A COMPREHENSIVE TEST METHOD FOR INLINE FLAME ARRESTERS

This document is a working paper for the CSA task force on flame arresters.

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INTRODUCTION

Flame arresters for hazardous gas/air mixtures see much use in the oil and chemical industries. They are used to protect systems from flashbacks in flares or incinerators, ignition due to impeller generated friction in compressor failure, or anywhere else that there is a hazard associated with the possible simultaneous occurrence of an explosive gas/air mixture and ignition source.

It has been pointed out by a variety of investigators that flame arresters should only be used for the exact flow system configuration for which they have been tested. The only test standard that exists at the moment is that of Underwriters Laboratories (UL525). This is highly inadequate for many applications because it only deals with venting applications which involve very short lengths of flame run-up and virtually unrestricted flame venting. Unfortunately, the lack of proper testing procedure is demonstrated by the fact that to this day, oil storage tank explosions due to flame arrester failure are common occurrences.

The flame quenching efficiency of commercially available flame arresters is very sensitive to the mode of flame propagation and the arrival pressure. It is very difficult to predict the pressure build up in a system because it depends on unpredictable flame front behaviour. For systems where there is even the slightest degree of uncertainty, flame arresters should be tested over the entire range of possible flame front arrival conditions. In a given application, the large number of possible flow system configurations would make it difficult and costly to custom test for all the different piping systems in which they are in use. Also, it is very difficult to control the removal of a unit from one system and its re-installation in a different one. It makes far more sense to test flame arresters in a system where they can be subjected to the whole range of flame front conditions that could possibly be encountered in actual use. This paper describes a comprehensive test method for inline flame arresters.

DEFINITIONS:

Flame propagation: The burning of a flame front through a flammable fuel/air gas mixture.

Flammability limits (explosive limits): The upper (UEL) and lower limits (LEL) of fuel concentration that will sustain flame propagation.

Equivalence ratio: The fuel to air ratio of a gas mixture over the fuel to air ratio of a stoichiometric mixture [(fuel/air)actual/(fuel/air)stoichiometric].

Stoichiometric mixture: A flammable fuel/air mixture in which the fuel to air ratio is such that the fuel and oxygen are completely consumed.

Deflagration: A flame front that propagates by the transfer of heat and active chemical species to the unburned gas ahead of the flame front. Overpressures can range from a very small fraction of the initial pressure to as much as twenty times the original. Flame speed can range from 0.4 m/s to supersonic (greater than 350 m/s) for very high pressure turbulent flames.

Detonation: A flame front that propagates by shock wave compression induced ignition in a flammable fuel/air mixture. Flame speeds are supersonic with Mach numbers ranging from 5 to 15. The pressure of a stable detonation is about 20 times the initial pressure but can go as high as 100 times the initial pressure at the moment of transition from deflagration to detonation.

Flame speed: The speed at which a flame travels relative to a set of fixed coordinates.

Burning velocity: The speed of a flame propagating in a still or laminar flowing fuel/air mixture.

Operating pressure: The absolute pressure in a flow system during normal operating conditions. It is the pressure that exists at the moment of ignition.

Overpressure: The pressure rise that is caused by the flame front when travelling through a flow system.

Absolute pressure: The total pressure in a system , gauge pressure plus atmospheric pressure.

Flame propagation spectrum (flame pressure spectrum): The range of overpressures that can be generated by a flame front in a flow system.

Sensitivity: A fuel property that denotes the relative difficulty in quenching flames propagating through a mixture of this fuel with air.

Quenching diameter: The largest diameter of a tube which will just quench a flame front in a particular fuel/air mixture. If the diameter is increased any further, the flame front can propagate in the tube without being quenched.

TEST METHOD

In order to test an inline flame arrester for any possible installation configuration, it must work over the entire range of flame front pressures to which it could be exposed in actual use. Based on this, a flame pressure spectrum has been developed and is shown in figure 1. This shows a plot of the flame front overpressure versus the ignition source distance L from the arrester.

The flame pressure profile of figure 1 was developed with the test system shown in figure 2. It was designed to generate the entire range of the flame propagation spectrum: low, medium and high pressure deflagrations, as well as over driven and stable detonations.

This system was specifically tailored to study flame arrester performance on hydrocarbon/air flames. The run-up section consists of 35 ft. (10.7m) length of 3 inch (76mm) sched 80 pipe. At the end furthest from the flame arrester, there is a flame accelerator. This unit is used to generate detonations in a much shorter length of pipe than could be required in a straight undisturbed flow system. There are 10 ignition locations along the run-up length.

The ignition locations are spaced along the pipe so as to generate reasonable coverage of the flame pressure spectrum. If one location is too far from the next, it is possible to skip over an overpressure condition at which a flame arrester cannot function properly.

There are many different kinds of flame arresters and the flow characteristics can vary significantly between two different types. Where one might fail in one part of the spectrum, another would perform successfully and vice versa in a different portion of the spectrum. The ignition locations must be arranged to ensure that a critical zone for a given flame arrester is not overlooked in a test series.

At any given location in the deflagration zone, the flame overpressure can vary by as much as 300% from one attempt to the next. Thus, when ignition locations are properly spaced, there will be a certain amount of data overlap between adjacent locations. This ensures reasonable coverage of the propagation spectrum.

On the protected side of the flame arrester, the degree of restriction to venting during flame propagation can have a very significant effect on flame arrester performance. The two extremes of this effect are completely unrestricted venting and highly restricted venting. In figure 2, unrestricted venting is represented by the placing of a 10 ft. (3m) length of pipe that is completely open on the protected side of the unit. The other extreme, highly restricted venting, is created by a 2 ft. (0.6m) length of pipe the outlet of which is reduced from 3 inch (76mm) diameter to 1/2 inch (13mm) diameter. Though the most extreme condition of venting restriction is that of a completely sealed off outlet, in the case of a completely closed valve it would be impossible to transmit flame beyond it. Flow restriction on the protected side of the arrester causes an upward shift in the flame pressure spectrum at the low pressure end as shown in figure 1.

PROCEDURE

The test system is purged with at least 3 volume changes of the specified fuel/air mixture. In addition to the type of combustible gas, the equivalence ratio of the gas or concentration in air must be specified. The composition of the fuel/air mixture must be verified by gas analysis during the system purge to ensure compliance with specifications.

The ignition sequence is commenced at the ignition source closest to the flame arrester. This permits testing of the low pressure part of the spectrum before any arrester damage is incurred at the high pressure end.

At each location, the flame arrester is subjected to five ignitions before moving to the next location. If, at anytime during the test, the flame arrester fails to prevent flame passage to the protected side of the unit, the test is considered to be unsuccessful and must be performed again after the unit has been modified.

Prior to ignition, the flow of flammable gas/air mixture should be shut off to prevent the occurrence of a continuous burning flame in the test system or the possibility of flashback into the flow metering system. No more than 5 seconds should elapse between the shutting off of the flow and ignition.

Measurement should be made of the pressure at the inlet and outlet of the flame arrester at the moment of flame arrival. The pressure transducer locations are marked in figure 2. The failure of the arrester to quench a flame front is determined by placing flame ionization sensors in the pipe on the protected side of the flame arrester. For each ignition, a record is kept of the upstream and downstream pressure, the flame ionization profile, and whether or not the flame arrester quenched the flame.

The firing procedure steps are as follows:

1. Charge system with specified fuel/air mixture.
2. Cut-off flow of mixture and ignite.
3. Re-start flow.
4. Record pressures, ionization and test result.
5. Repeat step 1 at this location until a total of 5 ignitions have been carried out.
6. Move to the next ignition location.
7. When all 10 ignition locations have been tested and reasonable coverage of the pressure spectrum has been obtained, the arrester should then be tested with an altered flow restriction on the protected side of the arrester.

OPERATING SPECIFICATIONS

TEMPERATURE

An increase in temperature decreases the flame quenching efficiency of a flame arrester by reducing the temperature gradient between the flame and the heat sink. Flame arresters can only be effective when the initial temperature is below the auto ignition temperature of the specific fuel. This is about 450°C for hydrocarbons. In most cases flame arresters are used at local ambient temperatures. They can range from minus 50°C to plus 100°C when exposed to solar radiation. Over this range of temperature there is very little effect on the flame quenching efficiency of an arrester. Flame arresters testing successfully at the normal indoor ambient temperature of 20°C would function just as well at the climatic extremes.

PRESSURE

The operating pressure of a flame arrestment system has a very significant effect on flame arrester performance. An increase in pressure reduces flame quenching efficiency. Since most flame arresters are used at atmospheric pressure, that will be the most common test specification for flame arresters. For atmospheric applications the test pressure should be 101.3 kPa (14.7 psia).

A flame arrester should not be used in a system where the operating pressure exceeds the test pressure by more than 5%. For atmospheric applications this corresponds to an operating pressure of 106.4 kPa (15.4 psia). It should be noted that in Alberta, due to difference in elevation, the local atmospheric pressure is approximately 11% less than that at sea level. It would be all right to use a flame arrester tested at sea level in Alberta, but it would be dangerous to assume that a unit tested in Alberta would function properly at sea level.

Flame arresters intended for use in pressurized systems [operating pressure greater than 106.4 kPa (15.4 psia)] should be tested for performance at the specified pressure.

COMBUSTIBLE GAS AND EQUIVALENCE RATIO

Flame arresters should be classified according to the test gas category: A - acetylene, B - hydrogen, C - ethylene, and D - propane. The sensitivity of a gas decreases in going from A to C. A flame arrester should only be used where the sensitivity of the gas for which it has been tested is greater than or equal to the sensitivity of the gas it will actually be used for.

Most flame arresters are used in hydrocarbon/air applications. This corresponds to D category. It should be noted that within this category there is a variation in sensitivity. Methane is less sensitive than propane and should not be used for acceptance testing in this category. Propane has a sensitivity that is greater than or equal to that of any gas in D category; this makes it appropriate for tests in this classification.

In sour flaring applications, gases contain hydrogen sulfide. At low concentrations the hydrogen sulfide does not have a significant effect on the sensitivity of a natural gas/air mixture. However, hydrogen sulfide gas itself is not in the same category as most hydrocarbons. Where methane and propane are group D, hydrogen sulfide is actually a group C gas; this makes it significantly more sensitive than methane or propane. Because the major component of natural gas is essentially methane, it is less sensitive than propane. The addition of a more sensitive fuel such as hydrogen sulfide raises the sensitivity of the natural gas. Flame arresters for sour flaring applications should be group D only if the hydrogen sulfide content of the gas is less than or equal to 20%. For concentrations greater than 20% hydrogen sulfide, flame arresters should be tested for a group C gas.

The performance of a flame arrester is strongly dependent on the equivalence ratio of the gas/air mixture with which it is tested. In any group classification, tests should be conducted with the fuel/air mixture that corresponds to the most sensitive equivalence ratio. This can be defined as the equivalence ratio at which the minimum quenching diameter for a particular combustible gas occurs. For most gases, the minimum quenching diameter occurs for equivalence ratios that are slightly richer than stoichiometric.

Figure 1 Flame Pressure Spectrum

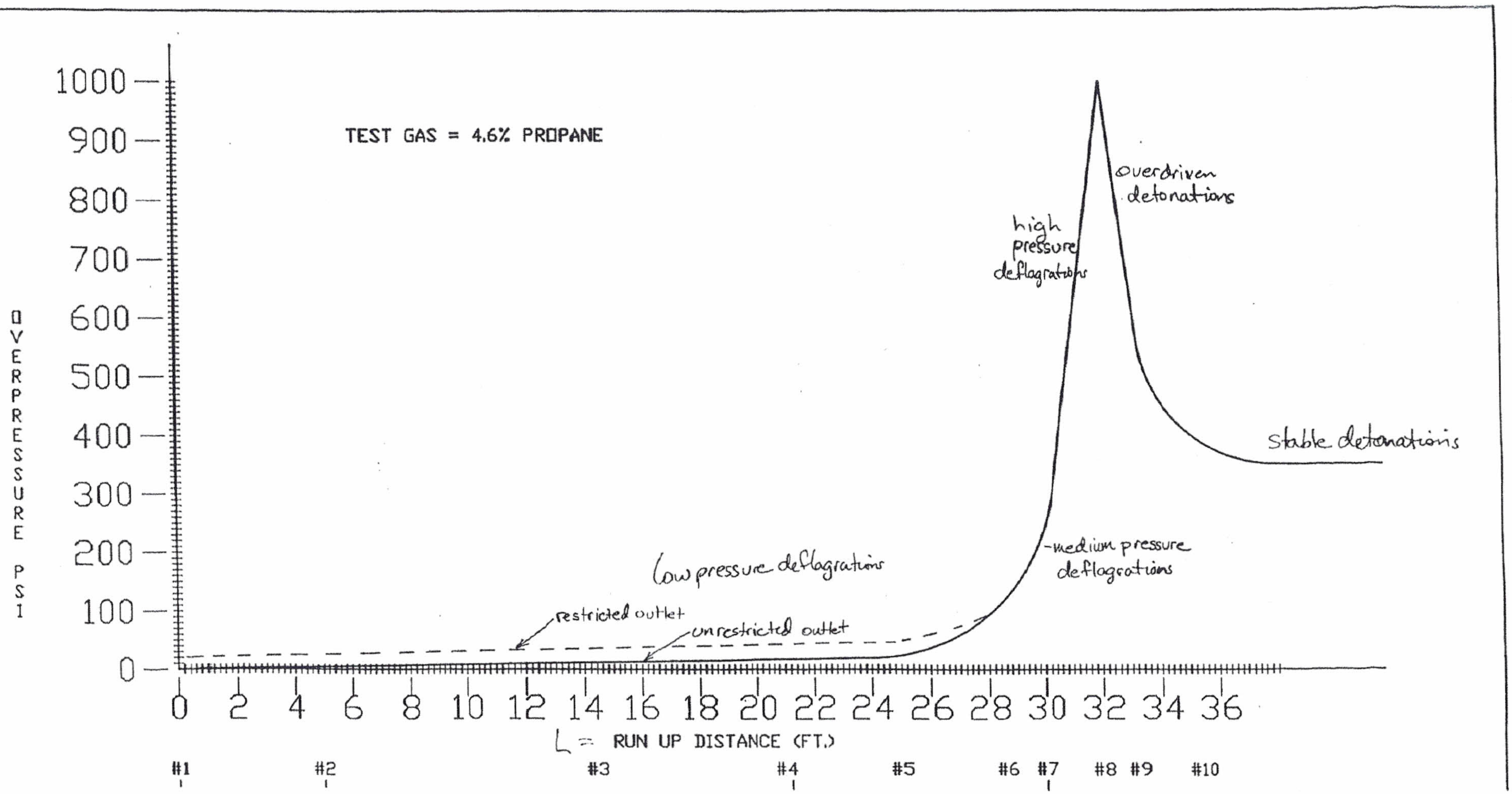
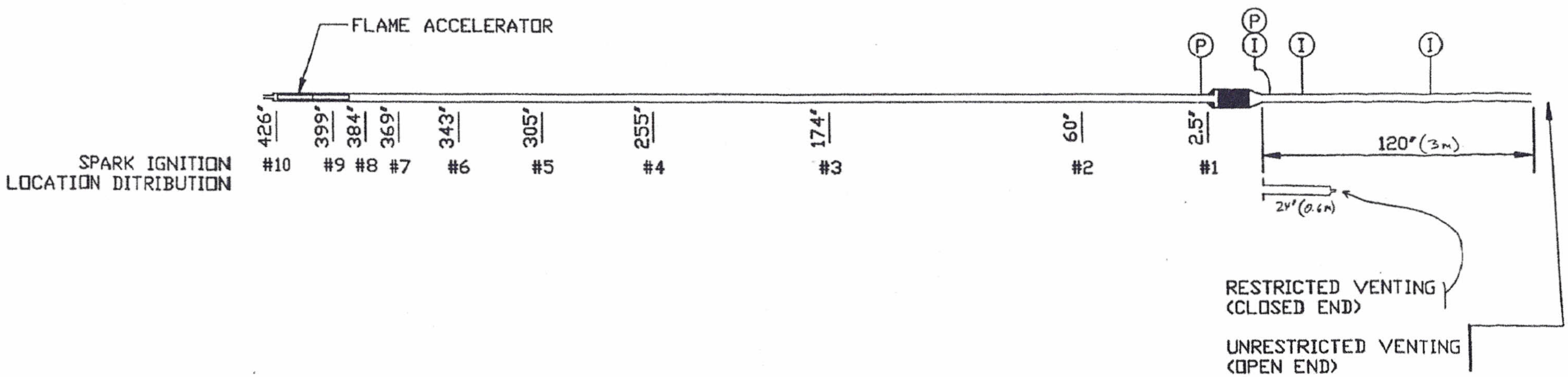


Figure 2. Flame Arrester Test System (3inch)



FLAME ACCELERATOR: 2 3/4" O.D. X 1 1/4" I.D. WASHERS
3 WASHERS EVENLY SPACED OVER 34'
AND HELD TOGETHER BY 1/2" ALL
THREAD RODS.

(I) = FLAME IONIZATION SENSORS TO DETECT PASSAGE OF FLAME THROUGH THE FLAME ARRESTOR.

(P) = PRESSURE TRANSDUCER.