Flame Arrestor

AZAR ENERGY
TABRIZ

CHEM GROUP
AZAR ENERGY Co.

Introduction

A Flame Arrestor is a device which allows gas to pass through it but stops a flame in order to prevent a larger fire or explosion. There is an enormous variety of situations in which flame arrestors are applied. Flame arrestors of numerous varieties have been applied in many industries. All of them operate on the same principle: removing heat from the flame as it attempts to travel through narrow passages with walls of metal or other heat-conductive material.

Flame arrestors are used in different industries, including refining, pharmaceutical, chemical, petrochemical, pulp and paper, oil exploration and production, sewage treatment, landfills, mining, power generation and bulk liquids transportation. In some cases, the flames involve exothermic (heat-producing) reactions other than oxidation. Processes which generate the combustible or reactive gases include blending, reacting, separation, mixing, drilling and digesting. These processes involve numerous equipment configurations and gas mixtures.

Where to Use

- Stopping the spread of an open fire
- Limiting the spread of an already occurred explosion
- Preventing potentially explosive mixtures from igniting
- Confining fire within a controlled location
- Stopping the propagation of a flame traveling at subsonic velocities

End-of-Line, Vent-to-Atmosphere Type

Most flame arrestor applications and designs fall into two major categories. One group consists of end-of-line flame arrestors, also known as the vent-to-atmosphere type (Figure 1). The classic application is in preventing fire in the atmosphere from entering an enclosure

Conversely, some end-of-line flame arrestors prevent fire in an enclosure from igniting an explosive atmosphere such as in a refinery. For instance, flame arrestors may be installed in furnace air inlets and exhaust stacks.

Figure 1: End of Line Flame Arrestor

In-Line, Deflagration or Detonation Type

The other major category consists of in-line flame arrestors, also known as deflagration and detonation flame arrestors. (Speaking non-technically, deflagration means rapid burning and detonation means explosion.) These units are installed in pipes to prevent flames from passing, as shown in Figure 2.

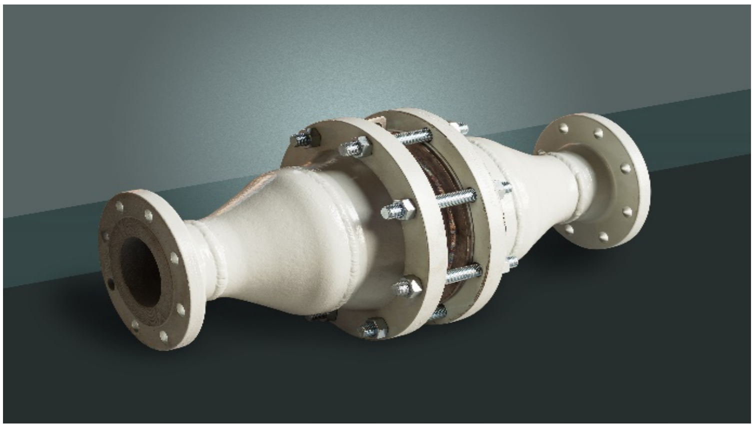

Figure 2: Inline Flame Arrestor

in-line flame arrestors are now subdivided into three categories on that basis. Furthermore, special provisions are made for each of the three major groups of gases according to degree of flame hazard (also explained later)—NEC Groups B, C and D. Thus, there are now as many as twelve different types of flame arrestors, as follows:

1. End-of-line, Group B
2. End-of-line, Group C
3. End-of-line, Group D
4. In-line, low/medium-press. deflagration, Group B
5. In-line, low/medium-press. deflagration, Group C
6. In-line, low/medium-press. deflagration, Group D
7. In-line, high-pressure deflagration, Group B
8. In-line, high-pressure deflagration, Group C
9. In-line, high-pressure deflagration, Group D
10. In-line, detonation, Group B
11. In-line, detonation, Group C
12. In-line, detonation, Group D

Explosion group		**MESG of mixture (mm)**	**Example**
IEC	NEC		
I		≥1.14	Methane
IIA	D	≥0.90	Fuel
IIB1	C	≥0.85	Ethanol
IIB2		≥0.75	Dimethyl ether
IIB3		≥0.65	Ethylene
IIB		≥0.50	Carbon monoxide
IIC	B	<0.50	Hydrogen

Unconfined Propagation of Flame

Flames generally propagate much faster in pipes than in the open atmosphere. Flames which are not restricted by physical barriers such as pipes are called unconfined. An unconfined flame is free to expand by consumption of unburned gas into an ever-widening volume. This expansion provides quick dissipation of the heat and pressure energy generated by the flame.

When the unconfined flame first begins to consume the unburned gas, the flame front travels below sonic velocity (the speed of sound in the atmosphere). If the velocity remains subsonic, the event is called a deflagration; the gas is said to deflagrate, meaning burn rapidly. By contrast, flame propagation at or above the speed of sound is called a detonation, which is an explosion strong enough to cause shock waves in the gas. Some gases can detonate without being confined, but it is not a common occurrence.

Confined Propagation of Flame

The most common example of confined flame is propagation inside a pipe or explosion inside a process vessel or liquid storage tank. The flame is usually a flashback, meaning that it propagates upstream, against the flow of gas and towards its source. The heat and pressure energy of a confined flame is not relieved as readily as that of an unconfined flame. This restriction of energy dissipation makes a tremendous difference in how the flame propagates and thus what kind of flame arrestor is required to stop it.

As the flame propagates down the pipe, it encounters gas with higher temperature and pressure, speeding the combustion reaction. This process feeds on itself, producing flame velocities, temperatures and pressures much higher than those seen in unconfined conditions.

While propagating down a pipe, the flame functions not only as a chemical reaction, but also as a mechanical reaction— like a piston in a cylinder—compressing the gas before consuming it and imparting more energy and velocity. If the pipe is long enough, in some cases the flame can reach hyper-sonic (much faster than sound) velocities as high as 6500 miles per hour / 2900 meters per second. The pressure may approach 4900 psig / 34,000 kPa.

Selection of an appropriate in-line flame arrestor depends on how intense any flame in the pipe is expected to be, in terms of velocity and pressure. Studies of flame propagation in pipes reveal seven distinct stages or phases which a flame may reach if the pipe is long enough and the combustion is fast enough and energetic enough (Figure 3).

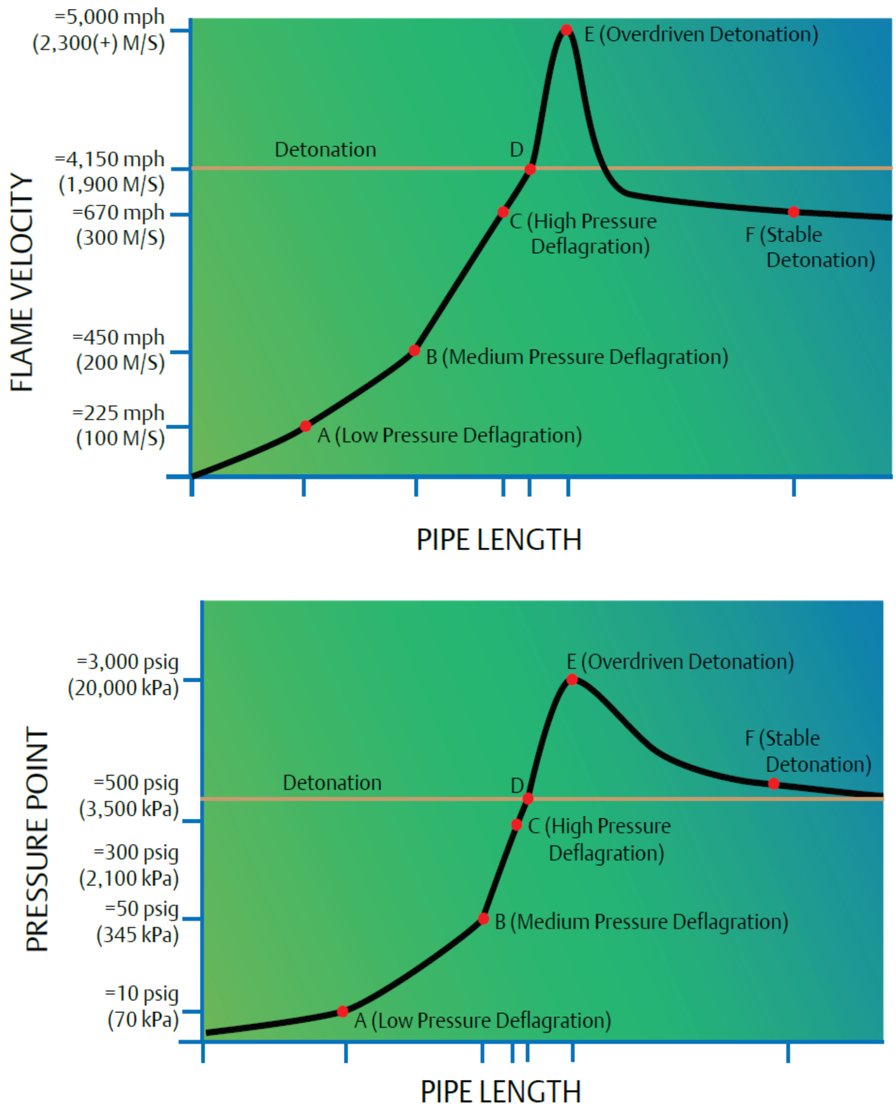

Figure 3: Pipe Length vs (Flame Velocity & Pressure Point)

Low-Pressure Deflagration

So long as the flame front travels well below the speed of sound with minimal pressure increase caused by the expanding boundary layer, its condition is considered to be low-pressure deflagration (Figure 4). That stage is generally associated with velocities up to about 112 meters per second and relative increases of absolute pressure (DP/ P_o) up to 1. (Assuming initial atmospheric pressure, the gauge pressure is less than about 100 kPa(g)).
(DP/P_o is the dimensionless ratio for deflagration and detonation testing as measured in the piping system on the side of the arrestor where ignition begins. P_o is the system initial absolute pressure. DP is the measured absolute pressure, minus P_o.)

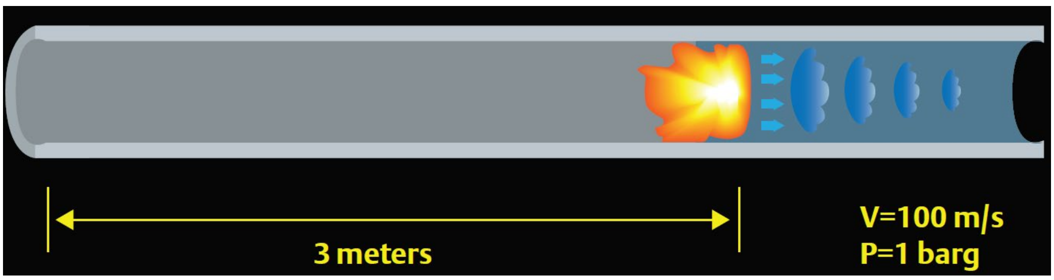

Figure 4: Low-Pressure Deflagration

Medium-Pressure Deflagration

As the flame propagates farther down the pipe, its intensity increases to the dynamic state of medium-pressure deflagration. Flame speed is higher but still subsonic—up to 200 m/s. The pressure impulse at the flame reaches levels considered to be medium, with DP/Po up to 10.

Figure 5: Medium-Pressure Deflagration

High-Pressure Deflagration

Beyond the limit of medium-pressure deflagration, the propagating flame reaches the condition of high-pressure deflagration. The flame front velocity—still subsonic—is up to 300 m/s and the pressure increase caused by the expanding boundary layer reaches a DP/DPo as high as 20.

Figure 6: High-Pressure Deflagration

Deflagration-to-Detonation Transformation

When the propagating flame front passes sonic velocity, what occurs is called transformation from deflagration to detonation, abbreviated DDT. The pressure impulse in front of the flame becomes a shock wave. The compressed gas immediately in front of the expanding boundary layer of gas just in front of the flame, which can reach pressures around 700 kPa(g), comes in contact with the flame. The result is an explosion. The energy of that explosion, which includes heat, velocity and pressure, has nowhere to go but down the pipe. The explosion generates tremendous shock-wave compression of the gases both upstream and downstream of the initial point of transformation (Figure 7).

Figure 7: Deflagration-to-Detonation Transformation

Detonation

A detonation is defined as a flame front moving at or above the speed of sound. It entails increased compression of the gases by shock waves in front of the flame. A detonation may have a velocity in the range of 300 m/s and a maximum impulse pressure of 3500 kPa(g), with DP/Po as high as 20.

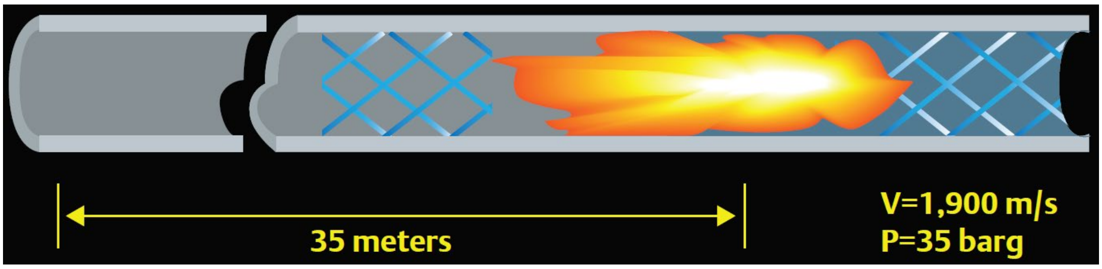

Figure 8: Detonation

Overdriven (Unstable) Detonation

As the flame propagates even farther down the pipe, it goes into the dynamic state of overdriven or unstable detonation. This is defined as a flame front moving at supersonic velocity and in some instances, at hypersonic velocity, attended by tremendous compression of gas by multiple shock waves. It is an unstable and transient condition. As the flame goes through DDT, it continues to pile shock waves into a dense concentration. Gas in front of the flame is compressed and heated above the ignition point like the fuel mixture in a diesel engine cylinder. When the compressed gas self-ignites, the explosion releases an extremely large amount of energy, much like the earlier DDT. Again, the energy is restrained by the piping and only allowed to move straight ahead. Since the flame velocity is already supersonic, the flame accelerates to hypersonic velocities (Figure 9). The reason this condition is temporary is that the flame velocity and pressure are dependent on numerous shock waves providing gas compression in front of the flame. These shock waves dissipate soon after the initial explosion and the velocity and pressure of the flame stabilize. An overdriven detonation has a typical peak velocity in the range of 2300 m/s and a maximum impulse pressure of about 20,995 kPa(g)—equivalent to a DP/Po of 130.

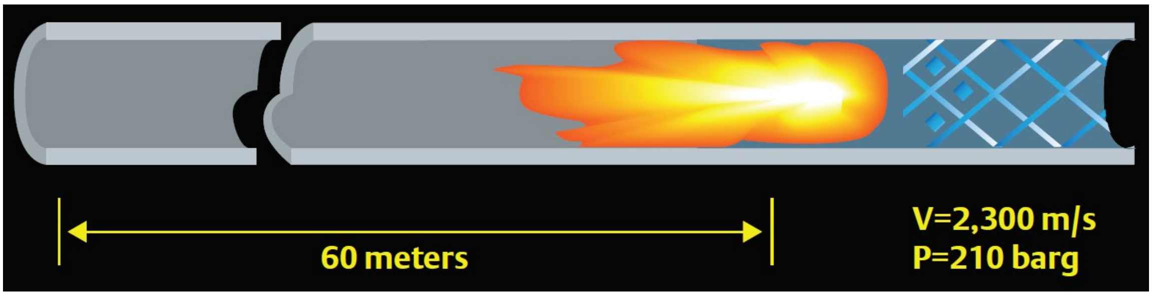

Figure 9: Overdriven (Unstable) Detonation

Stable Detonation

Beyond the transient overdriven detonation, the propagating flame finally reaches the dynamic state of stable detonation. The flame front moves at or above the speed of sound with shock-wave compression in front. The flame will not go through any more transitions but will remain in this stable condition to the other end of the pipe. A stable detonation has a velocity in the range of 300 m/s and a peak impulse pressure of 3,500 kPa(g), equivalent to a DP/Po of 20 (Figure 10).

Figure 10: Stable Detonation

Maximum Experimental Safe Gap (MESG)

Maximum experimental safe gap is a standard measurement of how easily a gas flame will pass through a narrow gap bordered by heat-absorbing metal. MESG was developed to classify gases for design and selection of electrical instrumentation, electrical enclosures and flame arrestor devices. The measurement is conducted with a standard apparatus consisting of a small, hollow metal sphere of a certain diameter which is split into two halves. The circular edge of each hemisphere is provided with a smooth metal flange of a certain width. The hemispheres are held close together in the apparatus with the flanges parallel and separated by a narrow gap. This apparatus is immersed in a stoichiometric mixture of the test gas and air at standard room conditions and the mixture inside the sphere is ignited with an electric spark. The experiment is repeated with a wider and wider gap between the two flanges, until the mixture outside the sphere is ignited. The MESG is the greatest distance between flanges at which the flame fails to pass through. The more hazardous the gas, the narrower the MESG. An arrestor must be designed for the MESG value of the process gas.

Selecting End-Of-Line Flame Arrestors

As explained before, end-of-line deflagration flame arrestors are designed for unconfined flame propagation, also referred to as atmospheric explosion or unconfined deflagration. They simply bolt or screw onto the process or tank connection. These designs incorporate well-established but simple technology. Most use a single element of crimped wound metal ribbon that provides the heat transfer needed to quench the flame before it gets through the arrestor element.

The main points of concern when selecting an arrestor for end-of-line applications are as follows:

1. Hazardous group designation or MESG value of the gas
2. Flame stabilization performance characteristics of the arrestor compared to the system potential for flame stabilization for sustained periods of time
3. Process gas temperature
4. Pressure drop across the arrestor during venting flow conditions, relative to the system's maximum allowable pressure and vacuum
5. Materials of construction that meet the ambient and process conditions – for example, extremely cold climate, salt spray, chemically aggressive gas, etc.
6. Connection type and size
7. Instrumentation requirements

Selecting In-Line Flame Arrestors

The various dynamic states explained earlier for confined flames can be very dangerous for a process system due to the tremendous energies associated with detonation pressure and flame velocity. Things happen fast and can turn catastrophic. These multiple dynamic states increase the challenge of providing a flame arrestor product or products which stop the flame and withstand the enormous pressures caused by explosions within the confined piping. The very wide range of possible behavior for a confined flame causes two particular problems for flame arrestor products. First, the high-pressure deflagration and stable detonation states have very stable kinetics of burning and the flame is moving very fast. Therefore, the arrestor must be able to absorb the flame's heat much faster than is required by standard low-to-medium-pressure deflagration conditions. Second, the instantaneous impulse pressures caused by the shock waves of overdriven detonation subject the arrestor to forces of up to 20,995 kPa(g) / 3000 psig. Thus, the arrestor must be structurally superior to standard low-pressure deflagration arrestors.

Confined Deflagration Flame Arrestors

In-line deflagration flame arrestors are designed for confined flame propagation, also referred to as flashback or confined deflagrations. Like the end-of-line variety, flame arrestors of this type have been used in numerous applications for many decades. They resemble end-of-line flame arrestors in many ways. However, things are much different for these arrestors, because they are subject to more severe flame states. For almost every state of flame, there is a special type of arrestor. For example, a standard in-line deflagration flame arrestor is designed to stop flame propagation in short lengths of pipe, involving low-pressure and medium-pressure deflagrations. The high-pressure deflagration flame arrestor is an enhanced version of the standard deflagration flame arrestor, designed to stop flames in the low, medium and high-pressure deflagration states.

Detonation Flame Arrestors

Since the early 1990s, detonation arrestors were developed and tested in accordance with the requirements of Appendix-A to Part 154 of 33 CFR, commonly called the "U.S. Coast Guard Standard" (USCG). These arrestors received USCG approval in 2 to 20 in. sizes, concentric and eccentric designs, with models for Group-D (IIA) and models for Group-C (IIB3) flammable vapors. Detonation arrestors approved to this standard must pass both stable and unstable detonations in addition to meeting other requirements, in other words, the most severe flame stage. There is no provision in this standard for detonation arrestors that are approved for stable detonations only.

None of the deflagration arrestor designs can withstand a detonation. Therefore, the detonation flame arrestor was designed. It has the heat transfer capacity and structural design to withstand all the dynamic conditions of flame propagation and still stop the flame. The detonation flame arrestor is the ultimate flame-stopping product and is used when the flame can be in any of the detonation states. These capabilities do not come without some trade-offs. Detonation flame arrestors impose higher pressure drops than deflagration flame arrestors due to heat-transfer requirements, they are heavier because of structural requirements and they are typically more expensive. Therefore in-line deflagration flame arrestors will always have a place in industry. The main points of concern when selecting an arrestor device for in-line applications are the same as listed before for end-of-line applications, except for one additional consideration: The L/D ratio and piping configuration between the arrestor and the potential ignition source.

Figure 11: Inline Flame Arrestors in Different Sizes manufactured by Azar Energy

Design Standards

A flame arrestor, the use of which in an open vent line or on the inlet to the Pressure/Vacuum Valve is an effective method to reduce the risk of flame transmission. The user is cautioned that the use of a flame arrestor within the tank's relief path introduces the risk of tank damage from overpressure or vacuum due to plugging if the arrestor is not maintained properly. More information on flame arrestors can be found in ISO 16852, NFPA 69, TRbF 20, EN 12874, FM 6061, and USCG 33 CFR 154.

Material of Construction

Azar Energy flame arresting devices are available in a wide range of materials (aluminum, stainless steel, ductile iron, hastelloy, etc.) The material must be compatible with the service conditions. Improper material choice can lead to contamination of the product being stored or reduction in the flame or detonation arrestor’s ability to operate safely. Information on the corrosion resistance of materials under various service conditions is available in corrosion handbooks and chemical dictionaries.

Flame Arrestor Application

A flame arrestor 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.

Storage tanks and other vessels containing flammable and/or explosive chemicals and mixtures are prevalent in chemical process industries (CPI) plants. Flame arrestors are installed on such equipment to prevent potential hazards associated with flammable and explosive materials. For example, flame arrestors 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.

Application Difference (Selection Guide) Between In-line vs. End-of-line Flame Arrestors

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

End-of-line flame arrestors 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 arrestors, 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 arrestor will prevent the flame from spreading from the outside atmosphere to the inside of the vessel.

Inline flame arrestors are installed in piping systems to protect downstream equipment from either deflagrations or detonations. The choice between a deflagration arrestor and a detonation arrestor depends on the distance between the potential ignition source and the arrestor, because this length relative to the pipe diameter (L/D) influences the transition of a deflagration to a stable detonation. Inline deflagration flame arrestors should be used only where the L/D ratio is less than 50 for hydro-carbon/air mixtures and less than 30 for hydrogen/air mixtures; detonation flame arrestors are used with longer lengths or where the location of the ignition source is not known.