

Protect Your Process with the Proper Flame Arresters

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A flame arrester may be installed to keep an external flame out of a tank or vessel or to ensure that a flame burning within a pipeline does not propagate to other equipment. Use the information presented here to determine what type of device is appropriate for your application.

Storage tanks and other vessels containing flammable and/or explosive chemicals and mixtures are prevalent in chemical process industries (CPI) plants. Flame arresters are installed on such equipment to prevent potential hazards associated with flammable and explosive materials. For example, flame arresters can stop the spread of a fire, limit the spread of an explosive event, protect potentially explosive mixtures from igniting, and confine a fire within an enclosed, controlled location.

A flame arrester works by forcing a flame front through very narrow channels. Gas travels through the device, but the passages are so narrow that the flame can no longer be maintained.

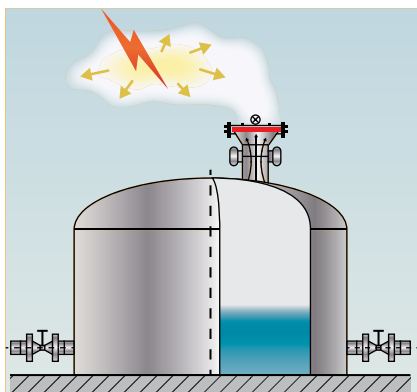
This article provides an overview of the use of flame arresters in the CPI. It defines some key terminology,

describes the different types of flame arresters, explains how flame arresters are tested and certified for specific process conditions, discusses the concept of layers of protection and how a flame arrester can serve as a layer, and offers guidance on choosing a flame arrester. The article also explains why conservation vents do not provide reliable protection against atmospheric explosions (sidebar, p. 18), and why flame arrester elements made of polytetrafluoroethylene (PTFE) can extinguish a flame rather than melt or burn (sidebar, p. 20).

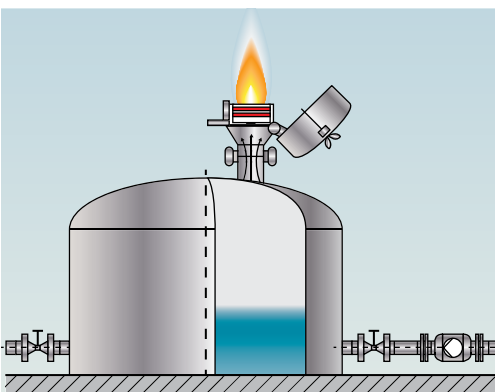
Key terminology

International standards (10) define the combustion processes relevant to flame arresters.

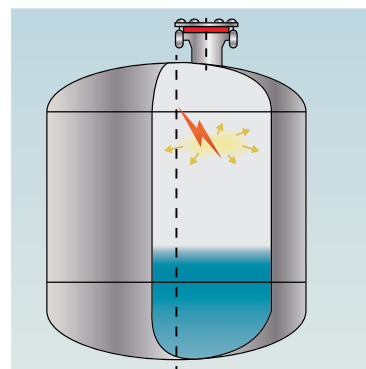
Explosion is the generic term for an abrupt oxidation or decomposition reaction that produces an increase



▲ **Figure 1.** An atmospheric deflagration occurs in the open air.



▲ **Figure 2.** A pre-volume deflagration takes place within a confined volume.



▲ **Figure 3.** Stabilized burning is an even, steady flame that is stabilized at or near the flame arrester element.

in temperature, pressure, or both simultaneously.

Deflagration is an explosion that propagates at subsonic velocity. The geometric shape of the combustion volume determines whether it is:

- an atmospheric deflagration, which occurs in open air without a noticeable increase in pressure (Figure 1)

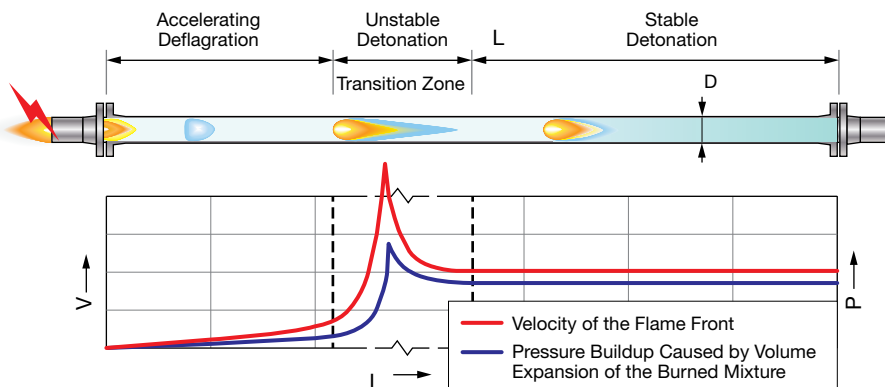
- a pre-volume deflagration, which is initiated by an internal ignition source and occurs in a confined volume, such as within a vessel (Figure 2)

- an inline deflagration, which is an accelerated explosion within a pipe that travels along the axis of the pipe at the flame-propagation speed.

Stabilized burning is the even, steady burning of a flame that is stabilized at or near the flame arrester element (Figure 3). A distinction is drawn between short-term burning (stabilized burning for a specific time period) and endurance burning (stabilized burning for an unlimited time).

Detonation is an explosion that propagates at supersonic velocity and is characterized by a shock wave. A distinction is drawn between a stable detonation, which has no significant velocity or pressure variation, and an unstable detonation, which represents the transition of a combustion process from a deflagration into a stable detonation.

Figure 4 illustrates the progression of an inline explosion. A pipe filled with an explosive gas is ignited at one end, and the flame propagates from the ignition source to the other end of the pipe. Initially, in the first section of the pipe, the flame-front velocity and the explosion pressure are low; this is a deflagration. The velocity of the combustion wave and the explosion pressure increase rapidly and the deflagration becomes an unstable detonation. When the velocity and pressure decline, the event becomes a stable detonation. Independent of the length of the pipe, the stable detonation propagates at supersonic velocities through the pipe.



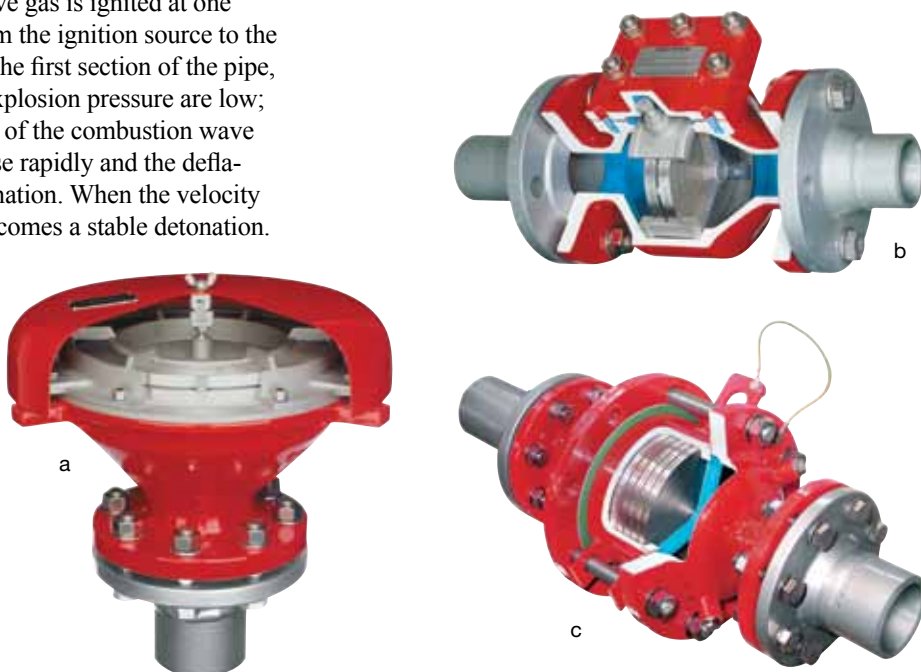
▲ **Figure 4.** An inline explosion begins as a deflagration, turns into an unstable detonation, and then becomes a stable detonation.

Flame arrester location in the process

Flame arresters are classified according to their location relative to the equipment they are designed to protect.

End-of-line flame arresters (Figure 5a) are located directly on a vessel or tank vent nozzle, or on the end of a vent line from the vent nozzle. They are usually deflagration flame arresters, and are commonly installed on atmospheric-pressure storage tanks, process vessels, and transportation containers. If the vented vapors are ignited, for example by lightning, the flame arrester will prevent the flame from spreading from the outside atmosphere to the inside of the vessel.

Inline flame arresters are installed in piping systems to protect downstream equipment from either deflagrations (Figure 5b) or detonations (Figure 5c). The choice between



► **Figure 5.** Flame arresters are classified as end-of-line (a) or inline based on the location relative to the equipment they protect, and they may protect against deflagrations (b) or detonations (c).

A CONSERVATION VENT IS NOT A FLAME ARRESTER

A conservation vent is a pressure/vacuum relief valve mounted on the roof of a storage tank to allow for tank breathing, thereby minimizing emissions and conserving product. A weighted or spring-loaded pallet within the valve keeps the vent closed as long as the pressure in the tank remains below the valve's setpoint. An increase in the pressure or vacuum causes the pallet to begin to lift off its seat, relieving the excess pressure (by allowing a small amount of vapor to exit the tank) or vacuum (by allowing air to enter the tank). An overpressure of 10–60% is usually required to achieve full lift of the pallet.

For several decades, government agencies and engineering societies have published guidelines for the design and safe management of storage tanks. Even though these guidelines are based on the latest research and engineering practices at the time they were developed, conflicts exist among some of the standards.

For example, the 5th edition of API Standard 2000, Venting Atmospheric and Low-Pressure Storage Tanks (1), states that a flame arrester is not considered necessary for use in conjunction with a pressure/vacuum valve venting to atmosphere, because flame velocities are lower than vapor velocities across the seat of the pressure/vacuum valve. On the other hand, the German TRbF 20 standard, Technical Regulations for Flammable Liquids (2), calls for flame arresters if the tank contains liquids that can create an explosive atmosphere — in other words, any liquid that is flammable. According to the United Nations Recommendations on the Transport of Dangerous Goods, Model Regulations (3) and the Globally Harmonized System of Classification and Labeling of Chemicals (GHS) (4), a liquid with a flashpoint lower than 60°C is considered a potential source of flammable vapor inside a tank.

Nevertheless, vents are a likely place of ignition, and it is a best practice to install flame arresters to prevent tank explosions (5).

These inconsistencies among globally recognized standards and publications prompted research to determine whether a conservation vent can truly assure flame transmission through the vent pallet to prevent flashback and thus explosions. During the development of ISO 28300: Petroleum, Petrochemical, and Natural Gas Industries — Venting of Atmospheric and Low-Pressure Storage Tanks (6), vents were tested according to the ISO 16852 flame arrester standard (7), and the results are incorporated into ISO 28300, as well as its equivalent, API 2000, 6th Ed. (8).

Two different tests were conducted:

- an atmospheric deflagration test, to investigate whether a conservation vent would fail if a vapor cloud in the vicinity

of the vent is ignited, for example by a lightning strike

- a high-velocity discharge test, to investigate whether the theoretical basis of engineering guidelines such as API 2210, Flame Arresters for Vents of Tanks Storing Petroleum Products (9), is correct in stating that flashback through the conservation vent is not possible because the discharge velocity is always above the flame velocity.

For the atmospheric deflagration test, an explosionproof vessel is filled with a flammable air/fuel mixture and vented through a 4-in. (DN 100) conservation vent into a plastic bag until the bag is completely full. A chemical igniter with a low ignition energy is used to ignite the air/fuel mixture approximately 1 m above the point where the valve is connected to the vessel. If the conservation vent cannot prevent flashback, the flame will propagate through the pressure/vacuum valve; an explosion will occur inside the vessel, the vessel diaphragm will burst, and flames will propagate out of the vessel.

Five manufacturers' conservation vents, each set at +10 mbar (+4.0 inH₂O) and –2 mbar (–0.8 inH₂O), were tested using propane (with explosive limits of LEL = 1.7 vol% and UEL = 10.8 vol%) at three concentrations (4.2 vol%, 5.5 vol%, and 6.0 vol%) as the fuel. In all of the tests, all of the conservation vents failed to prevent flame propagation into the vessel, the bursting diaphragm ruptured, and a large fire ball propagated out of the vessel.

The high-velocity discharge test is also conducted in an explosionproof vessel with a conservation vent installed on top of the vessel. A stoichiometric fuel/air mixture (4.2 vol% propane in air) is fed into the vessel and allowed to escape through the pressure side of the conservation vent. A pilot burner installed near the vent serves as an ignition source.

The first tests were performed using a volumetric flowrate of 85 m³/h of the explosive gas mixture. Upon ignition of the vapor cloud, the flame stabilized at the valve seat;

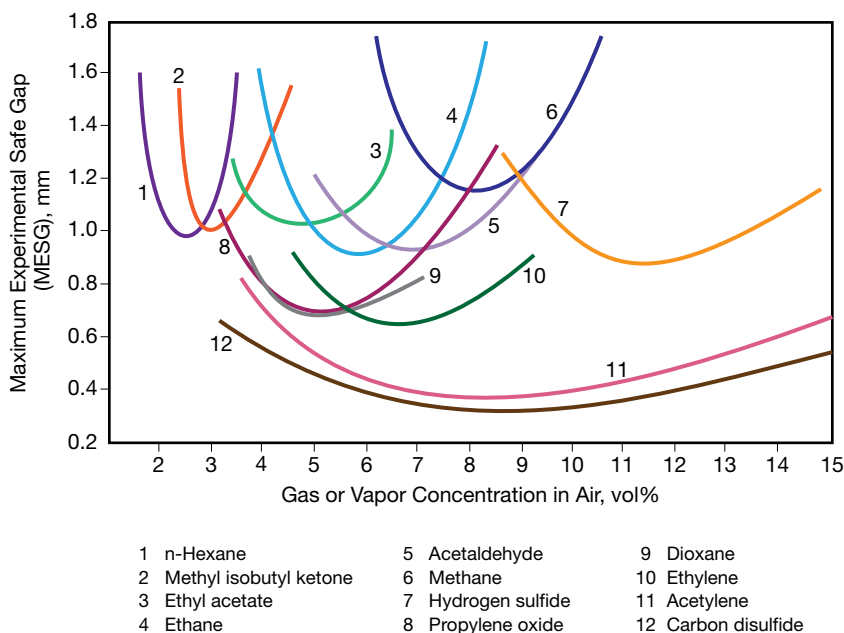
after a few seconds, the flame propagated through the gap between the seat and the pallet, causing an explosion inside the vessel; the vessel's rupture panel broke, and a fire ball propagated to the outside of the vessel. The second series of tests was conducted at a higher volumetric flowrate (100 m³/h). Again, just a few seconds after ignition, a flashback was detected.

These tests demonstrated that conservation vents do not act as flame arresters. These pressure/vacuum relief valves are not able to stop a flame. The flow of a typical pressure valve is not high, nor is it stable enough to stop the propagation of a flame. A conservation valve should not be used as a flame arrester, unless the device is approved according to flame arrester standards.



a deflagration arrester and a detonation arrester depends on the distance between the potential ignition source and the arrester (called the run-up distance, and designated L), because this length relative to the pipe diameter (L/D) influences the transition of a deflagration to a stable detonation. Inline deflagration flame arresters should be used only where the L/D ratio is less than 50 for hydrocarbon/air mixtures and less than 30 for hydrogen/air mixtures; detonation flame arresters are used with longer lengths or where the location of the ignition source is not known.

A third type of arrester, the *pre-volume deflagration flame arrester*, is used in some applications to protect the surroundings against the negative impacts of an internal vessel explosion.



▲ **Figure 7.** Each gas has a maximum experimental safe gap (MESG).

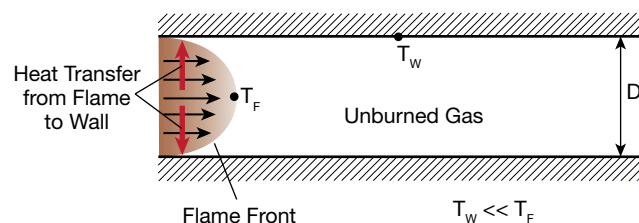
Assessing the application

Flame arresters are designed for particular operating conditions and should be selected for the intended use. To ensure that an effective flame arrester is selected, the conditions under which it will be used must be evaluated:

- What should be protected?
- What kind of explosive atmosphere can occur?
- Where may an explosive atmosphere arise?
- Where are the potential ignition sources?
- What are the operating parameters of the process (temperature, pressure, etc.)?

Maximum experimental safe gap

If a flammable gas or mixture enters (or is ignited in) a narrow gap between two plates, the flame propagates through the gap in the direction of the unburned gas (Figure 6). Heat is transferred from the flame front to the walls of the gap; the narrower and the longer the gap, the larger the influence of the cold wall on the flame profile. With an appropriately sized gap, this heat transfer extinguishes



▲ **Figure 6.** A flame arrester transfers heat from the flame front to the walls through the boundary layer.

the flame and prevents flashback. This is a flame arrester's principle of operation.

The appropriate gap size depends on the reactivity of the gas/air mixture. Each gas or vapor is associated with a maximum flame-quenching gap, called the maximum experimental safe gap (MESG). The MESG is an experimentally determined property of the gas mixture. It is defined as the maximum clearance between two parallel, 25-mm-long metal surfaces that has been found, under specified test conditions, to prevent an explosion in a test chamber from being propagated to a secondary chamber containing the same gas or vapor at the same concentration. Figure 7 provides MESG values for common gases.

Explosion groups

MESG values are one means of categorizing gases based on their capacity to produce a flashback. (The other, minimum ignition current ratio relative to methane [MIC] is not discussed here.) Table 1 shows the National Electrical

Table 1. Gases are classified into explosion groups based on their maximum experimental safe gap (MESG).

Maximum Experimental Safe Gap, mm	IEC Group	NEC Group	Reference Material
MESG = 1.14	I	—	Methane
> 0.9	IIA	D	Propane
0.5–0.9	IIB	C	Ethylene
< 0.5	IIC	B	Hydrogen

Code (NEC) and International Electrotechnical Commission (IEC) groups as a function of MESG. These groups form the basis for selecting flame arresters.

Flame arresters are tested with mixtures of vapors/gases in the different explosion groups, and based on the results of those tests are approved for a specific vapor group — IIA (NEC Group D), IIB (NEC Group C), or IIC (NEC Group B). The engineer then chooses a flame arrester with the appropriate approval level. For example, hexane has an MESG of 0.93 mm, making it a Group IIA vapor, so a Group IIA-certified deflagration arrester should be used.

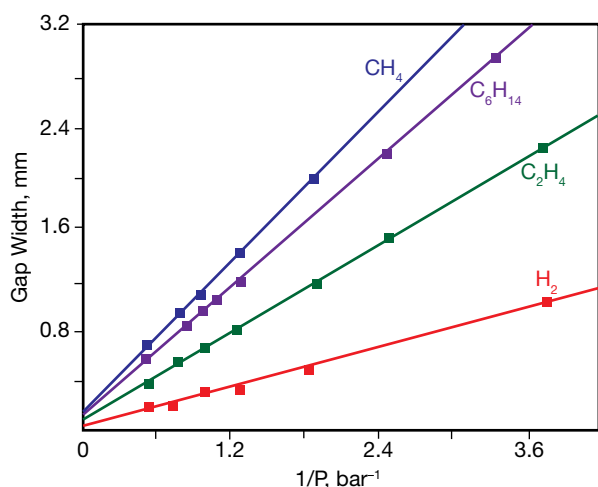
Arresters approved for one vapor group can be used for a lower group (*i.e.*, mixtures with a higher MESG), but arresters approved for a lower group are not suitable for a higher vapor group. For instance, a device certified for

Group IIC can be used for Group IIB or IIA mixtures as well, but not the reverse.

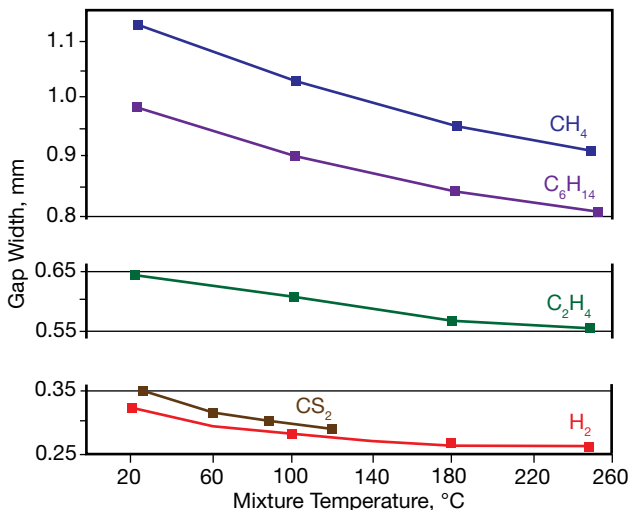
Common practice is to select flame arresters that have been approved based on MESG tests at standard atmospheric conditions, without regard for the effects of pressure, temperature, and oxygen concentration on the reactivity of the explosive gas mixture. Flame arresters tested at ambient conditions can be used at operational temperatures up to 60°C (140°F) and operational pressures up to 1.1 bar absolute (15.95 psia). If the working conditions are above these values, flame arresters that have been specifically tested for the actual conditions are needed. Figures 8 and 9 illustrate the effect of pressure and temperature on MESG.

Layers of protection

CPI plant safety relies on layers of protection — *i.e.*, independent measures that reduce the likelihood of an adverse event or the consequences of such an event should it occur, by control, prevention, or mitigation. Layers of protection include basic process monitoring and automation systems, alarms to trigger operator intervention, emergency shutdown systems, relief valves and rupture disks, containment dikes, and emergency response procedures. Flame



▲ **Figure 8.** As pressure increases, the maximum safe gap gets smaller.



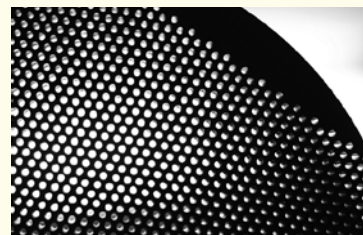
▲ **Figure 9.** As temperature increases, the maximum safe gap gets smaller.

HOW CAN FLAME ARRESTER ELEMENTS MADE OF PTFE EXTINGUISH A FLAME?

Static flame arresters operate by cooling a flame as it flows through the arrester elements to such an extent that the temperature of the gas mixture falls below the ignition point on the side being protected. In other words, the rate of heat diverted through the boundary layer to the flame arrester element is much greater than the heat added by the combustion reaction.

But the flame arrester element itself experiences very little warming, because it is subjected to a high temperature for an extremely short period of time — a few microseconds. Heat transfer is almost exclusively by convection/diffusion. Conduction through the element occurs only after the flame has been dissipated. This occurs more slowly in polytetrafluoroethylene (PTFE) than in stainless steel because of the former's lower thermal conductivity.

Thus, regardless of the material of construction — PTFE or stainless steel — the flame arrester element does not experience any serious warming. However, PTFE does provide protection against corrosion and plugging due to polymerization, making flame arresters made of PTFE a suitable alternative in applications subject to such issues.



arresters are commonly employed as one of these layers of protection.

Hazardous areas in a CPI plant are classified into zones according to the frequency and duration of the presence of an explosive atmosphere:

- Zone 0 is an area where an explosive atmosphere is always present, or is frequently present for long periods of time.
- Zone 1 is an area where an explosive atmosphere is sometimes present.
- Zone 2 is an area where an explosive atmosphere is rare or is present only for short periods of time.

Similarly, an ignition source may be present always, sometimes, rarely, or never.

Taken together, these two factors determine how many layers of protection must be provided to guard against flame transmission, as shown in Table 2. The selection of those safety measures depends on the specific process.

Figure 10 depicts a waste-gas incinerator classified as Zone 0, because the combustor operates around the clock and is a permanent ignition source. Thus, according to Table 2, three independent protection measures are required:

1. The first layer of protection is flow control on the air/nitrogen feed lines to the burner inlet nozzle. This maintains flow to the burner in case the waste gas flowrate drops below the low-flow setpoint.

2. The second layer of protection is an inline deflagration flame arrester installed as close as possible to the ignition source. This should be a temperature-monitored deflagration flame arrester that can detect a stabilized flame on the flame-arresting element.

3. The third layer of protection is a detonation flame arrester installed in line with the potential ignition source. Monitoring of the oxygen concentration in the incoming waste gas (not shown) could be added as an option.

These three independent measures ensure a high level of safety.

Choosing an effective flame arrester

To select the appropriate flame arrester for your application, provide the following information to the manufacturer:

1. *Service.* Briefly describe the intended use for the flame arrester.
2. *Analysis of gases or vapors.* Supply details of all flammable and nonflammable components so that the explosion group can be identified and the correct flame arrester design and materials of construction can be selected.
3. *Molecular weight or density of the gas or vapor.* This

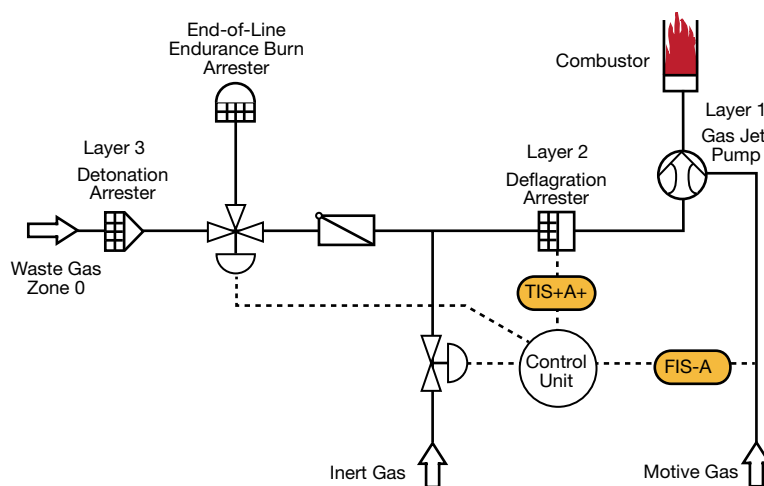


Figure 10. A Zone 0 waste-gas incineration process requires three layers of protection.

Table 2. The likelihood of an explosive atmosphere and an ignition source being present determine the number of layers of protection that need to be provided.				
Ignition Source	Explosive Atmosphere			
	Always (Zone 0)	Sometimes (Zone 1)	Rarely (Zone 2)	Never
Always	3	2	1	0
Sometimes	2	1	0	0
Rarely	1	0	0	0
Never	0	0	0	0

will allow an equivalent air flowrate to be calculated for pressure-drop determination.

4. *Flowrate.* This should be stated in volumetric terms, or sufficient information should be provided to allow a volumetric flowrate to be calculated. For storage tank applications, give the inbreathing and outbreathing requirements, or sufficient information on the tank type, pressure resistance shape, dimensions, and filling and emptying rates to allow these parameters to be calculated.

5. *Temperature ranges.* Provide the maximum and minimum temperatures for both design and operating conditions to allow the correct flame arrester element and mechanical design of the arrester's housing to be determined.

6. *Pressure ranges.* Supply the maximum and minimum pressures for both design and operating conditions. This information is also used (along with the temperature ranges) to determine the correct flame arrester element and mechanical design of the housing. The maximum pressure at which a flammable mixture can ignite in the process should be highlighted if this is different from the normal operating pressure. For storage tank applications, give both pressure and vacuum requirements.

Article continues on next page

7. *Allowable pressure drop.* This is determined from the volumetric flowrate, and will enable the correct flame arrester configuration to be selected.

8. *Type.* Specify whether an inline, end-of-line, or pre-volume arrester is needed, whether the device will experience short-term or endurance burning, and whether an unstable or stable detonation would be expected. For inline arresters, provide details of the piping between the flame arrester and the possible source of ignition in the form of a dimensioned sketch or isometric drawing.

9. *Orientation.* Note the intended orientation of the flame arrester — vertical or horizontal.

10. *Pipe size.* State the nominal size of the pipework connected to the flame arrester.

11. *Connection type.* Provide details of the flanged or screwed connections.

12. *Housing material.* State the preferred material of construction for the flame arrester housing. The manufacturer may verify the suitability of this material from an evaluation of the mixture composition and operating conditions.

13. *Element material.* State the preferred material of construction for the flame arrester elements. The manufacturer may verify the suitability of this material from an evaluation of the mixture composition and operating conditions.

14. *Construction.* Care should be taken when using materials such as aluminum or plastics, which, depending on the fluid and the operating conditions, may be subject to sparking and electrostatic charging.

15. *Documentation.* Tell the manufacturer what documentation you require. This could include, for example, material certificates or results of special tests.

CEP

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CHEM E ON DEMAND

Readers can explore this topic further by viewing author Davies' webinar, *Explosion Protection with Inline Flame Arresters*, on ChemE on Demand (www.aiche.org/resources/chemeondemand/webinars/explosion-protection-line-flame-arresters). AIChE undergraduate student members can view the webinar for free; nonstudent members can use a free credit. The price for nonmembers is \$99.