

1900 Pressure Relief, Flares, Flame Arrestors

Abstract

This section highlights pressure relief valve and flare system requirements from a fire protection viewpoint, and addresses conditions that place high demand on relieving devices. The *Instrumentation and Control Manual*, Section 1200 and API RP 520 and 521 are the primary references on relief valve and relief system design.

This section also describes the operation of and applications for thermal, water seal, and stream velocity flame arrestors.

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1910 Pressure Relief Systems

1911 Basic Design Considerations

Basic design requirements are detailed in the following publications:

- *Instrumentation and Control Manual*, Section 1200, Relief Systems
- API RP 520, "Design and Installation of Pressure-Relieving Systems in Refineries"
- API RP 521, "Guide for Pressure Relief and Depressuring Systems"
- Section VIII, Division I of the ASME Boiler and Pressure Vessel Code

These guidelines cover the following areas:

1. Determining emergency relieving rate requirements
2. Sizing and selecting relief valves
3. Establishing the relief loads for the design of relief headers and the disposal system

Single Risk Concept

The single risk concept specifies that only one emergency (or group of interrelated emergencies) will occur at one time, and that the emergency or group of emergencies develops from a single fundamental cause. The probability that multiple unrelated incidents would occur simultaneously is so low that it is not a credible consideration.

The size and cost of safety facilities would be excessive if they were designed to handle every conceivable emergency and to handle them all simultaneously. Consequently, the single risk concept has been accepted as the basic design criteria for sizing safety relief valves and discharge systems.

The single risk emergency that results in the largest load on the safety facilities is called the **largest single risk** and forms a basis for design of the safety equipment.

The emergency establishing maximum loads for individual safety valves could be different from that for maximum loads for the closed discharge system. For example, loss of the pumpout pumps could result in the maximum **individual** safety valve load on a vessel, while fire could result in the maximum **overall** system load in the same area. A plant-wide utility failure could also produce maximum load on the relief system (see API RP 520).

1912 Criteria for Determining Relief Load

Typical conditions requiring relief protection are covered in API RP 520 and 521. Relief capacity under an external fire scenario can be calculated using API RP 520.

Multiple Vessels

When more than one vessel is protected by a single safety valve, the combined wetted surface—below 25 feet—of all the vessels connected to the single safety valve is used in computing heat input from fire.

1913 Relief Valves Discharging to Atmosphere

Design Considerations

In addition to complying with local and environmental requirements, relief valves discharging directly to the atmosphere should meet the following good fire and safety practices:

- Only noncondensable vapors should be discharged to atmosphere.
- Discharge point of atmospheric releases must be located and oriented so that flammable concentrations do not reach ignition sources.
- Ignition of the effluent would not expose adjacent equipment or personnel.
- Vapor must not be toxic.
- Per API 2510A, the velocity of discharge at rated capacity should not exceed 100 ft/sec.
- The atmospheric vent shall be designed per Section 1920.

Acceptable Arrangements

If equipment can be easily removed from service, relief valve isolation capability is not important. To provide onstream testing and maintenance, the following acceptable arrangements are listed in order of preference:

1. Dual relief valves tied in to a three-way valve so that at least one relief valve remains in service at all times.
2. A single relief valve with a block valve between it and the pressurized system, providing that a positive seal or lock or other control method is employed to ensure that the block valve is open. Management should institute strict control over the closure of these block valves and maintain a program of regular inspection to ensure that the block valves remain open. Check local regulations on block valve requirements.

This method meets the ASME Boiler and Pressure Vessel Code, Paragraph UG-135 and Appendix M requirements.

3. A single relief valve with no block valve between it and the pressurized system.

This method does not meet the ASME Boiler and Pressure Vessel code requirements and is discouraged.

1914 Closed Relief Systems

Design Considerations

- Relief valve discharge piping and relief headers should be designed in accordance with API RP 520 and 521.
- Piping and knockout drum materials should be suitable for auto-refrigeration temperatures.
- Where it is readily apparent that a group of relief devices could operate simultaneously, such as during a cooling water failure, capacity should be provided for this emergency.
- Frequently, however, the characteristics of a process are such that operation of one safety valve removes sufficient material from the system so that a downstream relief device will discharge less fluid, and may even reset. In such cases, special design may be warranted.

1915 Typical Relief Valve Arrangements

Figure 1900-1 shows a typical arrangement of relief valves for protection of fractionating equipment. Note that a single safety valve protects the fractionating column, the overhead condenser and the reflux drum. Shell and tube exchangers seldom have pressure relief valves (PRVs) for fire exposure. The reasoning is that vapors generated in such vessels quickly flow unrestricted to the next accumulator or tower and are pressure relieved there. However, exchangers often have thermal relief valves to protect against overpressuring the cold side.

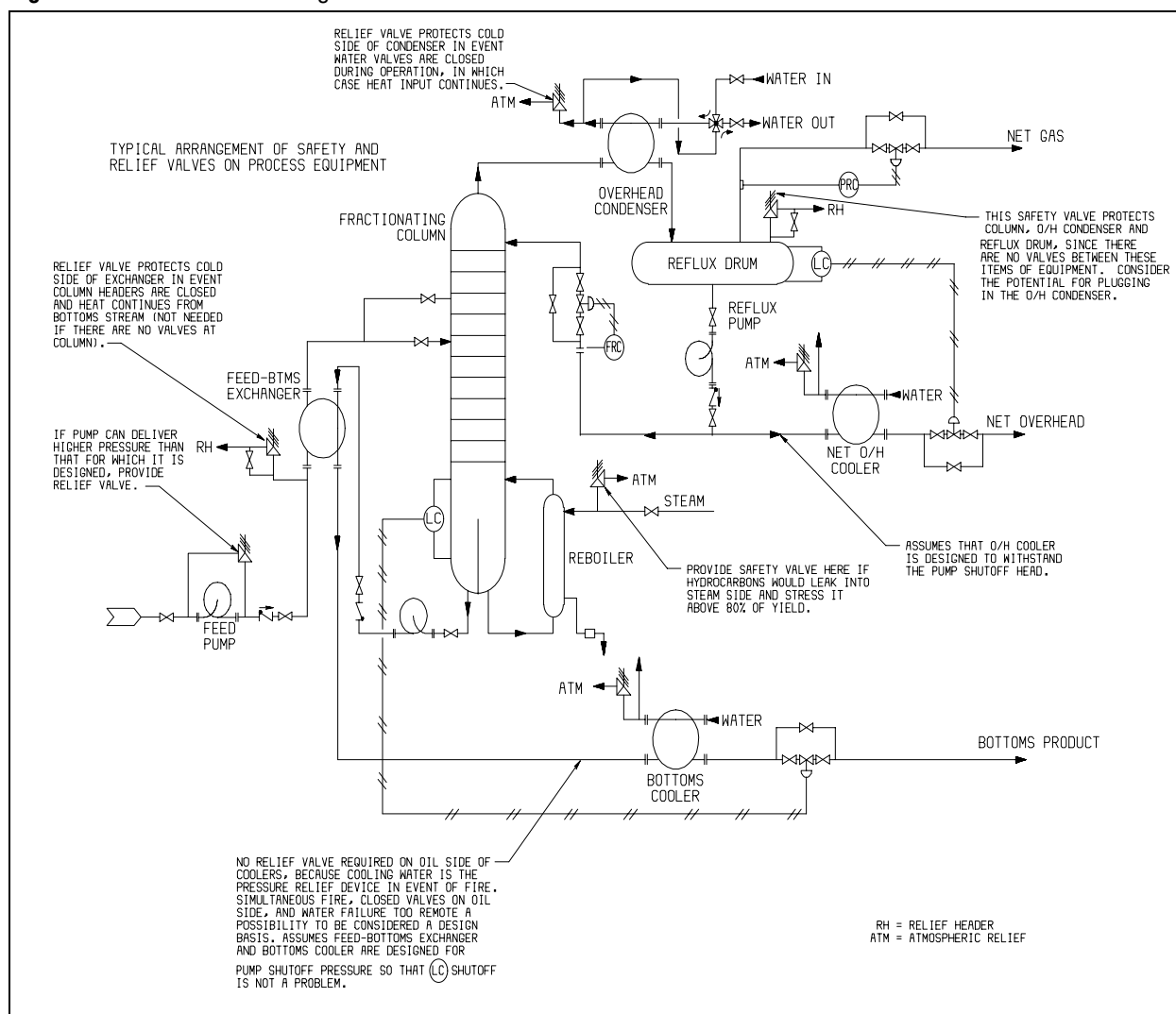
1916 Use of Block Valves on Pressure Relief Valves

Block valves are sometimes installed between the vessel and the relief valves to allow inspection and maintenance of the relief valve while the system remains in service. However, per the ASME Boiler and Pressure Vessel (B&PV) Code, Paragraph UG-135 and Appendix M, a block valve can only be installed between a safety valve and the system it protects if:

1. Closing the block valve will not leave the system with less than the required relieving capacity, and
2. The block valve is locked or sealed open and is only closed by an “authorized person,” and
3. There is additional operator monitoring of the system pressure when the block valve is closed

The concern with block valves is that they may be closed by mistake or they may fail closed (e.g., the gate falls off). Locking or sealing the block valve open protects against the valve being mistakenly closed.

Fig. 1900-1 Relief Valve Arrangement



Any block valve that is installed so that it can be closed by an operator shall be one of the following designs:

- A gate valve or slide gate valve installed with its stem at or below the horizontal position
- A slide gate valve with its stem above the horizontal position when a positive, secondary and externally visible device is provided to fix the wedge in the open position, such as a locked pin through the body and wedge
- A globe valve installed with the pressure source under the disc (assuming the globe valve pressure drop does not exceed the 3% maximum allowable pressure drop for the system)
- A quarter-turn valve (e.g., plug or butterfly valve) with a position indicator positively secured to the stem

1920 Atmospheric Venting

Vent lines and vent stacks on all atmospheric relief valves shall be installed as follows:

- Stacks should be at least three feet above the vessel, and 12 feet above grade. Stacks should also be 10 feet horizontally from mechanical equipment, or seven feet above the highest platform within a 10 foot radius of the vent outlet, whichever is highest.
- They should be properly supported and braced, with no caps, bends or obstructions in the discharge path.
- Discharge should generally be directed upwards, away from personnel or equipment.
- Drain holes must be provided at the low point of the discharge stack to prevent liquid or ice accumulation in the relief valve discharge. The drain opening should be 3/8-inch diameter. If larger, the drain hole must be directed away from the vessel and piping to preclude flame from the hole impinging on the vessel or piping, in the event of an ignition. Piping to safely direct gases that may be blowing from the drain hole shall be limited to a single ell or an ell and short nipple to minimize risk of plugging.
- Where vent stacks on hydrocarbon relief valves are susceptible to ignition by lightning, consider installing a snuffing steam connection tied into the discharge riser.
- Pressure relief valves capable of venting liquids should discharge through a separator to recover the liquids.

1930 Flares

Flares, knockout drums and seal pots are discussed in the *Instrumentation and Control Manual*, Section 1200, and in API RP 520 and 521.

Section 1300 gives the minimum spacing recommendations for flares.

1940 Flame Arrestors

1941 Background Information

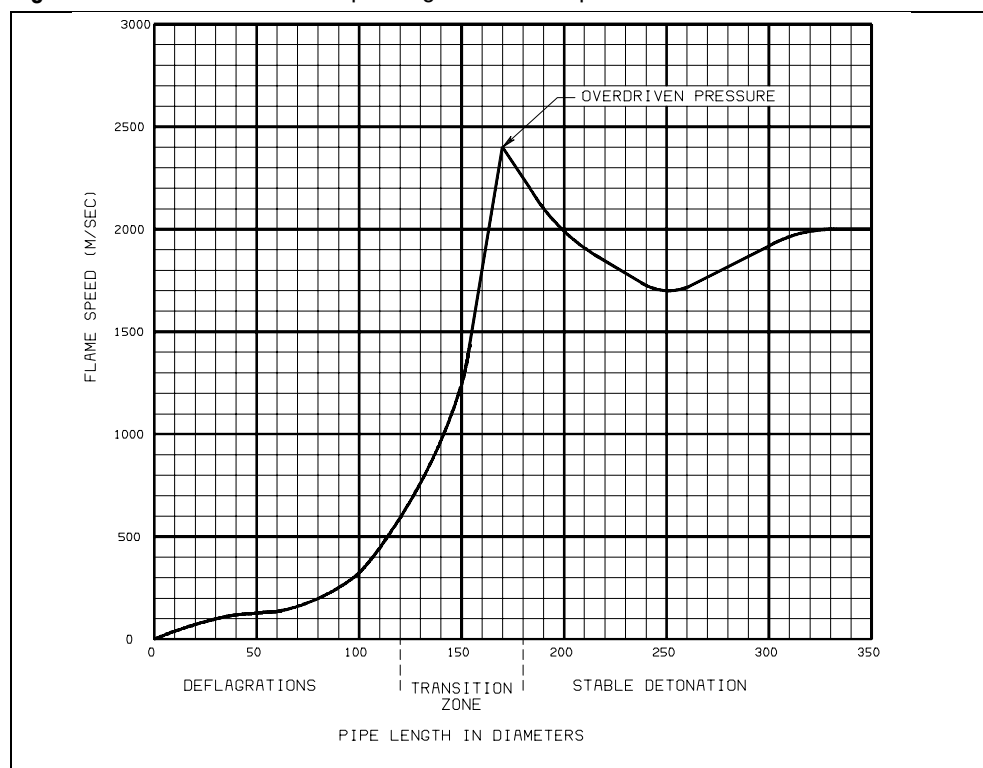
Flame burning at the open end of a vent or flare may continue to burn at that point provided either of the following conditions exist:

- The mixture being vented is above the flammable range in the pipe, or
- The mixture is in the flammable range, but the velocity at the open end exceeds the flame propagation velocity

A laboratory Bunsen burner is a good example. Under normal conditions, a flammable mixture of gas and air flows through the burner tube at a velocity which exceeds the flame propagation velocity. When the gas supply valve is closed slowly, a point is reached when the mixture velocity drops below the flame propagation velocity and the flame enters the burner tube. When this happens, the unstable flame quickly accelerates down the tube toward the supply of flammable mixture. If the burner tube were long enough, the flame propagation velocity would accelerate through the subsonic range and become supersonic.

See Figure 1900-2 for the relationship between flame speed and pipe length.

Fig. 1900-2 General Effect of Pipe Length on Flame Speed



A **deflagration** occurs when the flame front propagates by transferring heat and mass to the unburned vapor-air mixture ahead of the front. Flame speeds can range from 1-350 M/sec and peak overpressures can be as high as 20 times the initial pressure. If the flame front continues unchecked, it can continue to accelerate due to the shock wave produced in the front of the flame. A **detonation** occurs when the flame velocity reaches supersonic speeds of 2000-2500 M/sec. Peak overpressures can range from 20-100 times the initial pressure.

The distance required for a deflagration burning at subsonic speeds to accelerate to a detonation burning at supersonic flame speed depends on the flammable mixture, temperature, pressure, the enclosure and its length and configuration, and the ignition source. For these reasons, it is imperative that burning gases be controlled near the ignition point while the burning rate is manageable. Normally this is considered to be about 30 pipe diameters, or 15 feet.

A flame arrestor is a device or method that prevents the propagation of flame past a certain point for a specified period of time. Because no arrestor is 100% effective for all conditions, such a device should be considered only as a safeguard for the designated design conditions.

Occasionally, the term “in-line” flame arrestor is used. This can be a misnomer because “in-line” implies that a flame arrestor that can be placed anywhere in the pipe. Flame arrestors are tested by the manufacturer for maximum distances from the atmospheric outlet of the pipe in which they are installed. Typically, this is 15 feet. There have been many occasions where flame arrestors were installed incorrectly. It is imperative that flame arrestors be installed in accordance with the manufacturer's instructions. If there is a need to place the flame arrestor farther from the atmospheric outlet, or within a closed piping system, it must be tested for that location and service. The Fire Protection Staff is available for consultation.

1942 Thermal-type Flame Arrestors

This type of flame arrestor employs a cellular heat-absorbing medium to stop the flame by absorbing the heat of combustion, while at the same time permitting gas or vapor to flow through it. Other thermal-type flame arrestors use multiple layers of screens or perforated metal plates, bundles of short metal tubes, alternating layers of crimped and flat metal sheets, and packed spherical pellets of metal. In the usual design, the length of the path in the direction of gas travel is several inches, and the size of the aperture is on the order of 1/10 inch in the smallest dimension.

The principle of a thermal-type flame arrestor is the extinguishment of flame by cooling. The cooling is accomplished by combining a small passageway for the flow of fuel and a large amount of heat-absorbing material. Heat is absorbed by the metal plates or tubes, lowering the temperature of the vapor below its ignition temperature so that it no longer supports combustion.

If fuel flow through the arrestor is not safely stopped and the condition allowing the flame to burn at the arrestor is not corrected, the flame will continue to burn at the face of the heat-absorbing surface in the arrestor. If the flame arrestor is exposed to long burning periods, heat from the flame will raise the temperature of the arresting medium and its enclosure, and it is possible for the heat absorbing medium to become hot enough to ignite the flammable mixture on the downstream side of the arrestor. The thermal-type arrestor has a number of drawbacks which restrict its application to places where continuous flow of a flammable mixture is unlikely. Some of these drawbacks are:

- Failure to arrest flames if not installed in conditions similar to the ones for which it was tested and approved.
- Failure under prolonged burning
- Clogging of arrestor elements from deposits formed by vapors when they come in contact with air, or by solid materials carried by the gas stream
- Freezing of moisture condensation in the arrestor elements

- Reduced flow capacity of the system due to the large pressure drop across the arrestor element
- Failure of the small gas or vapor passages through corrosion or mechanical damage

For vent application in systems open to the atmosphere, use a UL-approved flame arrestor.

1943 Water Seal-type Flame Arrestors

This device employs a water seal in which a gas stream bubbles through the liquid. Gas distribution is important to prevent channeling of the stream and to maintain the flow as a stream of individual bubbles. The gas inlet connects to a distribution pipe drilled with rows of holes or vee notches below water level to form the water seal. The outlet connection is located on the top of the drum.

The water seal-type arrestor is most suitable for installation in systems where the following conditions prevail:

1. The flow is only in one direction.
2. There is a reliable flowing water supply to assure the seal is not lost.
3. The allowable pressure loss through the arrestor is at least several inches of water.
4. Freezing of the seal will not occur.

The seal at the base of flares is often of this type.

1944 Velocity-type Flame Arrestors

The velocity flame arrestor employs a method by which the flow velocity of the flammable mixture is maintained at a higher rate than the velocity of flame propagation through the mixture. The Bunsen burner is an example of this type of flame arrestor. A fuel-air mixture within the flammable range can be ignited above the burner tube, where the velocity has slowed due to expansion of the stream. However, flame does not pass down into the tube (or flash back) because the flow velocity in the burner tube is greater than the flame propagation velocity of the mixture.

If the flow velocity is sufficiently reduced, flashback can occur. When the gas flow velocity falls to near the flashback velocity, steam can be turned on, thus increasing flow velocity and tending to inert the flowing mixture. Velocity flame arrestors usually consist of a Venturi-type tube provided with a steam nozzle located close to the throat or steam ports in the throat of the tube. Depending on the corrosive nature of the gas medium, one system of steam injection may have advantages over the other. Other mediums may prove as effective and more economical than steam. Also, it may be economical to inject the steam or other gas continuously.

Tests have shown the flame flashback velocity to be a function of pipe diameter, fuel-air mixture properties, and gas temperature. Because heating of the Venturi throat may allow a flame to flash through the throat, flame should not be allowed to reside at the throat. Flow velocity must be sufficient to hold the flame at the ignition source. Where this is not always possible, a temperature sensor can be installed to detect flame at the Venturi. This can be designed to automatically increase flow or admit steam. The velocity-type arrestor may be used for continuously flowing streams such as air-gas mixtures from asphalt air blowing stills.

As with thermal-type flame arrestors, velocity flame arrestors must be designed to the conditions for which they have been tested. Normally this is about 20 pipe diameters and not more than 50 feet from the ignition source. Distance from the ignition source is critical. These flame arrestors are designed to prevent flashback, but if the flame speed is too high, flame may pass through the flame arrestor. This spacing limit ensures that the flame does not have sufficient distance to accelerate past its flashback velocity.

The velocity-type arrestor is most suitable for installations where the following conditions prevail:

- Gases or fumes are to be burned in a waste disposal furnace
- Flow is in one direction only
- Flow rate is normally constant
- Allowable pressure loss through the arrestor is small

Minimum Velocity

The minimum velocity at the venturi throat must be greater than the flame propagation velocity. The flame propagation velocity (flashback) through a flammable mixture can be calculated using the following equation:

$$V = 1.1034 (\mu/\rho)^{0.3070} (g_{F,L})^{0.6930} (D)^{0.6525}$$

where:

V = flame velocity (ft/sec)

μ = viscosity of hydrocarbon (cp)

ρ = density of hydrocarbon (lb/ft³)

$g_{F,L}$ = laminar flashback gradient at flowing temperature(sec⁻¹)

D = pipe i.d. (in)

Flame speeds of flammable mixtures vary from 5 ft/sec to 100 ft/sec with methane at the slower end and acetylene and hydrogen among the fastest. Typical values of $g_{F,L}$ at 78°F are:

Propane	550 sec ⁻¹
Methane	385 sec ⁻¹
Ethane	1400 sec ⁻¹

To correct for flowing temperature, multiply the above values by

$$\left(\frac{\text{temp } ^\circ\text{R}}{538 ^\circ\text{R}}\right)^{2.0771}$$

1945 Detonation Arrestors

Detonation arrestors are essentially heavy duty thermal-type flame arrestors designed to handle the peak overpressures of a detonation. These would only be used in “closed” systems where the UL criteria for distance from the atmospheric outlet or ignition sources cannot be met.

Large detonation arrestors (18-inch) are currently (1989-1990) being tested for use in marine vapor recovery. Several smaller detonation arrestors (less than 8 inches) have already been tested. Consult the Fire Protection Staff prior to selecting and installing a detonation arrestor.

The current testing standards for detonation arrestors are in Appendix A of 33 CFR 154, the USCG Standard for Marine Vapor Recovery Systems and UL 525.

1946 Applications

Atmospheric Storage Tanks

Steel cone roof storage tanks equipped with pressure-vacuum-type breather valves should not be equipped with flame arrestors. Cone roof petroleum storage tanks should be operated with a vapor space that is either too lean or too rich to burn. Properly operated tanks will not present a condition where a flammable atmosphere exists both within the tank and through the breather valve, and for some distance outside of the tank. Even if a flammable atmosphere did exist, the discharge velocity past the breather valve pallet would be greater than the flashback velocity if the valve discharges directly to atmosphere. Also, an ignition source must be present at the time of the flammable mixture discharge. Years of operating tanks safely shows that the risk of both a flammable atmosphere and an ignition source occurring at the same time is small.

In addition, putting a flame arrestor under a breather valve is not recommended because of the need for additional maintenance to prevent clogging, plugging, or freezing of the arrestor. This can cause a tank to collapse by vacuum if products are being pumped out.

Additional information on this subject may be found in the API PSD 2210, “Flame Arrestors for Tanks Storing Petroleum Products.”

Venting Systems to Atmosphere

Flame arrestors are not necessary on process vents normally discharging a rich mixture to the atmosphere because there cannot be a fire inside the vent. If the

process involves intermittent venting, or venting of a flammable mixture, consideration should be given to installing liquid seals or venting to a flare system.

Fume Systems

Where gases or fumes are to be burned in a waste disposal furnace (e.g., some vapor recovery systems) and there is a possibility of flammable mixtures being carried in the system, a water seal or velocity-type flame arrestor should be installed to prevent possible flashback from the burners. It is also possible to direct a certain amount of the fuel gas into the waste stream, thereby making that stream too rich to burn. If this is done, a flame arrestor is not needed.

Other Flame Arrestor Uses

Any gas disposal or gas handling system that feeds the gas stream into a flare, furnace, incinerator or other high temperature disposal system should have flame arrestor protection. Examples are:

- Flares, between the pilot flame and the incoming flow.
- Off gases from asphalt air blowing stills—install a flame arrestor near the incineration point.
- Vapor recovery systems for ship, truck and railcar loading should have flame arrestors to protect the recovery equipment from internal system ignition sources and external on-site ignition sources.
- Miscellaneous process plant waste gases that are incinerated in furnaces or on-site incinerators should have flame arrestors in the waste gas line near the incineration point.

1950 Vapor Recovery and Vapor Processing

More stringent air quality regulations have resulted in requirements to capture and process flammable vapor which, in the past, would have been vented to atmosphere. Examples of areas where vapor processing or vapor recovery is used include:

- marine terminal loading facilities
- waste water treatment plants and tank vents
- waste treatment facilities
- degassing facilities for tank maintenance
- marketing loading racks
- production tank batteries
- waste gas burning facilities in process plants

Handling flammable vapors in closed systems can result in the potential for increased risks. The following key areas should be considered in the design of these facilities:

Overpressure/Vacuum Protection. Tanks and vessels need to have overpressure/vacuum protection independent of the vapor processing system to prevent damage from a malfunction of the vapor-processing system.

Potential Ignition Sources. The vapors being processed can be in the flammable range. Therefore, control of ignition sources is critical.

- Vapor lines should be electrically conductive to prevent potential for static buildup
- Use of mechanical equipment to move vapors should be minimized.
- If mechanical equipment is needed to move vapors, it should be designed to prevent sparks under both normal and equipment malfunction conditions. Examples of this are liquid ring vacuum pumps and blowers with non sparking parts. Protective instrumentation (i.e. high vibration alarms, low lube oil pressure and flow alarms, low sealing liquid level, etc.) to warn of an impending equipment malfunction should be considered.
- Atmospheric vents should be located well away from possible ignition sources (see Section 1913)
- Locate unclassified electrical equipment at least 50 feet away from vapor recovery equipment or install equipment designed for use in a classified area.
- In waste handling facilities, activated carbon adsorption units have overheated to ignition temperatures. These systems should be protected by detonation arresters and high bed temperature shutdowns.
- Flares, thermal oxidizers and incinerators are open flame devices which under certain conditions can cause flashback into the vapor line. In general, there should be at least two levels of protection against flashback in these types of facilities. This can include:
 - a flame arrester at the atmospheric connection. For a flare, this would be just below the pilot and flare tips. On a thermal oxidizers or incinerators, this could be the vapor line connection to the shell.
 - an approved detonation arrester in the line (see Section 1945)
 - a water seal drum in the vapor line usually within 30 pipe diameters of the vessel.
 - a system to keep the vapor outside of the flammable range. This can be done with enrichment, dilution, or inerting (see Section 1960)
 - an automatic isolation valve to quickly isolate the vapor line from the ignition source if flame or heat are detected in the line.

NFPA 30, Section 5-5, can be used as a guideline for vapor processing systems.

1960 Inerting, Enrichment, and Dilution Systems

Inerting, enrichment and dilution systems are designed to keep the vapor composition outside the flammable range. Explosions have occurred in the industry because

inert systems have been taken out of service. These systems should be designed to NFPA 69, Standard on Explosion Prevention Systems. These systems are **critical** safety systems. As such, they must be designed for easy inspection and testing by operators. This inspection and testing includes:

- routine testing of vapor to verify composition is outside the flammable range. Critical processes use continuous analyzers to do this.
- routine testing of inert, enrichment or dilution gas to verify composition. This is especially important if the gas is being supplied as a byproduct of another process (example: CO₂ produced in a hydrogen plant)
- verification of adequate flow of inert, enrichment or dilution gas and alarms/shutdowns on low flow.

There should be a management system in place to prevent operating the facilities if the inert, enrichment or dilution systems are out of service.

1970 References

American Petroleum Institute (API)

API 520	Design and Installation of Pressure-Relieving Systems in Refineries
API 521	Guide for Pressure Relief and Depressuring Systems
API 525	Testing Procedure for Pressure-Relieving Devices Discharging Against Variable Back Pressure
API 2000	Guide for Venting Atmospheric and Low-Pressure Storage Tanks
API 2001	Fire Protection in Refineries
API 2210	Flame Arrestors for Tanks Storing Petroleum Products

API Guide for the Inspection of Refinery Equipment, Chapter XVI, Pressure-Relieving Devices

American Society of Mechanical Engineers (ASME)

ASME Boiler and Pressure Vessel Code

Department of Transportation (DOT)

United States Coast Guard (USCG)
33 CFR Part 154 Guidelines for Detonation Flame Arrestors

Underwriters Laboratories

UL525 Flame Arrestors

Chevron References

Instrumentation and Control Manual, Section 1200