Don’t Get Burned

Picking Dry-Type Flame Arresters

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Flame arresters prevent the propagation of a flame front from outside of a storage tank or process vessel to the inside, or of a flame between interconnected items of equipment. This article is based on a recent book by the author published by AIChE’s Center for Chemical Process Safety (CCPS) that covers a wide range of topics on flame arresters (see sidebar). Here, we will look at the major dry types available and their general uses. These devices employ a medium, known as the matrix, inside a casing that extinguishes the flame and, when appropriate, stops a shock wave from a detonation. Typical media are crimped-metal-ribbon, expanded metal and parallel plates. There are also proprietary dry-type arresters, as well as other types of flame arresters that do not contain a matrix; these find service where conventional dry types are not suitable or expensive. Among these are hydraulic (liquid-seal) and packed-bed arresters, velocity flame stoppers, high-velocity vent-valves, and conservation vent-valves. Space does not permit discussing these other types here, but the book covers them in detail.

Classification schemes for dry types

There are various ways to classify dry-type arresters:
• Deflagration vs. detonation models
• Direction of flame approach for which the arrester is designed to operate in a pipe. The pipe that connects the arrester with an identified ignition source is known as the unprotected side of the arrester. The pipe connecting the arrester to at-risk equipment that must be protected from flame penetration is the protected side.

These commonly used devices rely on an internal medium to extinguish flame fronts and take the punch out of shock waves, protecting piping and equipment, as well as personnel. Selecting such equipment involves considering the probable type of combustion, placement in the plant and other factors.

• The number of directions that an arrester may encounter a flame. If it is from only one direction, then the device is unidirectional; if from either direction, a bidirectional arrester is needed. The latter is either symmetrically constructed or has been tested and certified for deflagrations or detonations approaching from either direction. Back-to-back use of unidirectional flame arresters is generally not cost-effective.

Flame arresters are also grouped according to certain characteristics and operational principles, by their process location, combustion conditions, or arrester matrix.

Process location

When an arrester is located directly on a vessel or tank vent-nozzle, or on the end of a vent line from the vent-nozzle, it is called an end-of-line arrester, and usually is
installed to stop deflagrations. These devices are commonly installed on atmospheric-pressure storage tanks, process vessels and transport containers. If the vented vapors are ignited accidentally, say by lightning, then the arrester will prevent the flame from spreading to the inside of the vessel. Such flame arresters do not stop detonations. End-of-line flame arresters can be placed on vessels or tanks located inside buildings (Figure 1a) and outdoors as well (Figure 1b).

If the arrester is not connected to the end of a line, then it can be placed in-line. Such arresters can be built to withstand deflagrations or detonations (if properly designed for these more-extreme conditions), depending on the length of pipe and pipe configuration on the unprotected side of the arrester, and any restrictions on the protected side (e.g., the inclusion of valves or elbows). A detonation flame arrester is used where the run-up distance (that from the source to the arrester) is sufficient for a detonation to develop.

Some in-line deflagration flame arresters are called “pipe-away” or vent-line arresters. These are also installed on the vent-nozzles of atmospheric-pressure tanks and vessels, but have a short length of pipe attached to them to direct the vapors, and possibly flames, away from the tank or vessel roof (Figure 2).

The maximum length of pipe from the discharge side to the atmosphere is usually 20 ft for Group D gases, and is a function of the pipe size and the manufacturer’s design. For other gases (Group B or Group C), the maximum distance must be established by proper testing with the gas mixture and pipe diameter. The groups are established by the National Electrical Code (NEC) of the National Fire Protection Association (NFPA) (1). Typical Group B gases include butadiene and ethylene oxide, as well as gases that contain more than 30% of hydrogen by volume, among others. Those in Group C include ethylene, ethyl ether and other gases of equivalent hazard. Typical Group D gases include methane and other alkanes, alcohols, benzene and acetone.

In establishing how arresters can be used safely with certain gases, if turbulence-promoting devices (bends, elbows, tees, valves, etc.) will be present in the actual plant, then they must be included in the test setup. During the test, the turbulence promoters must be placed using the exact geometry of a specific installation. It is essential to ensure that run-ups to detonations cannot occur in an actual system. For some fast-burning gases, such as hydrogen/air mixtures, the run-up distance can be appreciably less than the 20-ft limit.
for Group D gases. In all cases, consult the manufacturer for the recommended maximum run-up length.

An in-line detonation flame arrester must be used wherever a detonation may occur. This is always a strong possibility in vent-manifold (vapor-collection) systems, where long pipe-runs provide sufficient distances for a deflagration-to-detonation (DTD) transition to occur. Figure 3 shows a typical installation of in-line detonation arresters in a vent-manifold system.

**Combustion conditions**

Deflagration arresters on tanks normally cannot withstand significant internal pressure and cannot stop detonations. Typical flame speeds of a deflagration in pipes range from 10–200 ft/s. Deflagrations of fuel/air mixtures usually generate pressures of 8–12 times the initial pressure in closed process vessels and equipment.

Detonation flame arresters withstand and extinguish high-speed, high-pressure flame fronts. Therefore, these devices must be able to resist the mechanical effects of detonation shock waves while quenching the flames. Some designs have a shock absorber in front of the flame-arresting element to lessen the effect of the high-pressure wave and its dynamic energy, and to split the front before it reaches the arrester element.

Detonations in piping have velocities of about 6,000 ft/s or more, and, in closed process vessels and equipment, can generate pressures from 20–100+ times the initial value. When installed in a vent-manifold, these arresters on the tanks can be uni- or bidirectional, depending upon the manufacturer’s recommendations. Detonation arresters preferably should be installed vertically, so if liquid is present, the arrester will drain. If they must be installed horizontally, drain connections are needed. Most detonation arresters have crimped-metal-ribbon elements, although expanded-metal cartridges are also used. Detonation arrester elements are usually longer than the elements used for deflagration arresters.

Some cases have been reported where a detonation arrester failed to stop a deflagration (2). This occurs when there is a restriction (e.g., a valve) on the protected side of the device. Roussakis and Lapp (3) present test data on three types of in-line flame arresters that corroborate this seemingly anomalous behavior. The causes are complex and depend on such factors as the effect of run-up length on the relative overpressure (the ratio of the pressure rise caused by the flame front to the absolute operating pressure at the time of ignition), flow restriction on the protected side, and the absolute operating pressure. The flame-quenching capability of a flame arrester is determined by the initial operating pressure. The new CCPS book previously mentioned explains this seemingly anomalous behavior.

**Regulations and requirements**

There are no regulations or other legal requirements for installing flame arresters in vapor-collection (vent-manifold) systems in chemical and petrochemical plants. However, many chemical companies follow the U.S. Coast Guard regulations as a guide.

The installation of flame arresters should be considered for vacuum pumps, activated-carbon adsorbers, and other equipment that emits flammable vapors and/or can serve as an ignition source.
Matrix constructions for dry arresters

Dry-type deflagration and detonation arresters have an internal arrester element that quenches the flame and cools the products of combustion. There are many types of arrester elements. The most common are crimped-metal-ribbon, parallel-plate, expanded-metal-cartridge, perforated-plate, wire-gauze (and wire-gauze in packs), sintered-metal, metal-shot in small housings, and ceramic balls. Some of these arresting elements are often used in both deflagration and detonation arresters. Compressed wire-wool flame arresters are available in the U.K., but are not sold commercially in the U.S.

Crimped-metal-ribbon (CMR)

This element is one of the most widely used types, especially for detonation flame arresters (Figure 4). CMR arresters are made of alternating layers of thin, corrugated metal ribbons and flat metal ribbons of the same width, which are wound together on a mandrel to form a many-layered cylinder of the desired diameter. The thickness of the cylindrical element is equal to the ribbon width. The spaces between the corrugations and the flat ribbon provide multiple small gas passages of approximately triangular shape. Elements can be made in a variety of crimp heights, ribbon and element thicknesses, and diameters.

Some major advantages are: (1) they can be manufactured to within close tolerances; (2) they are sufficiently robust to withstand mechanical and thermal shocks; and (3) they have a fairly low resistance to flow (pressure drop) because usually only about 20% of the face (cross-sectional area) of the arrester is obstructed by the ribbon. The layers of ribbon must not spring apart because this would increase the crimp height and render the device ineffective. Since effectiveness in quenching a flame diminishes rapidly with thin arresters, the elements should be at least 0.5 in. thick. One manufacturer produces a composite design consisting of multiple CMR elements with diverter shields (turbulence-inducing devices) between the elements.

CMR elements can be made circular, rectangular or square, depending upon the shape of the pipe or housing. The elements are often reinforced by inserting metal rods radially through the assembly. CMR arresters may use single or multiple elements with the crimp perpendicular to the ribbon. Newer designs include deflectors between element sections to redistribute flow.

A drawback of CMR arrester elements is their sensitivity to damage during handling. This must be considered during maintenance. Damage may lead to either enlarged channels that allow flame penetration, or to channel collapse that increases the pressure drop. Therefore, the manufacturer’s instructions should be strictly followed during maintenance and cleaning. Another possible problem is that the small channel size may make the elements more susceptible to fouling due to solids deposition, and regularly scheduled or predictive maintenance is essential when this is possible.

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Even less than that for the corresponding gauzes, but the percentage of the plate area available for gas flow is rated-metal arresters have greater mechanical strength and corresponding dimensions of coarse-gauze arresters. Perforated-plate and plate thicknesses, but the most-common devices are metal plates. They are available with a range of hole diameters and plate thicknesses analogous to the perborated openings. The perforated plates are usually metal (stainless steel), but some also incorporate perforated refractory disks and gauze pads in combination with the perforated metal. The spacing is maintained by gaskets or nubs on the plates. Parallel-plate devices are relatively inexpensive, robust and readily dismantled for cleaning. Their main disadvantage is their weight, especially in large sizes with housings made of steel or stainless steel. Heavy units may require independent support when mounted on a tank nozzle.

**Expanded-metal cartridge (EMC)**

EMC elements are comprised of a sheet of expanded metal that is wrapped similarly to a cartridge filter element (Figure 6). Diamond-shaped openings in the sheet are not aligned during wrapping, so that there is no direct path from one layer to the next. Such a design tends to reduce the incidence of plugging by suspended solids, since they will not be heavily deposited on the inlet face. The elements are normally offset, rather than inline, to the gas flow so that the flame passes radially toward the cartridge axis. This creates a relatively large inlet surface area that further reduces plugging problems. Another advantage is that liquids and solids drop out into an external container that surrounds the inlet. This may make these units suitable for use with reactive monomers. Disadvantages include support problems for larger pipe diameters due to their size and weight, so, often, EMCs must be located at or near grade to facilitate maintenance. These arresters are suited for deflagration and detonation, and are designed for bidirectional flow.

EMC elements are manufactured in different configurations. One is a cylinder that fits into a housing with offset inlet and outlet connections. Another is a thimble shape that is welded to a flange for insertion in an in-line, straight-through housing.

**Perforated-plate**

These elements are used primarily for deflagration arresters (Figure 7a). The perforated plates are usually metal (stainless steel), but some also incorporate perforated refractory disks and gauze pads in combination with the metal plates. They are available with a range of hole diameters and plate thicknesses, but the most-common devices have hole diameters and plate thicknesses analogous to the corresponding dimensions of coarse-gauze arresters. Perforated-metal arresters have greater mechanical strength and are less likely to overheat than gauze arresting elements, but the percentage of the plate area available for gas flow is even less than that for the corresponding gauzes.

**Wire gauze**

These arresters use either single gauzes, or a series or pack of gauzes (Figure 7b). They are manufactured such that the aperture size is carefully controlled. Single layers offer limited performance. Gauzes coarser than 28 mesh to the linear inch are ineffective at quenching a flame, and those finer than 60 mesh to the linear inch are liable to become blocked. The main advantages of gauzes are their low cost, ready availability and ease of fitting. Their disadvantages include limited effectiveness at quenching high-velocity flames, the ease with which they are damaged, and the high pressure drop of gases through fine gauzes.

Gauzes can be combined into multiple-layer packs, and if the gauzes are all of the same mesh width, they are more effective than single constructions. However, the increase in effectiveness is limited. Combined packs of a coarse and fine mesh are less effective than the fine gauze alone. A disadvantage of gauze packs is that the good contact required between gauze layers may be difficult to guarantee in practice without fusing and calendering. Since gauzes have limited effectiveness in quenching high-velocity flames, they are only used as end-of-line deflagration flame arresters.

**Sintered metal**

Sintered metal (Figure 7c) is effective as an arresting element, but it offers a high resistance to gas flow, and is suitable only when the gas flow is low or high pressure is available (e.g., on a compressor discharge line). Banks of sintered-metal flame arresters can be installed in parallel to offset the pressure-drop problem. Their small apertures tend to block easily, so these flame arresters should only be used with clean gases. One advantage is that they can be produced in a variety of shapes to suit various applications. How they are mounted is critical because the clearance between the arresting element and the housing must be less than the arrester passage dimensions. If a flame stabilizes on the surface of these elements, there is a risk that it will eventually burn its way through the sintered-metal disk. For this reason, these arresters may incorporate a pressure- or temperature-activated flow cutoff-device.

The apertures can be made so small that these arresters are able to quench detonations, provided that they have sufficient mechanical strength. Care is required to ensure a secure anchorage of the sintered element to prevent leakage around it caused by the impact of a shock wave.

The main uses of these arresters are in the sensing heads of flammable-gas detectors and in flame arresters for gas welding (oxy-acetylene) equipment.

**Ceramic balls**

In these devices, ceramic (alumina) balls are housed between stainless-steel grids (Figure 7d). These arresters have been tested for NEC Groups C and D gases, as well as for hydrogen. They have also been accepted by the U.S. Coast Guard. The ceramic balls are claimed to be cleaned.
easily and totally resistant to oxidation and corrosion. Also, the balls will withstand severe flame stabilizations without suffering any deterioration.

**Metal shot**

Metal-shot arresters consist of a tower or housing filled with various sizes of metal shot (balls) in about nine zones. The size varies from 4–7 mesh for the largest balls and from 40–60 mesh for the smallest ones. The larger balls are arranged in the outer layers of a zone with the smaller shot in the inner layers. A typical unit is 6 in. O.D. × 15 in. long, with 3/4-in. connections. The size of the apertures depends on the diameter of the shot, which is packed tightly together within the container to prevent movement. One advantage of this flame arrester is its ease of assembly and disassembly for cleaning. Another is that it can be made sufficiently robust to withstand detonations. One design using nickel shot contained in a thick-walled housing successfully stops acetylene detonations at initial pressures from 15 to 400 psig.

The disadvantages include their weight and relatively high resistance to gas flow. In addition, the size of the apertures is not controlled directly. Movement of the balls during a deflagration or detonation can lead to failure of the device (4).

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**Literature Cited**