix C, Ventilation System Design, to conform to current industry practices, to provide increased clarity, and to provide additional guidance on the measurement of safety ventilation rates.

H. Provided more specific design guidance for the sprinkler protection of ovens and dryers.

June 2009. The reference source for solvent chemical properties has been changed to NFPA 86, Standard for Ovens and Furnaces. NFPA 325M, Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids, has been withdrawn by the NFPA.

September 2003. This data sheet has been rewritten.

(2.1.2.3.4) The allowable clearance between exhaust ducts and stored combustible materials has been increased from 18 to 30 inches (45 to 75 cm) in agreement with Data Sheet 6-4 / 12-69, *Oil- and Gas-Fired Single-Burner Boilers*.

(2.1.3.4) The explosion venting recommendations have been revised to be in agreement with Data Sheet 1-44, *Damage-Limiting Construction* for weak construction and NFPA 68, *Venting of Deflagrations* for strong construction. The traditional 15 to 1 ratio, which is not based on anything except experience, has been dropped.

(2.1.4.4.2) The minimum safety control testing frequency has been changed from monthly to quarterly. This is a more realistic and practical approach.

(2.2.3.1) Temperature control recommendations have been revised, are more flexible and take into account flammable materials, multiple zones, location and set points. Low temperature alarms are recommended for multiple zones with process solvents. Rating of components such as thermocouple extension wires is also addressed. The previous Section 2.3.2.8 on excess temperature interlocks has been combined with this section.

(2.3.3.4 and 2.4.2.1) The recommendation for airflow switches is no longer an option and is now required.

(2.3.2.7) A low fire interlock is recommended for gas and oil, not just oil.

(2.3.2.10 Previous section) The section on FM cocks has been deleted. FM cock systems are still in existence, but should not be recommended for new installations. Combustion safeguard systems should be used.

(2.3.2.12) The three options were deleted. All that is needed is an interlock to prevent the fuel-aspirating combustion fan from running during purge. A second safety shutoff valve is already required, and the recommendation for an FM cock system has been deleted. A proof-of-closure switch is already required on burner systems greater than 400,000 Btuh (117 kW), and is not available on valves under 0.75 inches (2 cm).

(2.3.2.14(b)) The option for a second safety shutoff valve has been deleted since this is now always required.

(2.3.2.15) The recommended maximum trial-for-ignition time has been decreased to 5 seconds for direct spark ignition. A pilot can be supervised with a flame scanner whereas an electric igniter cannot. This time can be extended if needed, however.

(2.3.2.19.3 Previous section) The allowance for one flame scanner supervising two burners has been deleted. There is already an allowance for line-type burners to be supervised by a single scanner.

September 2000. Changes to safety ventilation and safety shutoff valve recommendations were made to be in agreement with NFPA 86 1999. These changes are justified based on loss experience and because there is no reason to differ from NFPA 86 with regard to any of these changes.

The nominal amounts of air required to render a solvent barely explosive have been increased for continuous and batch ovens. Example calculations have been revised to reflect this. The nominal amounts of air have been increased because the previous amounts did not account for LEL correction, and also so that the nominal method would be safe to use for more solvents. For batch ovens, this is especially important because the LEL can be reached at peak evaporation. This

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change does not affect Oven VentilationCalc for continuous ovens because a calculated method is used as opposed to the nominal method.

An equation has been added for LEL temperature correction. LEL correction is important because the LEL is reduced at elevated temperatures. This is not new to NFPA 86 and has been used all along in Oven VentilationCalc. The data sheet contained an LEL correction table, but did not include this factor in the examples.

LEL detector trip set point has been changed from 60% to 50%. This is not new to NFPA 86 and is in agreement with Data Sheet 6-11, *Thermal and Regenerative Catalylic Oxidizers*.

The amount of air required for combustion is now always added to the amount of safety ventilation needed for the process vapors regardless of the amount. The one third rule has been dropped. The NFPA 86 committee decided that there was no known reason for this rule.

Two safety shutoff valves are now recommended for all pilots and burners, regardless of size. A recommendation for multi-burner operation was also added.

June 1999. This document has been reorganized to provide a consistent format.

APPENDIX C SUPPLEMENTAL INFORMATION

C.1 Ventilation System Design

C.1.1 General

Whenever possible, determine necessary safety ventilation rates based on evaporation rates and properties of the solvents as determined from laboratory or field testing of individual site processes (i.e., detailed solvent rate data). “Detailed” in this context indicates an understanding of the rate of change of the introduction of solvents into the process atmosphere to a degree sufficient to determine peak process atmosphere solvent mass fractions. This information usually derives from detailed records of process flow rates. Often, this is obtained by weighing coated components prior to their insertion into the oven, and removing and weighing them at different times throughout the process to determine how much solvent had evolved at those times.

If detailed solvent rate data is unknown and unavailable, the use of nominal data may be used in some cases, using typical evaporation rates for most common solvents as applied to coated or dipped metal. Different solvents, work application, and degree of absorption will produce different evaporation rates of the volatiles. Dipped sheet metal produces the highest evaporation rates ordinarily encountered.

C.1.2 Ventilation Rate Calculations

For both batch and continuous type ovens, the safety ventilation system should furnish sufficient fresh air ventilation to dilute the vapor to a concentration not exceeding 25% of the lower explosive limit (LEL).

C.1.2.1 Batch Ovens

1. Calculate the necessary safety ventilation rate to dilute the vapors from 1 gallon (liter) of ignitable liquid to just below the lower explosive limit (100% LEL).

V = (8.33*SG) / (0.075*VD) * (100 / LEL) [US Customary Units]

V = (0.998*SG) / (1.201*VD) * (100 / LEL) [Metric]

Where V = ventilation volume per gallon (liter) of solvent (ft^3 / gal [m^3 / L])

SG = specific gravity (water = 1)

VD = vapor density (air = 1)

LEL = lower explosive limit (% by volume)

2. Multiply the calculated ventilation volume by the peak solvent evaporation rate.

$V_A = V * ER$

Where:

V_A = ventilation rate for peak solvent evaporation rate (ft^3 / min [m^3 / min]).

V = ventilation volume per gallon (liter) of solvent (ft^3 / gal [m^3 / L]).

ER = evaporation rate (gallons [liters] per unit time).

If detailed solvent evaporation rate data is unavailable, assume V_A = 450 ft^3 / min (12.6 m^3 / min).

3. Apply a safety factor of 4 (i.e., 25% LEL).

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4. If the temperature of the process exceeds 250°F (121°C), apply an additional safety factor of 1.4.

5. Add the products of combustion, if applicable (see Section 2.4.9.2.2).

6. If the temperature of the process exceeds 250°F (121°), apply a temperature correction factor to account for the impact of temperature on exhaust efficiency (see Section 2.4.9.2.3).

7. If the altitude exceeds 1000 ft (305 m), apply an altitude correction factor (see Section 2.4.9.2.4).

C.1.2.2 Continuous Ovens

1. If the temperature of the process exceeds 250°F (121°), correct the LEL.

$LEL_t = LEL_{77°F}$ [1 - 0.000436(t - 77°F)] [US Customary Units]

$LEL_t = LEL_{25°C}$ [1 - 0.000784(t - 25°C)] [Metric]

Where $LEL_{77°F}$ ($LEL_{25°C}$) = lower explosive limit at ambient temperature

LEL_t = lower explosive limit corrected for process temperature

t = process temperature

2. Calculate the necessary safety ventilation volume to dilute the vapors from 1 gallon (liter) of ignitable liquid to just below the lower explosive limit (100% LEL):

V = (8.33*SG) / (0.075*VD) * (100 / LEL) [US Customary Units]

V = (0.998*SG) / (1.201*VD) * (100 / LEL) [Metric]

Where V = ventilation volume per gallon (liter) of solvent (ft^3 / gal [m^3 / L])

SG = specific gravity

VD = vapor density

LEL = lower explosive limit (% by volume)

3. Multiply the calculated ventilation volume by the solvent flow rate.

$V_A = V * FR$

Where V_A = ventilation rate for peak evaporation rate (ft^3 / min [m^3 / min])

V = ventilation volume per gallon (liter) of solvent (ft^3 / gal [m^3 / L])

FR = solvent flow rate (gallons [liters] per unit time)

4. Apply a safety factor of 4 (i.e., 25% LEL).

5. Add the products of combustion, if applicable (see Section 2.4.9.2.2).

6. If the temperature of the process exceeds 250°F (121°), apply a temperature correction factor to account for the impact of temperature on exhaust efficiency (see Section 2.4.9.2.3).

7. If the altitude exceeds 1000 ft (305 m), apply an altitude correction factor (see Section 2.4.9.2.4).

C.1.2.3 Powder Curing Ovens

For powder fusing or curing in continuous ovens, design and test data should be available for the maximum powder application rate and the percent of volatiles released during the cure cycle. Calculate the necessary ventilation as follows:

1. If the temperature of the process exceeds 250°F (121°), correct the LEL.

$LEL_t = LEL_{77°F}$ [1 - 0.000436(t - 77°F)] [US Customary Units]

$LEL_t = LEL_{25°C}$ [1 - 0.000784(t - 25°C)] [Metric]

Where $LEL_{77°F}$ ($LEL_{25°C}$) = lower explosive limit at ambient temperature

LEL_t = lower explosive limit corrected for process temperature

t = process temperature

2. Calculate the necessary safety ventilation volume to dilute the vapors from 1 gallon (liter) of powder to just below the lower explosive limit (100% LEL):

V_1 = (8.33*SG) / (0.075*VD) * (100 / LEL) [US Customary Units]

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V_1 = (0.998*SG) / (1.201*VD) * (100 / LEL) [Metric]

Where V_1 = ventilation volume per gallon (liter) of powder (ft^3 / gal [m^3 / L])

SG = specific gravity

VD = vapor density

LEL = lower explosive limit (% by volume)

3. Divide the calculated ventilation rate by the density of the powder to determine the necessary safety ventilation volume to dilute the vapors from 1 pound (kg) of powder to just below the LEL (or the corrected LEL_t, if applicable).

$V_2 = V_1 / \rho$

Where V_1 = ventilation volume per gallon (liter) of powder (ft^3 / gal [m^3 / L])

V_2 = ventilation volume per lb (kg) of powder (ft^3 / lb [m^3 / kg])

ρ = Powder density (lb / gal [kg / L])

4. Multiply the calculated ventilation volume by the powder feed rate.

$V_3 = V_2 * FR$

Where V_3 = ventilation rate based on oven's powder feed rate (cfm [m^3 / min])

V_2 = ventilation volume per pound (kg) of solvent (ft^3 / lb [m^3 / kg])

FR = powder feed rate (pounds [kg] per unit time)

5. Adjust the ventilation rate based on the percentage of volatiles released by the powder. The percentage of flammable gases given off varies widely with the type of powder: approximately 2% in epoxy, 3% for acrylics, 5% for polyesters and 9% for vinyl. The release value of 9% is generally accepted for the purpose of calculating ventilation rates. It is assumed that all volatiles given off are flammable, although the exact compositions are normally unknown.

$V_A = V_3 * FV$

Where V_A = ventilation rate based on the percentage flammable vapor released (ft^3 / min [m^3 / min])

V_3 = ventilation rate based on oven's powder feed rate (ft^3 / min [m^3 / min])

FV = flammable vapors released (%).

6. Apply a safety factor of 4.

7. Add the products of combustion, if applicable (see Section 2.4.9.2.2).

8. If the temperature of the process exceeds 250°F (121°), apply a temperature correction factor to account for the impact of temperature on exhaust efficiency (see Section 2.4.9.2.3).

9. If the altitude exceeds 1000 ft (305 m), apply an altitude correction factor (see Section 2.4.9.2.4).

C.1.3 Measurement of Safety Ventilation Rates

Dilution of a solvent with air is based on mass fractions, and the mass of air in one unit of volume (e.g., one cubic foot or meter) varies inversely with temperature and elevation (i.e., directly with pressure). Therefore, the volume of air required to dilute a certain mass of flammable vapor is relative to the temperature and pressure at which the volume was measured

The actual volume of air necessary to dilute a defined quantity of solvent vapor at a specific location will vary from the standard air volume determined by calculations. Therefore, the calculation procedures in this appendix include corrections for ovens operating at high temperatures and / or altitudes. This allows conversion from standard air volumes to actual air volumes at elevated temperatures and / or altitudes. These corrected values should be compared to the air volume as measured on site.

The actual air volume is specific to the point of measurement. For example, if the air is measured in a location prior to process heating, such as at the fan intake, corrections for elevated temperatures should not be applied in the calculations. If the air is measured in a location after process heating, such as in the oven exhaust, corrections for elevated temperatures should be applied. The contractor responsible for the measurements should clearly stipulate the temperature at the point of measurement.

While an understanding of the actual air volume necessary to dilute a flammable vapor is important, standard air volume (e.g., standard cubic feet or meters per minute) still needs to be considered to verify if the fan selected for a specific process will provide the required amount of air flow at process conditions. Fans are typically rated by the manufacturers in terms of conditions at standard atmospheric conditions (e.g., scfm), In order to compare the process conditions to

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the fan ratings, a review of calculations or revised fan curves that compare standard to actual air volume based on the specific oven process is necessary.

C.1.4 Symptoms of Inadequate Ventilation

Vapor explosions often occur some time after ventilation becomes inadequate. Investigate the following symptoms and take corrective action immediately:

A. A cold exhaust duct or stack while the oven is operating (usually indicates reversal of flow in the stack or inadequate safety ventilation)

B. Evidence of negative pressure in the oven room, with respect to adjoining rooms and outdoors when the door to the oven room is opened (may indicate inadequate safety ventilation and sometimes reversal of airflow in the exhaust stack)

C. A record of fires or puffs from work in a particular oven (may indicate inadequate safety ventilation, dangerously high vapor concentrations, and increased probability of an eventual serious oven explosion)

D. A record of work leaving the oven with paint incompletely dried (an indication of inadequate safety ventilation)

E. Heavy deposits of condensed paint vapor at the exhaust stack outlet (may indicate that interior fouling has dangerously reduced the safety ventilation) flow

F. Paint fume deposits around oven door cracks (may indicate higher pressure inside the oven than in the oven room, and a lack of positive safety ventilation)

C.2 Other Standards

The corresponding NFPA standards are NFPA 86, *Standard for Ovens and Furnaces;* and NFPA 68, *Standard on Explosion Protection by Deflagration Venting.* There are no known major conflicts with NFPA 86. Some deviations are as follows:

- Data Sheet 6-9 permits manually controlled purge where the external oven volume is less than 350 ft^3 (10 m^3).
- Data Sheet 6-9 permits natural draft ventilation of a work chamber when less than 64 ft^3 (1.8 m^3).

NFPA 86 provides recommended venting ratios and other guidance with reference to NFPA 68. NFPA 68 discusses explosion venting for a broad range of building occupancies and equipment. There are conflicts with the referenced NFPA 68 in the method of determining the vent size, the recommended maximum mass of the vent, and allowing the relief of the vented gases into a structure. The design criteria of NFPA 68 address equipment that appears to be considerably stronger than a typical oven.

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