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Performance Requirements for Flame Arresters

Guidance on their Principles of Operation, Selection, Application, and Maintenance

An ioMosaic White Paper

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Abstract

The purpose of this article is to present a basic understanding of flames, flame arresters, and the multitudinous designs of flame arresters to help an Emergency Relief System (ERS) designer in selecting an appropriate flame arrester. The need to understand the characteristics of the flammable system and appropriate testing is presented. Various prominent manufacturers of flame arresters are presented and a recommendation to select the final product is also presented. After having the basic understanding of flame propagation and flame arresters, one has to define the scope of application. This article addresses the application of overpressure protection of near atmospheric or low pressure equipment and interconnecting piping header of equipment from flame-related deflagration and detonation. The generation of the property of a flammable mixture using various Maximum Experimental Safe Gap (MESG) apparatuses differs widely. So, the reader is advised to be informed: Application of flame arresters is deceptively simple!

Overpressure protection from flame-related deflagration of low pressure equipment, such as baghouse and pressure vessel, are beyond the scope of this article.

Introduction

A flame is a physical manifestation of the combustion process in the visible spectrum of light or luminous intensity. It can happen when a flammable or combustible substance is in contact with an oxidizer in the presence of an ignition source as in the case of an open pool fire or at the exit of a vent from equipment containing a flammable vapor.

There are some flammable materials which do not need an oxidizer to decompose and generate a flame. It can also happen similarly inside a confined environment such as piping, storage vessel, and process equipment. Flame arresters prevent the overpressure effects from these scenarios.

This paper addresses the aspect of flame propagation and protection of equipment from the effects of internal combustion process by a judicious application of equipment known as the flame arresters. The effect of flame propagation inside confined equipment is more devastating than that of external fire because the former has both temperature and accelerating pressure effect on the containment. Standards of flame arresters are shown in Tables 1A & 1B. The name "Flame Arrester" is a generic name for devices that allow flow of gas, but are impermeable to any flame, and is used to protect equipment from overpressure caused by internal flames.

Application of Flame Arresters

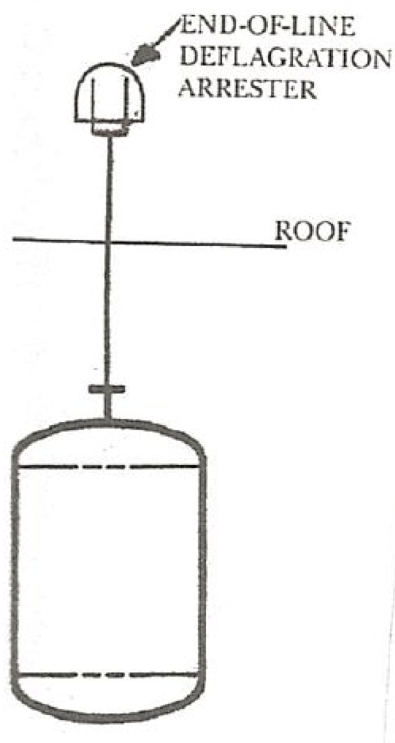
Flame arresters are used in process industries to prevent propagation of flame from entering a vessel or a piping system during either emergency relief or normal operation.

Flame arresters are used at the opening of equipment or at the exit side of a pressure relief device protecting equipment from overpressure. A flame can be triggered during the emergency relief or normal operation. The flame arresters may also be installed in the piping connecting a system of enclosures. As the name implies, the flame arresters prevent the passage of flame but allows the flow of gas.

The stoppage of flame is accomplished by forcing the flame through narrow passages that are long enough to decelerate the flow and increase the residence time for heat and mass transfer. The passages must be small enough to increase surface area to volume ratio with due consideration of acceptable pressure drop and plugging due to particulate matter.

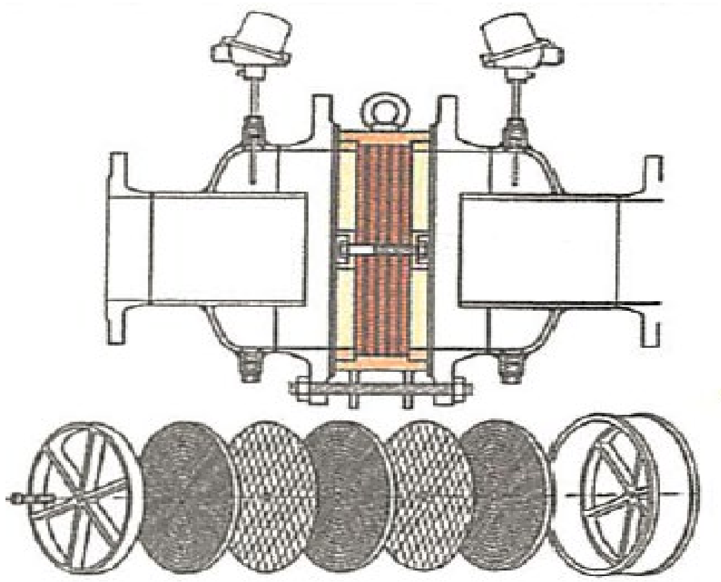
A good flame arrester should have a temperature sensors at the inlet and outlet. A pressure sensor at the inlet and outlet is also desirable. When the flame arrester is installed directly on the equipment or at the exit of a relief device, it is called the "end-of-line flame arrester". If the arrester is placed in the pipeline connecting two or more equipment, it is called the "in-line arrester". An "end-of-line flame arrester" is shown in Figure 1(a). Vapors are allowed to escape into the atmosphere through an "end-of-line flame arrester". When outside air enters due to pressure gradient, and a spark is generated simultaneously, the flame arrester prevents the flame from entering the equipment.

Figure 1A: End-Of-Line Flame Arrester[1a]



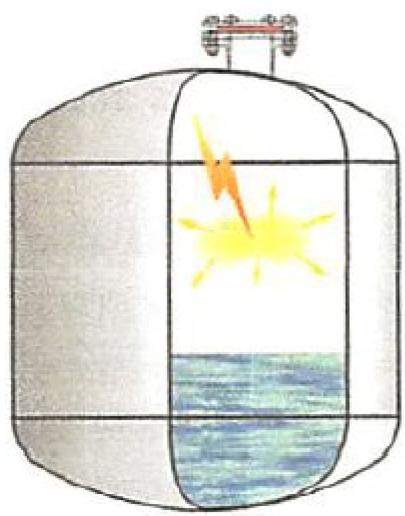
Source: Stanley Grossel: Deflagration and Detonation Arresters, CCPS, AIChE

Figure 1B: Flame Arrester with Inlet and Outlet Temperature Sensors and Details of Elements[2a]



Source: PROTEGO® Catalogue

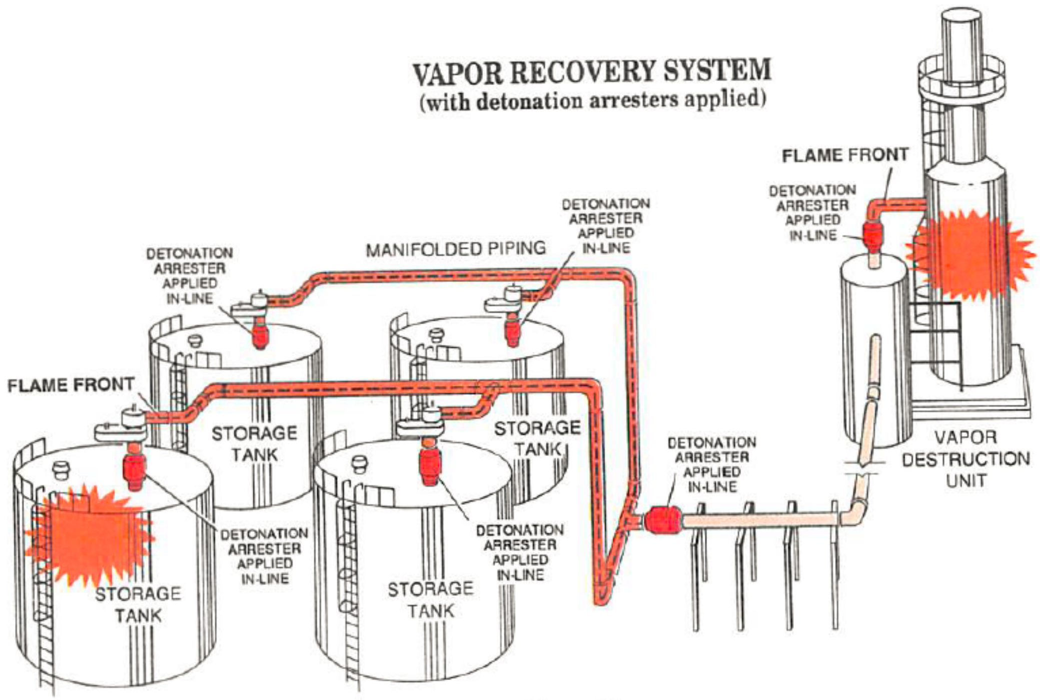
Figure 1C: Pre-Volume Deflagration[2b], Deflagration Inside a Vessel



Source: PROTEGO® Catalogue

A process vessel or piping system with a length-to-diameter ratio less than five is called a "Pre-volume vessel" in Europe according to CEN Standard EN 12874[1c].

Figure 2: Example of “In-Line” Flame Arresters



Source: : Stanley Grossel, Deflagration and Detonation Flame Arresters, CCPS (AIChE)

Fundamentals of Flame Physics

There are a plethora of flame arrester types. Before going into details, it is imperative to understand the physics of flame.

A flame is a self-propagating combustion or decomposition reaction propagating through space. The wave front of the reaction increases its speed by compressing the unburned gas in its front or travel path and is known as deflagration until its speed reaches the speed of sound in the medium. When its speed reaches the speed of sound or higher in the medium, the phenomenon is known as detonation. Detonations manifest in shock waves which are more devastating to associated process equipment. In the deflagration phenomenon, the energy releases can be controlled by conductive heat transfer and diffusion, but not so in the detonation phase. Figure 3 and Figure 4 pictorially explain the birth of deflagration, its transition (run up) to detonation, and fully developed detonation.

An explosion is a result of rapid pressure increase culminating in a loud noise perceptible to an observer. An explosion may be divided into deflagration and detonation. Deflagration could be atmospheric and confined. Confined deflagration can take place in vessel and piping. Detonation can be stable and unstable; and can also happen in confined space. A stable detonation progresses through a confined space without significant change in velocity and pressure.

The burning of a flammable material is called stabilized burning when the flame is stabilized at or near the flame arrester element.

Dynamics of flame propagation

Burning velocity

This is the velocity of a flame which propagates towards the unburnt gas, *relative to the velocity of the unburnt gas*.

Flame velocity

This is the velocity of a flame front *relative to a fixed reference point.*

Laminar burning velocity, S_L

This is the burning velocity when the fluid is moving in line with the net-velocity vector tangential to the line of propagation. Pictorially, the streamline flow in a pipe is represented by a series of unbroken parallel lines diametrically from one side of a diameter to the other. The velocity front is perpendicular to the direction of flow.

Turbulent burning velocity, S_t

Once the laminar burning velocity reaches a critical value, the streamlines are broken resulting in significant local fluctuation of velocity. The velocity of the flame front under such circumstance is known as turbulent burning velocity.

Apparent velocity of unburnt product, V_f

This is the apparent higher (peak) velocity of the unburnt gas caused by the combustion process ahead of it.

Fundamental burning velocity, S_u

The fundamental burning velocity (length/time) is a fundamental property of a flammable material dependent on chemical kinetics of decomposition/reaction and physical properties of reactants and products of combustion. It is a measure of how fast a flammable material is consumed and converted into combustion. It is the burning velocity of a laminar flame under the stated conditions of temperature and pressure.[13]

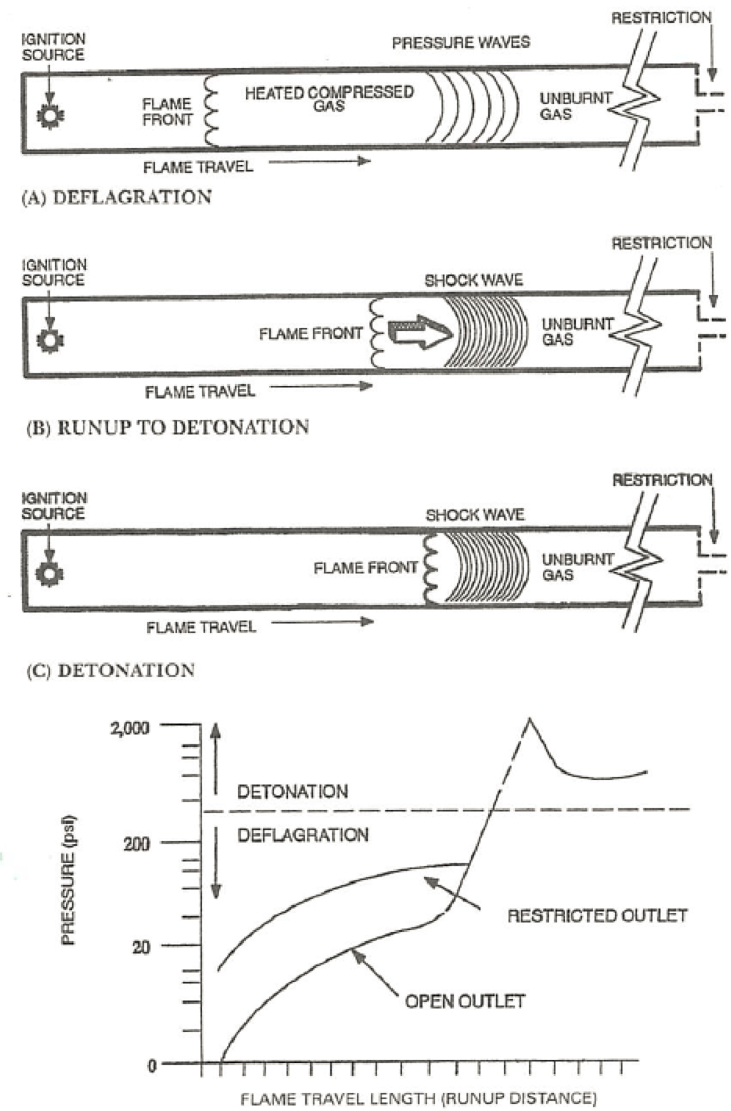
Mean unburned gas velocity, U_G

This is the mean velocity with which the unburned gas moves due to the expansion of the products of combustion ahead of it.

From the above description, it may be concluded:

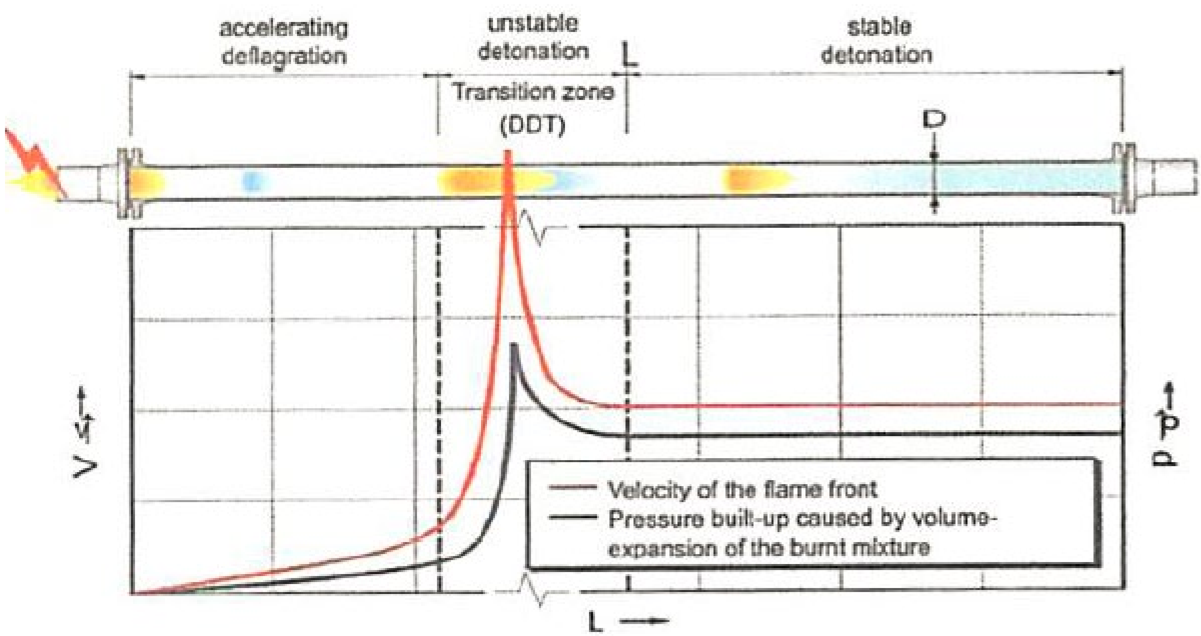
$$V_f = U_G + S_t \qquad \text{Equation (1)}$$

Figure 3. Birth of Deflagration, its Transition (run up) to Detonation, and Fully Developed Detonation[1b]



Source: : Stanley Grossel, Deflagration and Detonation Flame Arresters, CCPS (AIChE)

Figure 4: Deflagration – Unstable Detonation – Stable Detonation[2b]



Source: : PROTEGO® Catalogue

L = distance from ignition source, D= diameter of pipeline, V = velocity of the flame front, p = pressure, DDT = Deflagration-to-Detonation Transition

Flame Acceleration and Deflagration-to-Detonation Transition (DDT)

The flame starts with a laminar flame flow as a deflagration and accelerates to a turbulent flame flow to a point when a shock wave forms resulting in "overdriven detonation". This is followed by a stable detonation. This transient phenomenon from deflagration to detonation is known as DDT. During this transition, the initial peak pressure is higher than the pressure during stable detonation and the phenomenon is known as "overdriven detonation". Stable detonations propagate at the sonic speed. Shock waves are caused by the transition from velocity (Ma>1) to below sonic velocity (Ma<1) and vice-versa. The propagation of shock waves is better explained by the intersection of Fanno line and Rayleigh lines. It is also somewhat explained by Chapman-Jouguet theory, ZND (Zeldovich, Neuman, Doring), and Hugoniot adiabaticity. Please refer to Figure 4.

Pressure Piling[3a]

Pressure piling is a phenomenon related to combustion of gases in a pipe, such as a vent header system, connecting two or more vessels. The expanding gases of the combustion products can compress the gas mixture ahead of the burning material. The amount of compression varies depending on the geometry of piping, surface roughness, pipe fittings, location of ignition source, size difference between the connected equipment, and may vary by a factor of eight to nine times the initial pressure in absolute. Where multiple vessels are connected by piping, ignition of gases in one vessel and pressure piling may result in a deflagration to detonation transition and a very large explosion overpressure.

Run-up Distance or Run-up Length

The two terms, Run-up Distance or Run-up Length, are synonyms. They are measured from the point of the ignition in the direction of flow at any point in the piping system. As this distance increases, the phenomena of deflagration, pressure piling, DDT, overdriven detonation, unstable detonation and stable detonation take place depending on the availability of a flame arrester. Please see Figure 4 (parameter L).

Relevant Flame Arrester Codes and Standards to Follow

Two tables are offered for consideration. Table 1A addresses the codes and standards in the USA, and Table 1B addresses the codes and standards in the UK, Europe, and International area.

Table 1A: United States Codes and Standards on Flame Arresters

Item#	Institution	Code/Standard	Remarks
1	API	2028, June 2020	Flame Arresters in Piping Systems. Discusses flame propagation.
2	API	2210, March 2020	Flame Arresters for Vents of Tanks Storing Petroleum Products
3	API	500, January 2014	Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Division I and Division 2
4	NFPA	(1) 30- 2015, (2) 69-2019 (3) 67 (4) 497	(1) Flammable and Combustible Liquid Codes (2) Explosion Prevention Systems (3) Explosion Protection in Piping System (4) NEC Classification of Flammable Materials
5	ASTM	F 1273	Minimum Requirements of Vent Flame Arrester
6	USCG	Title 33 CFR, Part 154, Subpart E	United States Coast Guard guideline for deflagration and detonation flame arresters
7	UL	525, 6th edition or later	Underwriters' guidelines on end-of-line flame arresters including deflagration flame arresters (Part II) and detonation flame arresters (Part III). Addresses storage tank for petroleum and gasoline.
8	FMR		Factory Mutual Research adopted USCG, but modified endurance burn test

Table 1B: Canadian, British and European/International Codes Standards on Flame Arresters

Item#	Country/International	Codes/Standards	Description
1	Canada	CSA 1998	Safety & Sustainability Standard
2	UK	BSI 1990, BS 7244, BSEN 12874-2001	British Standard, British/European Standard
3	Europe	CEN 12784	Comprehensive coverage
4	International Maritime Organization	IMO 1994	
5	International Standard	ISO 16852	Classification of flame arresters

Flammable Liquid Classification

NFPA 30 (2015) in Paragraph 22.7.1.1.3 advises the user to know the flammability class of the stored liquid. If the stored liquid belongs to class IIIB and meets some dike/drainage criteria, no emergency vent due to fire is required.

Table 2: Flammable Liquid Classification

Class	Flash Point °F
I	<100
II	>=100<140
IIIA	>=140<200
IIIB	>=200

Statement of NFPA 30 (2015), Paragraph 22.7.1.1.3

"Tanks storing Class IIIB liquids that are larger than 12,000 gal (45,400 L) capacity and are not within the diked area or the drainage path of tanks storing Class I or Class II liquids shall not be required to meet the requirements of 22.7.1.1."

"22.7.1.1 Every aboveground storage tank shall have emergency relief venting in the form of construction or a device or devices that will relieve excessive internal pressure caused by an exposure fire."

Table 3: Flammable Liquid Classification Class 1 – Venting Requirements

PARAMETER	CLASS 1A	CLASS 1B	CLASS 1C
Flash point (Closed cup), °F	< 73	< 73	73≤FP < 100
Boiling point, °F	< 100	= >100	No specification
Venting device	CV & FA	CV or FA	CV or FA
Above-ground tanks	Note 1	Note 1,2,3	Note 1,2,3

Notes (for Table 3: NFPA-30, Paragraph 21.4.3.10):

Note 1: CV = Conservation Vent, FA = Flame Arrestor

Note 2 :Open vent allowed if product is crude petroleum, area is crude production facility; capacity max is 3000 bbl. (126,000 gallons). For outside above-ground storage, open vent permitted for max capacity is < 23.8 bbl. (1,000 gallons).

Note 3: In the event of a plugging possibility, CV & FA may be omitted.

Layer of Protection

A flame arrester, like any other safety device, is the last line of defense against flame-related overpressure. It should not be used as the only line of defense or as a control device. For example, in a vessel fitted with a conservation vent, a pad-depad system using an inert gas should be provided to control pressure during outbreathing and inbreathing. The breather vent comes in to control pressure/vacuum only when the pad-depad control system fails to maintain pressure.

Endurance and short-term burn tests[16]

This is a test of integrity of the performance of a flame arrester under prolonged fire, and generally manufacturers avoid such tests. Fire endurance time may vary from 1 minute to 2 hours; with 30 minutes being typical.

Preventative Methods to Avert Deflagration

In order to prevent deflagration from occurring, the following preventative steps are recommended:

1. Use flame arresters as addressed in this article.
2. Reduce oxidant concentration[12]. This can be done by inerting or by fuel enrichment. To reduce oxidant concentration, one has to know Limiting Oxidant Concentration (LOC).
3. Reduce combustible concentration. In this method, the combustible concentration is reduced below Lower Flammability Limit (LFL) by air dilution/ventilation.
4. Suppress deflagration[12]. This method requires an early detection mechanism and is followed by delivering a extinguishing agent in the equipment or piping.
5. Use strong equipment to contain deflagration[12]. The equipment may be permanently damaged, but would not rupture (known is "shock-resistant" in Europe; typically needs 145 psig MAWP if operating pressure is near atmospheric)

Flame Arrester Types and Design

Deflagration and Detonation flame arresters are broadly divided into the following groups:

1) Dry Type Arresters: Arresters have an internal matrix. Flowing fluid does not have a condensed liquid phase or does not use liquid as a barrier to flame

    a. Crimped metal ribbon
    b. Parallel plate
    c. Expanded metal cartridge
    d. Perforated plate
    e. Wire gauze and wire gauze in packs
    f. Sintered metal
    g. Metal shot in small housings
    h. Ceramic balls

2) Wet Type Arresters

    a. Liquid Flame Arresters
    b. Hydraulic (liquid seal)
    c. Packed bed
    d. Velocity flame stoppers
    e. High velocity flame valves

3) Conservation vent as a flame arrester

Crimped metal ribbon flame arrester

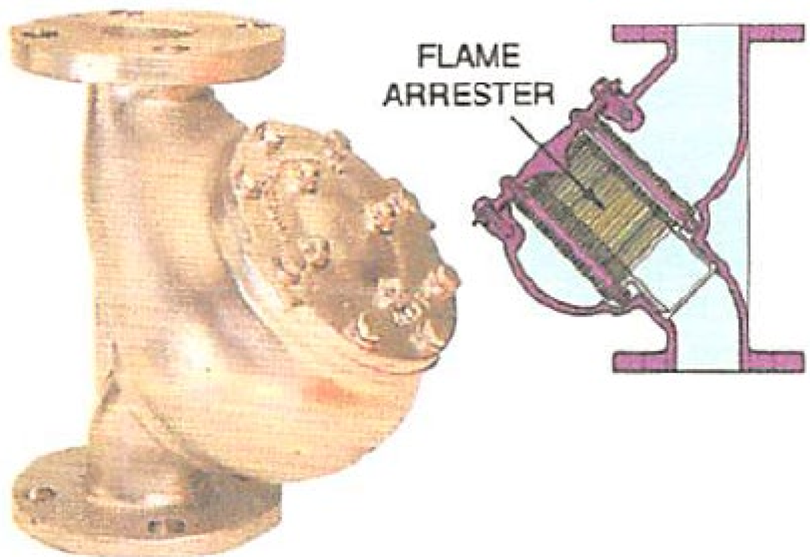
This type of flame arrester is used for preventing deflagration and detonation. They consist of alternate layers of thin corrugated metal ribbons and a flat metal ribbon of the same width. They are machine-wound together to make a cylindrical assembly of multiple layers. The space between corrugation and the flat ribbon provides small triangular passages. The corrugation provides sufficient heat transfer area to quench the flame. The arrester, like any other type with a matrix element, must qualify for the application when its design is viewed against Maximum Experimental Safe Gap (MESG) test.

Further explanation of the MESG test is provided in Appendix A.

Parallel plate flame arrester

The parallel plate flame arresters are made of a series of heavy gauge parallel plates aligned in a matrix assembly. They can be used both as end-of-line and in-line flame arresters. Their primary application is for the prevention of deflagration. They are used in open vent pipe or bleed lines from storage or processing tanks. They are suitable for NEC Group D (IEC Group IIA) vapors. See Figure 5.

Figure 5: Parallel Plate Flame Arrester[5]



Source: Protectoseal Bulletin

Extended Metal Flame Arrester

Expanded metal arresters are made by spirally winding a sheet metal with diamond-shaped openings such that the openings are not aligned with a direct path from one layer to the next. The flow passes radially to the cartridge axis. The elements create large inlet surface area minimizing the plugging issue.

Advantages: Reactive monomer service

Disadvantages: Support problems

Application: Deflagration, detonation, & bidirectional flow.

Extended Metal Flame Arresters conform to USCG Standards on Group C and D gases.

Perforated Plate Flame Arrester

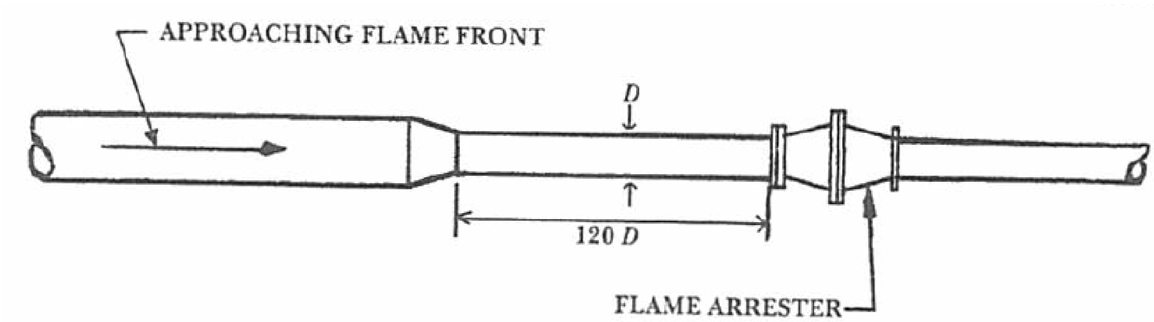
Perforated metal plates or refractory-disks/gauze-pad/metal-plate combination systems are used as elements in the Perforated Plate Flame Arrestors primarily for deflagration applications.

Other types include Wire Gauge Flame Arrester (low cost, deflagration application), Sintered Metal Flame Arresters (effective, but offers high resistance to gas flow, applicable to compressor discharge line), Ceramic Balls Flame Arresters (used as detonation arresters, NEC Group C and D gases, Hydrogen, acetylene etc.), and Metal Shot Flame Arrester (uses metal balls of various sizes: 4 to 60 mesh, has high resistance to gas flows, used as detonation arresters).

Recommended pipe diameter upstream of inline flame arresters

If the diameter of the pipe carrying the flame front to the flame arrester is bigger than the inlet size of the flame arrester, then low pressure flame front can pass through the flame arrester. To prevent this, a recommended practice is to reduce the pipe size and allow a straight run of pipe before the inlet of the flame arresters so that the length/diameter of the straight section is at least 120. See Figure 5A below[1].

Figure 5A: Required Straight Pipe of Identical Diameter as the Inlet of Flame Arrester



Source: Stanley Grossel, Deflagration and Detonation Flame Arresters, CCPS (AIChE)

Explosion Protection for Gaseous Mixtures in Pipe Systems[15]: NFPA 67

Detonations are more typical in piping systems because of availability of longer travel path for the flame. NFPA 67, Chapter 10 explains the strategy of passive protection systems for underground vessels, aboveground vessels, process units connected to thermal oxidizers, and carbon-adsorption units.

This standard also describes Detonation Arrester Systems (DAS), which is a composite system comprising an instrument device to detect the propagation of a flame front (pressure detection and flame detection) and activation system of rapid-response barrier to prevent propagation of the flame front beyond a specified point in a pipe by extinguishing the flame.

Special Applications for Flame Arresters

The following table recommends the type of flame arresters to use for applications involving high fundamental burning velocity and/or high decomposition potential. The key species are hydrogen, acetylene, and ethylene oxide.

Table 4: Special Flame Arresters

No	System	Comments
1	Hydrogen, H_2/CH_4/air	Recommended flame arresters are Velocity Stopper, Crimped Metal Ribbon, and Hydraulic Seal. Use ASTM Standard F1273. Consult PROTEGO (Germany)
2	Acetylene	Acetylene can decompose in absence of an oxidant. Recommended flame arresters are hydraulic seal where wet type is acceptable, and for the dry type: sintered metal and metallic balls. The manufacturers for the second category are: Praxair, Western Enterprise of Westlake, OH, Rexarc of West Alexandria, OH, and PROTEGO of Germany.
3	Ethylene Oxide	It can also decompose in absence of an oxidant in vessel and piping (>12 inch diameter). DDT can occur with a pressure rise of 137 times the initial pressure in absolute. Consider liquid seal, packed bed, bubble screen. Manufacturers are Recklinghausen of Germany (packed bed) and John Zink (bubble screen).

Various Types of Wet Type Flame Arresters are described as follows:

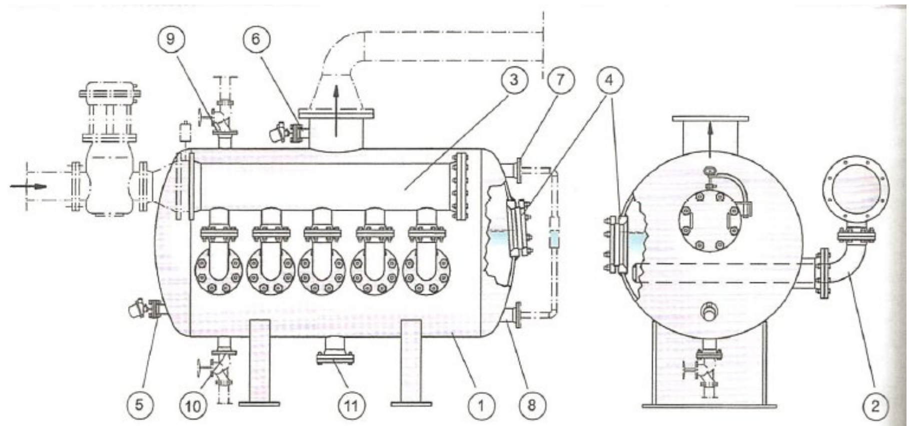
Liquid Flame Arrester

These are used in liquid filling lines. Examples are PROTEGO® LDA-W and PROTEGO® LDA-WF (W) liquid detonation flame arresters which are installed outside the container in the filling lines to protect the container. The "WF" arresters have flame filter cage. The PROTEGO® LDA-W arresters are good for NEC (Group D to C, MESG>=0.65 mm) and PROTEGO® LDA-WF (W) are good for NEC (Group D to C, MESG >=0.65 mm).

Hydraulic (Liquid Seal) Flame Arrester

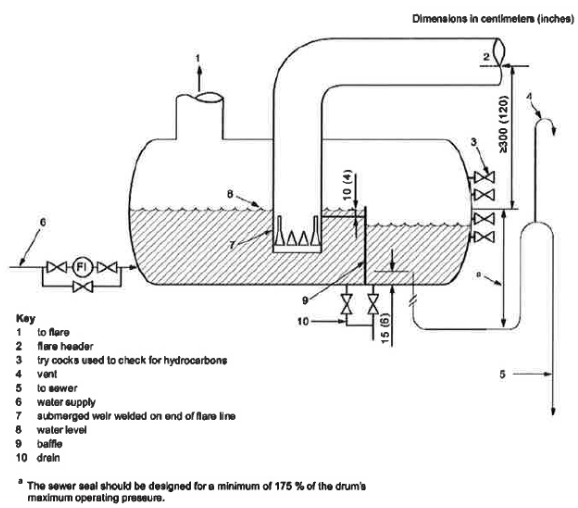
These are typically used in the plant off-gas header before the gas enters the flare system. The hydraulic (Liquid Seal Flame Arrester) should be used when there is potential of plugging dry flame arrester and their cleaning is impractical. They can be horizontal and vertical in design. A horizontal design is shown in Figure 6.

Figure 6: Hydraulic (Liquid Seal) Flame Arrester, Horizontal (PROTEGO®)



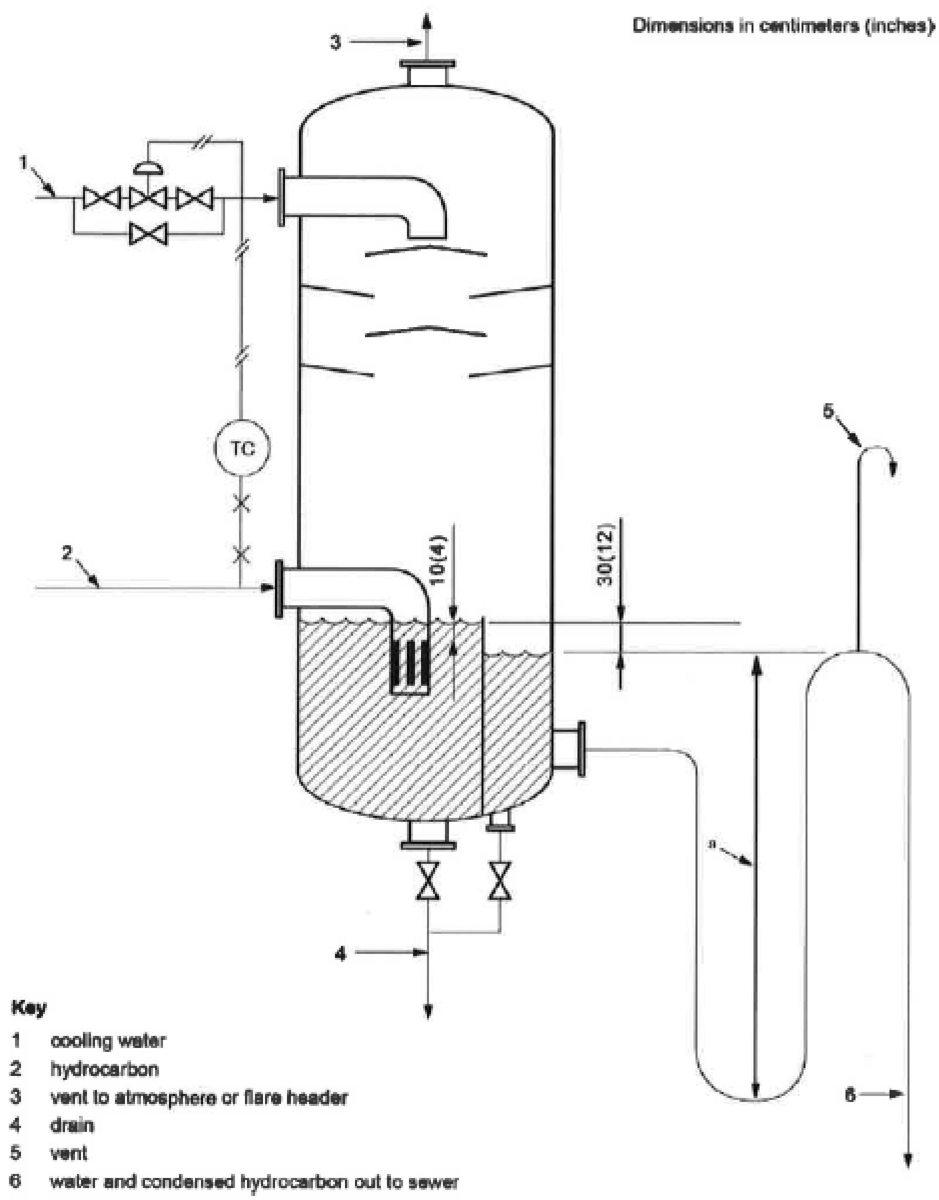
Source: PROTEGO® Catalogue

Figure 7: Hydraulic (Liquid Seal) Flame Arrester, Horizontal (API 521 Annex D June 2020)



Source: API Standard 521 Annex D (2014)

Figure 8: Hydraulic (Liquid Seal) Flame Arrester, Vertical (API Standard 521 Annex D June 2020)



Source: API Standard 521 Annex D (2014)

Note: The water seal should be designed as a maximum of 175% of drum's maximum operating pressure.

The hydraulic flame arrester contains a liquid, typically water, to serve as the flame barrier. One such PROTEGO® model TS/ series is shown in Figure 6. PROTEGO® has proprietary designs both for horizontal and vertical flame arresters. The identifications of the various parts are shown below through the front and side views of the model.

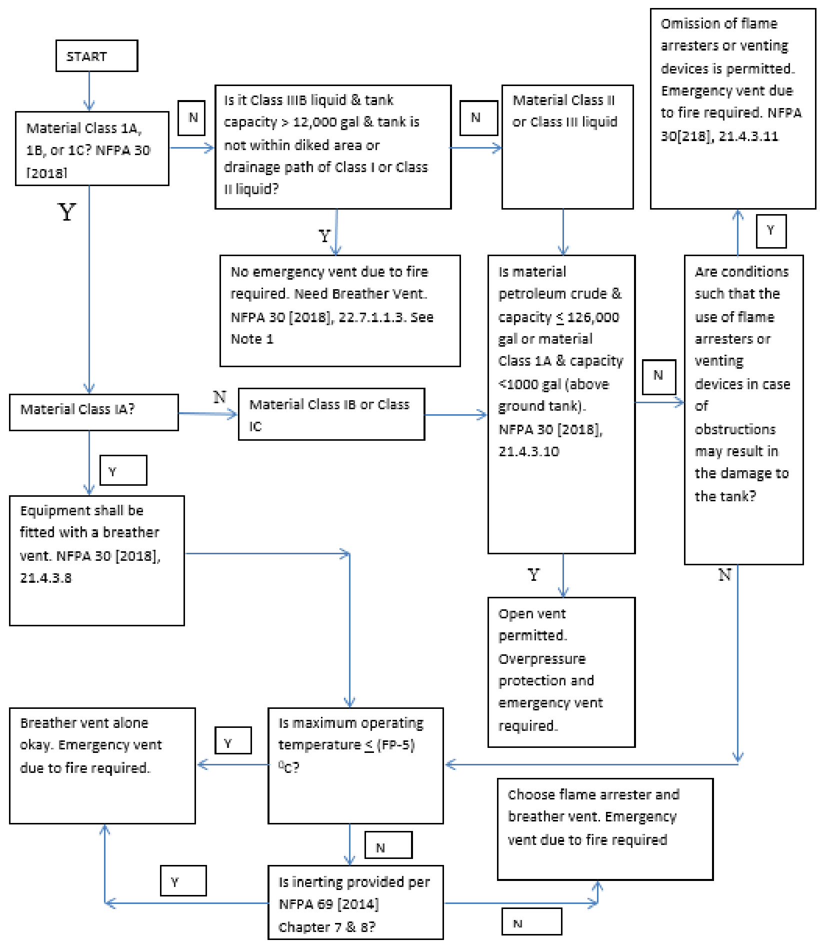
Table 5: Various Parts of PROTEGO® Hydraulic (Liquid Seal) Flame Arrester

Item No	Name	Purpose
1	Horizontal Immersion Tank	This holds the liquid for the inlet gas containing flammables to bubble through.
2	Sparge pipes	The five sparge pipes with elbows enter into the immersion tank into the subsurface of the liquid
3	The main inlet header	This header distributes the inlet gas into the sparge pipes, item 2.
4	Sight Glass	Local monitoring of level
5 & 6	Nozzles for temperature sensors	No 5 is for liquid temperature, and No 6, gas temperature
7 & 8	Nozzles for liquid level gauge	Local level
9 &10	Nozzles for level control instrument	No 9 is for high level, and No 10, low level
11	Nozzle for drain	Cleaning

Appendices B and C provide a list of information required for selecting flame arresters, and information required for selecting hydraulic (liquid seal) flame arresters, respectively.

NFPA 30 Guidelines for Low Pressure Tanks in the Application of Breather Vent and Flame Arrestors are shown in the following decision tree.

Figure 9: Decision Tree 1 : Need for Conservation Vent, Flame Arrestor, or both, Emergency Vent due to Fire for Combustible and Flammable Materials



Source: Proposed by Author, Dilip K. Das

Notes for Application of Decision Tree

1) Low pressure tanks requiring pressure and vacuum protection need both pressure and vacuum vents. Such vents may be open or breather type.

2) A breather vent may substitute a flame arrester as long as the pressure side is set to close at or below ¾ inch water column and vacuum side has a flame screen (API 2210, para 5.2). Both pressure and vacuum side must have no piping attached.

3) Every aboveground storage tank shall have an emergency relief vent in the form of a device or devices to relieve overpressure due to fire exposure.

4) Open vent or breather vent can serve as an emergency vent also for low pressure tanks. Open vent can serve as an emergency vent for pressure vessels in some states, such as the state of Missouri, in the USA.

5) All breather vents and flame arresters (independent testing through third party) require periodic maintenance service.

6) This is a guideline only. The user must use her/his discretion to override the recommended practice. In any event the user assumes responsibility.

Mechanical Integrity Program for Flame Arresters[11]

A responsible owner of a flame arrester must have a well-defined Mechanical Integrity program to select the flame arrester for the appropriate application followed by cradle-to-grave maintenance program for a productive life cycle of the flame arrester.

Some key issues are noted below.

1. Inspection, Testing, and Preventive Maintenance (ITPM) program. Under this program, the flame arrester is inspected regularly, and the decision to revalidate its use is made. When the ITPM program indicates continual lowering of inspection frequency, the flame arrester should be replaced by a new one, or one with alternative design. Regularity is the keyword. A manufacturer may require the first inspection after one month of operation and then at least annually thereafter. Depending on the observation of annual inspection, the next inspection period may be reduced. In-place inspection may or may not be feasible. For in-place inspection, operating platforms must be designed accordingly. If the flame arrester or its element cannot be removed, such as one in a pipeline, two parallel flame arresters with adequate switch-over valving should be provided.

2. Cleaning of some flame arresters may be demanding especially when the service is laden with particulates and is debilitating to the arrester. In such applications, particularly for large-diameter flame arresters, multiple in-place spray nozzles should be provided. The cleaning could be done concurrently using steam and hot deionized water, or other compatible solvents, for applications where the arresters are in the header leading to an incinerator. The cleaning can be triggered by a differential pressure transmitter placed across the flame arrester or by a timer action based on experience. The tapping points of the differential pressure transmitters will also require cleaning.

3. The cleaning method must be compatible with the flame arresters. Solvents, water, steam, compressed air, or ultrasonics may be used.

4. To avoid design damage with consequential disqualification of warranty, the flame arresters whose elements have MESG, should be returned to the manufacturer for cleaning.

Table 6: Inspection Checklist

	Flame Arrester Type	What to Look For
1	Dry fixed element	Plugging, corrosion, physical damage, incorrect bolt torque, contaminants, incorrect orientation, instrumentation malfunction
2	Hydraulic	Improper liquid level, seal fluid contaminants, foam, vessel corrosion, distributor pluggage, instrumentation malfunction
3	Packed bed	Packing damage, corrosion, fouling or plugging, distributor pluggage, instrumentation malfunction

The following table summarizes the activities of the Mechanical Integrity of a flame arrester.

Table 7: Mechanical Integrity Activities for Flame/Detonation Arresters

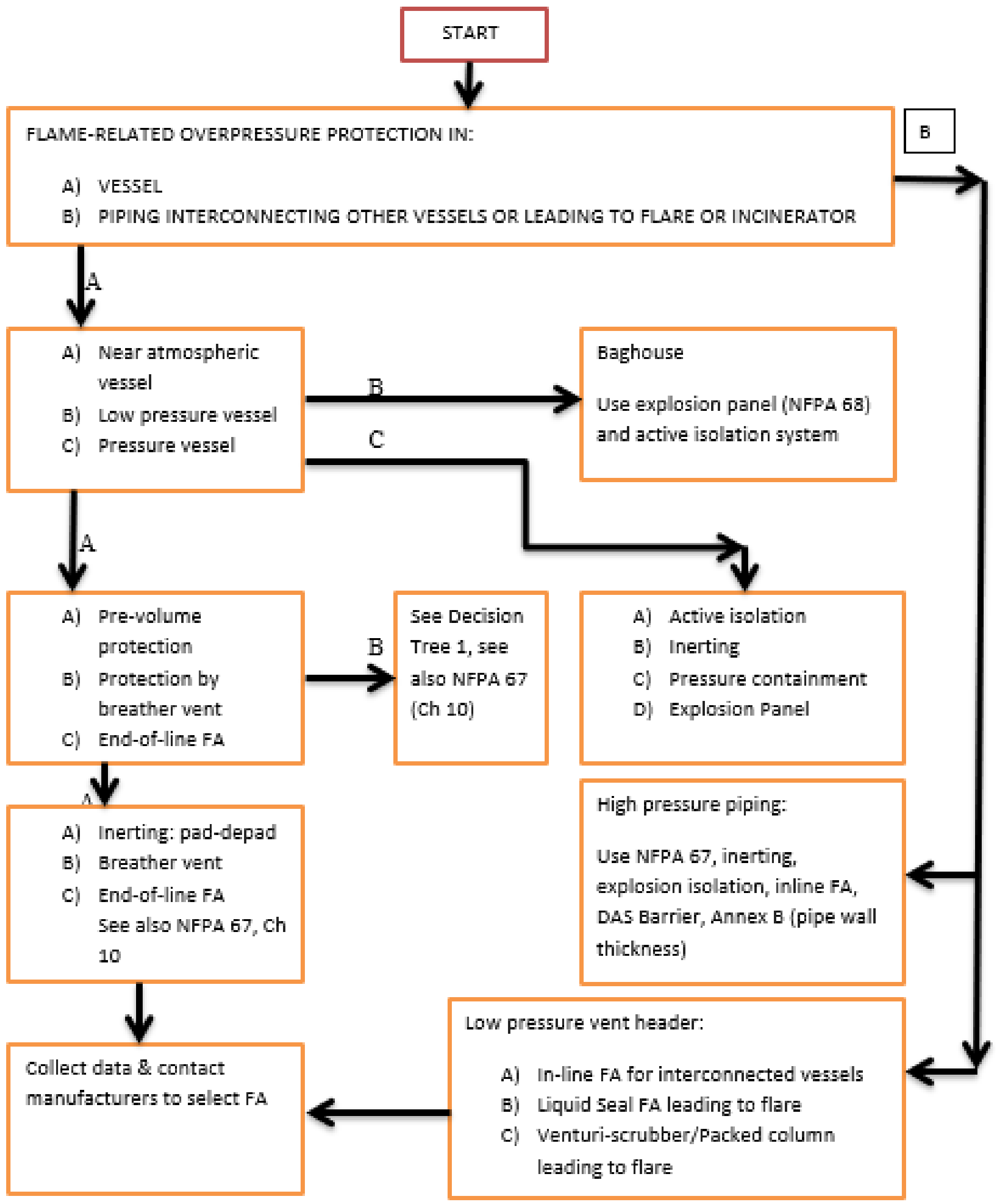
Information	New Equipment Design, Fabrication, and Installation		Inspection and Testing		Preventive Maintenance		Repair	
	Activity	Frequency	Activity	Frequency	Activity	Frequency	Activity	Frequency
Example Activities and Typical Frequencies	Verify equipment specifications are met: ▪ Service requirements ▪ Materials selection ▪ Sizing design basis and sizing calculations	As required for fabrication and installation	External visual inspection	Annual	Activities identified from FMEA or other analysis techniques for RCM or similar working planning initiatives, such as: ▪ Routine visual surveillance ▪ Process performance monitoring	As required to meet PM schedule or process monitoring needs	Equipment replacement-in-kind Mounting locations - repair or renewal Cleaning of device removal of plugging materials	As required by the condition of the equipment based on recommendations from the ITPM activities.
	Fabrication shop/contractor qualifications ▪ Design approval by plant ▪ Welding/QC plan		Internal inspection	As appropriate for the service				
	Fabrication and installation							
	Inspection							
	Documentation / Commissioning and testing		Inspection of inlet and outlet piping for fouling and plugging	Whenever the device is replaced or removed for testing				
	Acceptance and turnover		Additional inspections for specific degradation modes	As required by service conditions, condition of equipment, and rate of degradation				
Technical Basis for Activity and Frequency	QA practices for flame/detonation arrestor fabrication, testing, and installation		Scheduled with intervals set by the results of previous activity or at intervals based on inspection code or jurisdictional requirements		Company or jurisdictional requirements		Performed when indicated by failure, by the results of PM activities, by the results of inspection and testing activities	
Sources of Acceptance Criteria	Codes for design and fabrication in conjunction with requirements for the vessel being protected Company Engineering Standards, in facility-specific or jurisdictional requirements		Acceptance criteria from inspection codes or jurisdictional requirements		Company requirements and good engineering practice for process conditions defined in the Process Safety Information		Codes for design and fabrication in conjunction with requirements for the vessel being protected Company Engineering Standards, in facility-specific or jurisdictional requirements	
Typical Failures of Interest	Incorrect materials or internal components, incorrect dimensions, inadequate flow rate provided, misalignment or out of square flanges, or improper installation		Plugging of the device by process materials, insects or dirt or by corrosion		Plugging of the device		Incorrect materials or internal components, incorrect dimensions, inadequate flow rate provided, misalignment or out of square flanges, or improper installation	
Personnel Qualifications	Manufacturer requirements, documented skills, inspection certifications or technical training for		Specific technical training on flame/detonation arrester relief valve		Specific technical training on flame/detonation arrester relief valve inspection, testing, handling, and installation procedures		Specific technical training on flame/detonation arrester relief valve inspection, testing, handling, and installation procedures	

Information	New Equipment Design, Fabrication, and Installation		Inspection and Testing		Preventive Maintenance		Repair	
	Activity	Frequency	Activity	Frequency	Activity	Frequency	Activity	Frequency
Example Activities and Typical Frequencies	Verify equipment specifications are met: ▪ Service requirements ▪ Materials selection ▪ Sizing design basis and sizing calculations	As required for fabrication and installation	External visual inspection	Annual	Activities identified from FMEA or other analysis techniques for RCM or similar working planning initiatives, such as: ▪ Routine visual surveillance ▪ Process performance monitoring	As required to meet PM schedule or process monitoring needs	Equipment replacement-in-kind Mounting locations - repair or renewal Cleaning of device removal of plugging materials	As required by the condition of the equipment based on recommendations from the ITPM activities.
	Fabrication shop/contractor qualifications ▪ Design approval by plant ▪ Welding/QC plan		Internal inspection	As appropriate for the service				
	Fabrication and installation							
	Inspection							
	Documentation / Commissioning and testing		Inspection of inlet and outlet piping for fouling and plugging	Whenever the device is replaced or removed for testing				
	Acceptance and turnover		Additional inspections for specific degradation modes	As required by service conditions, condition of equipment, and rate of degradation				
	inspection and acceptance activities during manufacture and installation Trained in the sizing, selection, and specification of the device in accordance with the manufacturers' recommendations or other applicable code or standard		inspection, testing, handling, and installation procedures					
Procedure Requirements	Written procedures describing: ▪ Engineering standards for specification of equipment ▪ Project management (including hazard and design review schedules) ▪ Vendor qualification ▪ Documentation requirements ▪ Project acceptance and turnover requirements ▪ Proper installation requirements		Written procedures describing the inspection or test activity, including: ▪ The manner, the extent, the location, and the timing for the inspection or test, and by whom ▪ The documentation and analysis of results ▪ The resolution of functions or conditions not meeting acceptance criteria		These activities generally do not require task specific procedures		Craft skill procedures for typical tasks encountered in replacements or repairs (e.g., gasket installation, bolt tightening) Job-specific procedures developed for replacements, repairs, or alterations	

Overall Strategy: Define the Application Problem

Having assimilated the foregoing information, the reader should be able to define the scope of application of the flame arresters.

Figure 10: Define Scope of Application



Source: Proposed by author, Dilip K. Das

Why Flame Arresters Fail[1]?

By definition, if the flame goes past a flame arrester, the flame arrester fails to deliver its duty.

Some of the causes of the failure of flame arresters are:

1. Inadequate Mechanical Integrity program, in particular, frequency of inspection and cleaning. Failure to identify that the model is outdated.
2. Incorrect choice of MESG and NEC group
3. Incorrect choice of composition of flammables
4. Incorrect choice of material of construction leading to corrosion failure. Note that corrosion allowance is not added to flame arrester elements.
5. Layout-related issues:
6. Less pipe run of equal diameter upstream of flame arrester
7. Larger pipe size upstream of flame arrester
8. Too many fittings compared with what was used in the test
9. Lack of freeze protection
10. Overheating due to heat-tracing or impeding heat transfer due to insulation
11. Use of deflagration arrester in a pre-volume vessel system
12. Bypassing of flame arrester by piping or instrumentation
13. Use of "Grandfathered" flame arresters

Conclusions

This article provides the working knowledge to choose the appropriate flame arrester by navigating the information of the plethora of mechanical design of the flame arresters. The flame arrester should not be designed from first principles and the applicable system property should be tested for the final selection of the dry-type flame arresters. Hydraulic seal flame arresters can be sized using the applicable standard and methodology. Appropriate mechanical integrity should be followed after installation.

There is a learning curve for those unfamiliar with the technology, and the anxiety due to uncertainty increases with learning. A considerable personal effort is needed to overcome the initial anxiety. The content of this paper is complemented by the ioMosaic white paper "How Flame Arresters Work", by G.A. Melhem, PhD. Additionally, this white paper has also been recorded in video format as "Guidelines for Selecting Conservation Vent and Flame Arrestor - How Flame Arrestors Work".

There is a paucity of information about MESG values which differ considerably depending on which apparatus is used to measure it. The reputation of the manufacturer should be given proper weight in the final selection the flame arrester.

Flame dynamics can also be studied using Process Safety Office® SuperChems™, developed by ioMosaic Corporation. SuperChems™ offers a number of separate validated models for single/multi-phase reacting flow, dispersion analysis, droplet dynamics, fire, and explosion dynamics. All models in SuperChems™ are true multi-component models with support for petroleum fractions and mixture toxicity. In addition, SuperChems™ provides several power productivity tools including:

- Advanced reporting and data lifecycle management with ioXpress™
- Thermodynamic and physical properties database for more than 3,000 components with complete property estimation tools.
- Chemical Reactivity Management Expert
- SuperChems™ is the ideal choice for process safety and risk professionals in chemicals, pharmaceuticals, oil and gas, refining, and many other process industries. A subset of SuperChems™ focused on fluid flow (single and multi-phase) is adopted and marketed by the American Institute of Chemical Engineers as SuperChems™ for DIERS.

Safety is a virtuous business value which should be applied to promote continuous improvement in working place to minimize accidents to justify a line of business, a specific production or an existing practice for the greater goodness of the society and sustainability of planet earth.

In the end, flame-arrester application is deceptively simple. This is one of the many applications of Emergency Relief System Designs where our best efforts conducted through a myopic hazard analysis against the alignment of Swiss Cheese Holes for accident propagation is imperfect because of the latter's potential for an increase in entropy. Let's, nevertheless, give our best effort!

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19. 33 CFR Pt. 154, App B, Attachment 1 Table of flammable gas or vapor and corresponding MESG
20. National Electrical Code (NEC)-NFPA 70-1971 Chapter 5, Article 500 –Classification of chemical by Groups A, B, C, D, and location classification

21. Melhem, G.A., PhD “How Flame Arresters Work”, ioMosaic Corporation White Paper
22. ioMosaic Corporation White Paper Video “Guidelines for Selecting Conservation Vent and Flame Arrestor - How Flame Arrestors Work”

Appendix A: MESG

The MESG is the maximum clearance between two parallel 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. It is based on the concept of quenching distance: the inability of the flame to pass through a tube smaller than a certain diameter.

There are two types of apparatuses to test MESG: the Westerberg type, originally developed by UL, USA and the European type developed in the Physikalisch Technische Bundesanstalt (PTB), Germany. The PTB apparatus is now International MESG apparatus. The diameter and schedule number of the tube used in the apparatus is a key variable.

The MESG values of flammable mixtures are apparatus-sensitive. Therefore, it is advisable not to confuse values determined by one type of apparatus with those of the other. Calculation involving application of Le Chatelier's rule may lead to the inappropriate selection of flame arresters. In particular, the inerts should be excluded in such calculation for conservative results. The calculation of MESG of a mixture of n components on an inert-free basis is given by:

$$MESG_{mixture} = \frac{1}{\sum_{1}^{n}\left(\frac{y_i}{MESG_i}\right)} \qquad \text{Equation (2)}$$

where,

$y_i =$ vapor fraction of component i on inert-free basis

$MESG_i =$ MESG of component i on inert-free basis

$MESG_{mixture} =$ MESG of mixture on inert-free basis

Minimum Igniting Current (MIC) ratio:

$$\text{MIC Ratio} = \frac{\begin{array}{l}\text{Minimum current required from an inductive} \\ \text{spark discharge to ignite the most easily} \\ \text{ignitable mixture of a gas or a vapor}\end{array}}{\begin{array}{l}\text{Minimum current required from an inductive spark} \\ \text{discharge to ignite methane under the same conditions}\end{array}} \quad \text{Equation (3)}$$

The MIC ratios are used as an alternate to MESG to classify flammable liquids, gases, or vapors.

After computing the $MESG_{mixture}$ the appropriate NEC group classification of the mixture can be made.

For example, NEC Class I flammable or combustible vapors or gases are divided into four groups:

1. Group A: Acetylene
2. Group B: Flammables having either a MESG </= 0.45mm or a minimum igniting current ratio (MIC) </=0.4
3. Group C: Flammables having either a MESG > 0.45 mm and </=)0.75 mm or a minimum igniting current ratio (MIC) > 0.4 and </=0.8.
4. Group D: Flammables having either a MESG > 0.75 mm or a minimum igniting current ratio (MIC) > 0.8.

It must be noted that US groupings and European Groupings are not the same.

Table A1 : European Classification of Vapor and Gases & their Relation to MESG (Source: PROTEGO®)

Explosion Group	Maximum Experimental Safe Gap or MESG, mm
IIA1[a]	>= 1.14
IIA	>0.90
IIB1	>=0.85
IIB2	>=0.75
IIB3	>=0.65
IIB	>=0.5
IIC	<0.5

Note: Group IIA1 used to be designated as Group I previously.

NFPA 497 Table 4.4.2 and Annex C Table B.1 and 33 CFR Pt. 154, App B Attachment 1 list various flammable gases and corresponding MESG values.

Appendix B: Information Required for Selecting Flame Arrester

1	Company Name				
2	Address				
3	Phone				
4	Fax				
5	Email				
6	Project/End User				
7	Date				
8	Issued by				
9	Type of Flame Arrester (Inline deflagration/Inline detonation or End-of-line Deflagration/ End-of-line Detonation)				
10	For inline flame arrester : distance of flame arrester from source of ignition				
11	Flame Arrester Tag Number		Tank Number		
11	Pipe size		Schedule No		
12	Tank Capacity		Tank Design Pressure/Vacuum		
13	Supply Line, P&ID & Isometric Layout Drwg. No				
14	PROCESS DATA	Fluid state (Vapor/Gas/Liquid)			
14a	Gas/vapor % or ppm				
14b	Gas/vapor % or ppm				
14c	Gas/vapor % or ppm				

14d	Gas/vapor % or ppm					
14d	Gas/vapor % or ppm					
14e	Gas/vapor % or ppm					
14f	Are particulates, sticky solids or polymeric materials present? (yes/no)					
15	AIT (Autoignition Temperature), ^{0}F/^{0}C					
16	MESG (Maximum Experimental Safe Gap), mm		Calculated or Tested?		NEC Group	
17	Molecular weight average/ Sp. Gravity					
18	Vapor Group NEC or IEC or ISO 16852 Rating					
19	Flash Point, ^{0}F/^{0}C					
20	Operating Temperature, ^{0}F/^{0}C, Minimum/normal/maximum					
21	Operating pressure, Minimum/normal/maximum					
22	Back pressure, maximum					
23	Inlet gas volumetric flow, normal/maximum					
24	Max. allowable Pressure loss/ Maximum accumulation					
25	Emptying rate/Inbreathing rate/vacuum setting					
26	Filling rate/outbreathing rate					
27	Material of construction: Body or Housing		Element or Matrix			
28	Coating or special paint on body or element					

29	Pressure sensor at Inlet and/or outlet required? (yes/no)		Explosion-proof						
30	Temperature sensors at Inlet and/or outlet? (yes/no)		Explosion-proof						
31	Does the housing need jacket or heat tracing? (yes/no)								
32	Test Protocol: UL 525/USCG/FM/CEN 12874								
33	Listing/Approval: (a) UL Listed or Classified (b) FM Approved								
34	Flange Rating	ANSI Class		DIN		EN		PN	
35	Is continuous burning possible on flame Arrester? (Yes/No)		Endurance time, min						
36	Arrester type: Deflagration/Detonation								
37	Flame Arrester Size: Inlet/Outlet		Breather Vent size: Inlet/outlet						
38	Removable Element or non-removable element for cleaning/inspection?								
39	Unidirectional or bidirectional?								
40	Is in-place cleaning nozzles required for dirty service? (yes/no)								
41	Manufacturer								
42	Series Number								
43	Model Number								
44	Drain Plug Required? (yes/no)		Operating platform required? (yes/no)						
45a	Manufacturer Deliverables:								

45b	Certified Drawing	
45c	Certified Flow Curve	
45d	Flame Arrester Weight	
45e	Calculations	
46	Installation and Maintenance Guidelines including Mechanical Integrity Advice for cleaning and inspection frequency	

Appendix C: Information Required for Selecting Hydraulic (Liquid Seal) Flame Arrester

1	Company Name					
2	Address					
3	Phone					
4	Fax					
5	Email					
6	Project		End User			
7	Date					
8	Issued by					
9	Orientation of Flame Arrester:	Horizontal		Vertical		
10	Flame Arrester Assembly Number		Tank Number			
11	Tank Capacity					
11	Inlet Pipe size/schedule No		Outlet Pipe size/Schedule No			
12	Tank Design Pressure, recommended 50 psig to stand deflagration		Tank Design Vacuum			
13	Supply Line, P&ID & Isometric Layout Drwg. No					
14	PROCESS DATA	Fluid state (Vapor/Gas/Liquid)				
14a	Gas/vapor % or ppm					
14b	Gas/vapor % or ppm					
14c	Gas/vapor % or ppm					

14d	Gas/vapor % or ppm			
14d	Gas/vapor % or ppm			
14e	Gas/vapor % or ppm			
14f	Gas/vapor % or ppm			
15	AIT (Autoignition Temperature), ^{0}F/^{0}C			
16	MESG (Maximum Experimental Safe Gap), mm			
17	Molecular weight average/ Sp. Gravity			
18	Vapor Group NEC or IEC or ISO 16852 Rating			
19	Flash Point, ^{0}F/^{0}C			
20	Operating Temperature, ^{0}F/^{0}C, Minimum/normal/maximum			
21	Operating pressure, Minimum/normal/maximum			
22	Back pressure, maximum			
23	Inlet gas volumetric flow, normal/maximum			
24	Max. allowable Pressure loss/ Maximum accumulation			
25	Material of construction, inlet & outlet			
26	Material of construction, body & sparger			
27	Coating or special paint on body or sparger			
28	High & Low level sensors?		Explosion proof	
29	Sight glass? (yes/no)		Explosion-proof	
30a	Temperature sensors at vapor and liquid? (yes/no)		Explosion-proof	

30b	Local level gauge? (yes/no)								
31	Test Protocol: UL 525/USCG/FM/CEN 12874								
32	Listing/Approval: (a) UL Listed or Classified (b) FM Approved								
33	Flange Rating	ANSI Class		DIN		EN		PN	
34	Other								
35	Other								
36	Other								
37	Other								
38	Other								
39	Manufacturer								
40	Series Number								
41	Model Number								
42	Other								
43	Manufacturer Deliverables:								
43a	Certified Drawing								
43b	Certified Flow Curve								
43c	Flame Arrester Weight								
43d	Calculations								

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1	Company Name	
2	Address	
3	Phone	
4	Fax	
5	Email	
6	Project	
7	Date	
8	Issued by	
9	SERVICE CONDITION	Please specify units of measurement
9a	Tag Number	
9b	Tank Number	
9c	Capacity of tank	
9d	Tank Design Pressure	
9e	Tank Design Vacuum	
9f	Gas/vapor % or ppm	
9g	Gas/vapor % or ppm	
9h	Gas/vapor % or ppm	

9i	Gas/vapor % or ppm	
9j	Gas/vapor % or ppm	
9k	Gas/vapor % or ppm	
9l	Gas/vapor % or ppm	
9m	Gas/vapor % or ppm	
9n	Other	
10	Molecular weight average	
11	Vapor Group NEC or IEC or ISO 16852 Rating	
12	Flash Point, ^{0}F/^{0}C	
13	Operating Temperature, ^{0}F/^{0}C, normal/maximum	
14	Operating pressure, normal/maximum	
15	FLOW REQUIREMENTS	
15a	Inlet gas volumetric flow, normal/maximum	

15b	Pressure loss	This will dictate the immersion length and velocity head in sparge pipes and line loss.
16	Material of construction	Carbon steel, stainless steel, coated or lined carbon steel for tank and Stainless steel, Hastelloy, or plastic.
17	INSTRUMENTATION	
17a	Sight Glass	Explosion-proof
17b	Temperature sensors, vapor and liquid	Explosion-proof
17c	Local level gauge	Explosion-proof
17d	High and low liquid level sensors	Explosion-proof
18	Flange Rating	ANSI Class / DIN/EN/PN
19	Other	
20	Other	

Appendix C: List of Manufacturers

The alphabetical orders of names are:

1. Emerson Tulsa
2. ESAB Welding and Cutting Products
3. FENWAL Safety Systems
4. FIKE
5. GROTH
6. IMI Safety Systems
7. KEMP
8. KnitMesh Limited
9. Matheson Gas Products
10. NAO, Inc.
11. OSECO
12. Protectoseal Company
13. PROTEGO®
14. REMBE GmbH
15. Rexarc
16. Selas Corporation of America
17. Shand & Jurs
18. Tornado Flare Systems
19. Varec
20. Western Enterprise
21. John Zink Company

Appendix D: Acronyms

API: American Petroleum Institute

ASTM: American Society for Testing and Materials

BS: British Standard

BSI: British Standard Institute

BSEN: British Standard European Norm

CEN: Comité Européean de Normalisation

CFR: Code of Federal Regulations

CSA: Canadian Standards Association

CV: Conservation Vent

DAS: Detonation Arrester System

DIN: German Industrial Standard (Deutsche Industrial Norms)

DDT: Deflagration-to-Detonation-Transition

EN: Européean de Normalisation or European Norm

ERS: Emergency Relief System

FA: Flame Arrester

FMR: Factory Mutual Research

IEC: International Electrotechnical Commission

IMO: International Maritime Organization

ISO: International Organization for Standardization

ITPM: Inspection, Testing, and Preventive Maintenance program

LFL: Lower Flammability Limit

LOC: Limiting Oxygen Concentration

MESG: Maximum Experimental Safe Gap

MIC: Minimum Igniting Current

NEC: National Electrical Code

NFPA: National Fire Protection Association

PTB: Physikalisch Technische Bundesanstalt (PTB), Germany

TÜV: *Technischer Überwachungsverein (Technical Inspection Association)*

UL: Underwriter's Laboratory, USA

USCG: United States Coast Guard