Flame Arresters in Piping Systems

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American Petroleum Institute
1220 L Street, Northwest
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Safety and Fire Protection Department

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FOREWORD

This publication is intended to alert industry to the limitations of flame arresters. Flame arresters are usually tested in configurations that produce low flame speeds only. The highly variable conditions surrounding arrester applications may result in high flame speeds that could render the arresters ineffective.

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CONTENTS

Flame Arresters in Piping Systems

SECTION 1—GENERAL

1.1 Purpose

The availability of commercial flame arresters listed by nationally recognized testing laboratories has frequently led to the installation of these arresters in piping systems; however, the actual conditions under which these arresters will operate may be far different from the conditions under which the arresters were tested and listed by the testing laboratories. Listed arresters are normally tested under nonflowing conditions and with ignition at the open ends of pipes attached to the arresters. The testing is conducted with limited lengths of the attached pipes. Flames propagating through piping systems continuously accelerate and can reach velocities that are much higher than those at which the arresters were tested. As a result, flame arresters, whether listed or not, may not be effective when they are incorrectly applied in piping systems. Listed arresters should not be installed in piping systems unless they have been tested under conditions equivalent to those expected in the specific applications.

This publication is intended to alert industry to the limitations of flame arresters. The highly variable conditions surrounding applications of arresters may result in high flame speeds that could render the arresters ineffective.

1.2 Referenced Publications

The most recent editions of the following standards, codes, and specifications are cited in this publication.

API
- Publ 2210 *Flame Arresters for Vents of Tanks Storing Petroleum Products*

UL[1]
- UL 525 *Flame Arresters for Use on Vents of Storage Tanks for Petroleum Oil and Gasoline*
- *Gas and Oil Equipment*

SECTION 2—FLAME PROPAGATION

Flames propagating through piping systems are capable of reaching extremely high speeds. Initially, the flames travel at a burning velocity characteristic of the mixture; this velocity, sometimes tabulated in handbooks, is usually a few feet per second. Then the flames begin to accelerate. This acceleration process is assisted by turbulence, which can be induced in the unburned mixture by the flames themselves or can result from such factors as flow, pipe wall roughness, or turbulence-producing fittings [1].

Note: The flame velocity at a given point is a function of the length of pipe and size of pipe through which the flames have traveled, the intensity of turbulence, the properties of the particular flammable mixture, and other factors.

Flames can accelerate to a velocity that permits their travel upstream as well as downstream of the original direction of the flow [2]. They can readily reach a velocity of several hundred feet per second. If the flames are propagating in the unburned medium at a velocity less than the speed of sound, it is known as a deflagration, but if the pipe is long enough, flame propagation under detonation conditions can occur. In detonations, flames can travel several thousand feet per second and are accompanied by pressure pulses; the magnitude of the pressure pulses may exceed 20 times the initial absolute pressure [1].

Although the magnitude of the pressure pulses may exceed 20 times the initial absolute pressure, there are a number of ways in which even higher pressures can be generated:

a. At closed ends and elbows, the pressure is increased by reflection of the detonation wave.
b. At the point where the deflagration transforms into a detonation, even higher pressures can occur during a phase of the detonation known as the overdriven phase [3].
c. When flames are propagating toward a closed system, pressures higher than 20 times the initial absolute pressure can occur under certain circumstances because of a process known as pressure piling. In pressure piling, the deflagration causes precompression of the gas before the transition to detonation.

Flame propagation makes the installation of flame arresters in piping systems fundamentally different from the installation of arresters on tank vents. Tank vents have little or no pipe length present between the arrester and an external ignition source at the open end (see Underwriters Laboratories' *Gas and Oil Equipment* and API Publication 2210).

[1]Underwriters Laboratories, 333 Pfingsten Road, Northbrook, Illinois 60062-2096.

SECTION 3—LISTED FLAME ARRESTERS

3.1 Problems in Piping Systems

Installing flame arresters in piping systems with extended or continuous pipe lengths presents a complex design problem. The criteria for the design of flame arresters for continuous piping systems have not even been established yet. Systems with extended or continuous pipe lengths may have pipe lengths that would permit flames to attain enough velocity to pass through an arrester. Alternatively, the high pressures developed may damage the arresting element or rupture the housing, enabling a flame to pass through the device. Pressures resulting from within a pipe may exceed the strength of an attached vessel.

3.2 Design

Listed flame arresters are usually cellular arresters and include the following types: perforated-plate arresters, parallel-plate arresters, crimped-metal-ribbon arresters, and sintered-metal arresters [4]. These devices are barriers that arrest the flames by quenching (that is, the heat of the flames is transferred to the walls of an array of small passageways in the arrester). The critical parameters that govern the effectiveness of cellular arresters are the diameter or width and the length of the flame passages.

Cellular arresters (discussed in API Publication 2210) are listed by nationally recognized testing laboratories as intended for installation on atmospheric pressure tank vents storing petroleum products and on vents from the tanks of oil tankers (see *Gas and Oil Equipment*) [1]. The listings are usually based on tests made with mixtures of gasoline vapor and air and may not cover other mixtures. Arresters tested with gasoline vapor are probably suitable for use with most common paraffin or aromatic hydrocarbons; however, they should not be used with fast burning gases and vapors, such as hydrogen, acetylene, or olefinic hydrocarbons, without additional tests.

3.3 Limitations

While listed arresters are tested by laboratories, the test conditions may not be equivalent to or representative of the actual service conditions of particular piping system designs. The listings indicate whether the test conditions included ignition at the open end of a pipe attached to the device. If they indicate that ignition at the open end of a pipe was included, the listings would also indicate the maximum permissible length of the pipe. This limitation of pipe length means that the stated length is the greatest for which the arrester was successfully tested; this presumes that the pipe is a straight section of pipe that is the same size as the arrester. To be effective, listed arresters must be installed in accordance with their listed installation parameters.

3.4 Test Procedures

The test procedure for listed arresters which is provided in UL 525 defines ignition as occurring at the open end of the discharge pipe and under nonflowing conditions, so this test procedure is not appropriate for listed arresters in closed piping systems or with flowing flammable materials. Before arresters are installed in piping systems, the arresters should be tested with a procedure that adequately represents the service conditions under which they will be used. The parameters of the test procedure must be equivalent to the operating conditions, which include fuel mixture composition, temperature, pressure, flow rate, and potential ignition locations relative to the arresters. In some cases, testing under overdriven conditions or with pressure piling effects considered may be appropriate. In other cases, testing detonation arresters at deflagration conditions should be considered because arresters suitable for detonations have failed deflagration tests [3].

3.5 Untested Arresters

Some improper installations of listed arresters have been in service for years without an accident, but this should not be considered as proof that such installations are safe. In most of these cases, the arresters have never been subjected to flame fronts. The statistical risk is low because the required mixture and an ignition source have not occurred simultaneously.

In facilities that terminate at continuous ignition sources, such as furnaces, flare pits, or pilot lights, the probability of a simultaneous occurrence of the proper mixture and an ignition source is greater. Where arresters have been installed in piping between the gas and ignition sources, there have been many instances of flames occurring within the piping, migrating through the arresters, and resulting in an explosion.

3.6 Flame Arresters in Series

In many cases, placing two or more flame arresters in series provides only slight additional protection when compared to a single arrester. If flame propagation conditions cause the first arrester to fail, there is a significant probability that an identical second arrester will also fail. In any case, there is little if any test work to verify the benefits of arresters in series.

SECTION 4—UNLISTED ARRESTERS

4.1 Description

Besides listed arresters, there are other arresting devices and techniques in use within the hydrocarbon processing industry, including water seals, packed beds, velocity-type arresting devices, and mechanical interruption of the flame path. These arresting devices and techniques also have limitations and should be tested at full scale to determine their effectiveness under actual service conditions.

4.2 Water Seals

Water seals are often designed and installed to prevent reverse gas flow, and their design is potentially capable of preventing flame propagation [4,5,1]. In each water seal, the gas mixture is bubbled through a reservoir of water, a process that may prevent the passage of flames. The flames are interrupted because each gas bubble is isolated from the next.

No standard design or listing is available for water seals. Each installation presents a specific problem involving the rate of the gas flow, the depth of the seal, and the size and the configuration of the vessel that contains the water. Some important design considerations for the water seal are as follows:

a. It should prevent rupturing under flame-produced pressure.
b. It should reliably maintain the required water level for normal as well as flame-produced conditions.
c. It should protect against freezing.

4.3 Packed Beds

For many years, gravel, raschig rings, small pebbles, and other bulk materials have been used as flame arresters in packed towers or columns. There are no established design criteria for using packed beds as flame arresters.

4.4 Velocity–Type Arresting Devices

Where the flow of a gas mixture is limited to a single direction, it is possible to ensure, by design, that the flow velocity will never be less than the velocity corresponding to the maximum rate of propagation of flames in the mixture under consideration [1]. For a small diameter pipe discharging gasoline vapors into the open air, an efflux velocity of 10 feet per second is considered adequate [2,6]; however, the appropriate velocity must be determined for each case. The appropriate velocity can be determined from the gas mixture and pipe diameter [1].

Controlling flow velocity through a velocity-type arresting device should be regarded as an effective technique for preventing flashbacks only when the ignition source is at the open end of the pipe. In the design of a velocity-type arresting device, some means must be provided either to maintain a minimum velocity under all operating conditions or to interrupt the gas supply if the flow velocity becomes too low. The design must also provide some means either to interrupt the gas supply or to extinguish burning within the velocity section of the arrester. This prevents the flames from heating the arrester enough to permit them to pass through it, which can occur within a few minutes.

4.5 Mechanical Interruption of Flame Path

A closed pipe valve can prevent flame passage as long as the valve can be closed quickly enough. Using a valve as a flame arrester appears to be a limited option, though. Achieving the rapid response time for closure is difficult; however, because flames are accompanied by vibration, pressure rise, temperature, and ultraviolet emissions, sensing devices positioned some distance from the valve can be used to close it, precluding the passage of flames. Mechanical interruption is probably more useful in combination with the other approaches discussed in this publication.

SECTION 5—SUMMARY

For cellular and other tested arresting devices, the following guidelines are recommended:

a. Only a listed or tested arresting device that is within the range of its listed or tested parameters should be used.
b. For applications that use listed arresters outside the range of their test parameters and for all unlisted devices, a full-scale test under conditions equivalent to actual service conditions should be conducted. Actual service conditions include mixture composition, temperature, pressure, flow rate, and ignition location relative to the arrester. If detonation conditions can occur at the arrester, the device must be tested under detonation as well as deflagration conditions.
c. The arresting device must be installed and maintained in the exact mechanical form in which it was tested; this in-

cludes maintaining the exact form of the element, its housing, and gaskets.

d. For piping system applications where both the flammable mixture and an ignition source are likely to be present simultaneously, flame arresters should not be considered as the sole means of protection but should be used as a supplement to other systems or operational controls.

e. If the arresting device is not designed to withstand sustained burning on the face, a provision must be made to detect and suppress or prevent burning.

f. When an arrester is installed in a piping system, it should be checked periodically to ensure that it has not been damaged, has not clogged, or has not corroded. Therefore, the inline arrester must be installed in a location that facilitates inspection and required maintenance.

SECTION 6—REFERENCES

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