Pipeline Fire Protection 101: Flames in Pipelines

1. Flames in Pipelines

Process plants regularly transport and store flammable and explosive gases. A flame propagating through these gases can cause catastrophic damage within a system ranging from the destruction of process equipment, to the destruction of entire facilities, and the loss of human life.

Presently, several different technologies and methods are used to prevent process gas ignition and stop flame travel in pipelines; however, before any method of fire protection can be applied the user must possess both an understanding of the system being protected and an understanding of flame travel within a pipeline.

1.1. What is a flame?

A flame is a chemical reaction between a fuel and an oxidant that releases heat and product gases. The release of the hot product gases produces localized volumes of pressurized expanding gas. In the case of a burning gas, the expanding product gases preheat nearby fuel gas. Heat from the burning reaction ignites the preheated nearby fuel gas and the flame accelerates (Oakley, 13).

1.2. Deflagrations

A deflagration is a flame propagating below the speed of sound in the burning media (NFPA 69 3.3.8).

In a deflagration the hot combustion gases expand in front of the flame front, mixing with the unconsumed fuel gas. This mixing drives the burning reaction and accelerates the flame.

In a pipeline, expanding product gases and unconsumed fuel interact with the pipe walls; the pipe walls increase turbulent mixing, and restrain the expansion of the gas. Consequently, pipeline deflagrations accelerate much more rapidly than do deflagrations in the open due to “…the positive feedback that arises between gas flow ahead of the flame, flow induced turbulence and [the] subsequent increased turbulent mass combustion rates” (Thomas, 1).

Deflagrations occur in pipeline fires during the first several pipe diameters of flame travel. The distance from the ignition source to a given point is the run-up length. The exact run-up length over which a flame travels as a deflagration is a product of the fuel gas, the fuel to oxidant ratio, the pressure and temperature of the gas, the strength of the ignition source, and any media in the pipeline that may induce turbulence.
1.3. **Deflagration to Detonation Transition and Overdriven Detonations**

At some critical point, the localized volume of high-pressure gas leading a deflagration erupts in a short-lived pulse of extremely high pressure and extremely high flame speed (Grossel 64). At this instant, the flame is traveling well beyond the speed of sound. A flame traveling beyond the speed of sound in the burning media is a *detonation* (NFPA 69, 3.3.11). This phenomenon of extremely high pressure and propagation well beyond the speed of sound is an *overdriven detonation* or an *unstable detonation* interchangeably (EN 12874, 3.1.11).

The overdriven detonation exists for only a few pipe diameters (typically less than one millisecond). During this time, the flame can reach speeds of 2000 m/s, and generate radial pipe pressures of up to 100 times the initial absolute pressure (Grossel, 66).

Shortly after consuming all the fuel available in the localized high-pressure region, the flame decelerates from the overdriven condition to a stable detonation.

The period between the spontaneous eruption of the high pressure region to the deceleration to a stable detonation is the **Deflagration to Detonation Transition (DDT)** (Grossel, 64).

![Figure 1.2: Deflagration just before DDT](image1)

![Figure 1.3: Deflagration to Detonation Transition (DDT)](image2)

1.4. **Stable Detonations**

A *stable detonation* is a flame traveling at a constant velocity beyond the speed of sound in the burning media. For most hydrocarbons, this speed is around 1600 m/s; for hydrogen it is around 1900 m/s (Grossel 67). Once a flame has transitioned to being a stable detonation it, with certain exceptions, cannot accelerate and cannot transition back to a deflagration. Stable detonations, are fully developed flame fronts that do not change except when interfered with by changes in piping configuration (Grossel 67).

During a detonation the flame front and pressure wave are traveling in unison and arrive simultaneously (Grossel 66). There is no leading high-pressure region to compress or preheat the fuel gas.

![Figure 1.4: Detonation Flame in a Pipeline](image3)

Stable detonations exhibit both by high velocities and by high pressures. The radial pressure on the system piping typically ranges from 18-30 times the initial absolute pressure (Grossel 67).
1.5. **Factors Affecting Flame Propagation**
Strength of ignition source, fuel gas, fuel to air ratio, gas temperature, pipeline turbulence, and pipeline pressure are several factors affecting flame propagation. Pipeline turbulence and pipeline pressure are the most important of these factors.

1.5.1. ***Turbulence***
“The main mechanism causing the flame to accelerate in pipes, is turbulence. When the gas burns, it expands and pushes unburned gas ahead of the flame front. The flow ahead of the flame will cause a turbulent boundary layer to grow and the turbulence will enhance the burning rate,” (Wingerden 4). Any pipeline geometry that increases turbulence in the gas flow will promote flame acceleration and shorten the distance required for transition to detonation.

1.5.2. ***Operating Pressure***
By the ideal gas law, for a given volume and temperature, doubling the pressure doubles the number of molecules present, doubling the available chemical energy. Increasing the available energy results in more rapid flame propagation and higher flame pressure; consequently, the operating pressure of a pipeline is the best indicator of the damage potential of a flame propagating within that pipeline.

1.6. **Summary**
Pipeline flames have the potential to destroy process equipment and injure or kill nearby personnel. Due to this capability, it is necessary to protect against pipeline flames.

Pipeline flames have three distinct phases, deflagration, overdriven detonation, and stable detonation. Each of these phases has a unique flame speed and pressure, with deflagrations being the least severe and overdriven detonations being the most severe.

Each condition in flame travel occurs within a certain run-up length. Fuel gas, fuel to oxidant ratio, temperature, pre-ignition pressure, strength of the ignition source, and turbulence increasing geometries are all factors affecting the run-up length to deflagration to detonation transition. Turbulence increasing geometries and pipeline pressure are the two most important factors because they have the greatest effect on the run-up length to DDT and on the maximum potential for damage.

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2. References:


Grossel, Stanley “Deflagration and Detonation Flame Arresters” American Institute of Chemical Engineers, New York, New York


Oakley, G.L. and Thomas, G.O. “Investigations into Concerns About BS EN12874: 2001 Flame Arresters,” University of Wales, Old College, King Street, Aberystwyth Wales.


Wingerden, Kees, Bjerketvedt, Dag, and Bakke, Jan “Detonations in Pipes and in the Open,” Christian Michelsen Research, Bergen Norway.
3. Glossary of Terms

**Deflagration**
A flame traveling down a pipeline in such a manner that the flame velocity is less than the speed of sound within the flammable media.

**Detonation**
A flame front traveling at or above the speed of sound within the flammable media. For hydrocarbon-air mixtures the speed is greater than 1600 m/s. For hydrogen-air mixtures the speed is greater than 1900 m/s.

**Overdriven Detonation**
The very short-lived transition period between a deflagration and a detonation. An overdriven detonation is characterized by extremely high pressure and extremely high velocities.

**Stable Detonation**
A fully developed flame front traveling beyond the speed of sound. A stable detonation is a detonation that has decayed to a steady, nearly constant velocity and pressure after the deflagration to detonation transition.

**Operating Pressure**
The pressure inside a pipeline containing a flammable vapor, usually expressed in terms of absolute pressure.

**DP/Po**
Dimensionless ratio between peak dynamic pressure and initial pressure. Defined mathematically as \((P_{max} - P_i)/ P_i\) where all pressures are absolute pressures.

**Flame Speed**
Speed of a flame propagating through a pipe.

**Run-up Length**
The length of pipe between the flame arrester flange connection and the ignition source.

**Deflagration to Detonation Transition**
The nearly instantaneous transition from a subsonic, low pressure flame to a supersonic, high pressure detonation, characterized by a short-lived period of extremely high flame speed (>7000 ft/sec) and extremely high pressure. This is when the phenomena known as an overdriven detonation occurs.