Safety Moments – Lessons Learned from Incidents in the Natural Gas & LNG Industries

An Online Continuing Education Course for Engineers

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Safety Moment 1

Leak vs. Rupture for gas pipelines and vessels

DOT defines three types of gas pipelines: gathering pipelines, distribution pipelines, and transmission pipelines.

In this safety moment, we will focus on distribution and transmission pipelines only (however, the same technical mechanisms/consequences can occur in gas plant vessels).

Distribution pipelines can leak but will not rupture at normal MAOP when a significant pipeline defect occurs. Besides having an excavator pulling a gas main fully out of the ground or having a ground collapse, a distribution pipeline may leak for various reasons. The most common causes of such leaks are mechanical impact or a pipeline defect such as corrosion.

Think of it like a balloon just barely filled with a small amount of air and pricked with a pin. The air leaks out.

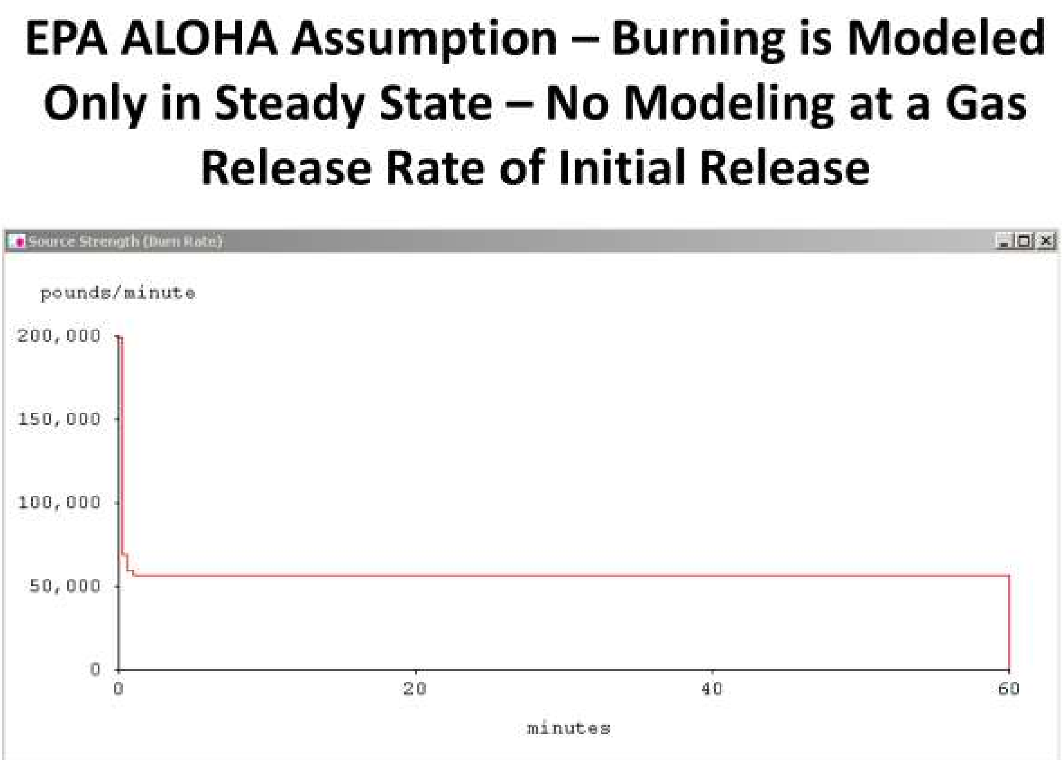
Transmission pipelines will “either” leak or rupture at normal MAOP when a significant pipeline defect occurs. A leak is a relatively small release of gas compared to a rupture. A leak typically involves a hole in the pipeline. A rupture rips the pipe open, often blowing a section of pipe out of the ground and resulting in two open-ended pipes blowing gas into the rupture point.

The section of pipe ripped open and/or blown out of the ground can be tens of feet long. Mechanical impact or a pipe defect, such as corrosion, is the most common cause of such leaks or ruptures.

However, there have been cases where newly installed transmission pipelines and/or pipelines re-certified as fit for service have ruptured well below their MAOP. Examples of such events include:

- A gas transmission pipeline was inspected, and the 14” pipe was rated as fit for service after repairs. However, as they increased the pressure, it ruptured—Milford, Pa.
- A newly built 42” gas transmission pipeline in Philo, Ohio, failed in its 2nd day of operation. Although it was rated for an MAOP of 1,480 psig, it ruptured at 1,197 psig.
- A 30” transmission gas pipeline ruptured in Natchitoches, Louisiana. 6 months earlier, it had been smart-pigged and found no defects.
- A 30” – 6-month-old gas pipeline ruptured, making a 60-foot crater – no fire.

Typically, a rupture involves a mechanical explosion, with or without ignition. Think of it like a highly filled, highly stressed balloon, pricked with a pin – the balloon ruptures. The greatest gas release rate of a rupture occurs during the first second after the rupture. However, even after the initial release (3-5 times larger than the steady state release), the magnitude of gas released is extremely large. Imagine a gas pipeline operating at 1,100 psig and having two instantaneous guillotine cuts made, say 30 feet apart on that gas pipeline. The figure below shows the gas release rate as a function of time for a specific case.



For the above case, the release is initially at a pressure of 1,170 psig, but after the first second, the release pressure decreases due to pipe friction. The follow-on leakage rate is still extremely high, but only about ¼ of the initial release rate due to the friction of the gas flow along the pipe walls.

As can be seen by the figures below, a rupture often results in a total separation of the piping and can result in a large section of pipe being blown out of the ground. The first photos below show the 30” San Bruno ruptured pipe segment blown out of the ground, and the second set of pictures below show the 14” pipe rupture in Milford, PA.

Appendix 1 - Photos - 122980

Pipeline Failure Investigation Report

Figure 7: **Bent 21.7 foot section of pipe in swamp**

Appendix 1 - Photos - 122980

Pipeline Failure Investigation Report

Figure 5: **End of severed 37.1 foot section of pipeline**

Very often, ignition does occur. When it does, it is not unusual for home structures and ground damage to occur within a ¼ mile radius of the rupture. Often, in urban areas, secondary fires can spread the destruction even further.

Below is a link to a security video of a rupture that occurred in a petrochemical plant. Note that the initial release is a mechanical explosion, and a follow-on ignition occurs a short time after the mechanical explosion. It should be noted that even though petrochemical plants have emergency shutdown devices that close off the supply of fuel to a rupture via valve closures, the pent-up pressure is significant enough to cause a catastrophic mechanical explosion that can result in a secondary ignition deflagration or detonation.

RIGHT-CLICK AND OPEN THE HYPERLINK BELOW OR CLICK ON THE VIDEO ICON.
https://www.youtube.com/watch?v=ZW9sW_fJqOo

So why will a distribution pipeline leak but not rupture, and a transmission pipeline leak or rupture?

To understand this, we must first understand the term Specified Minimum Yield Strength (SMYS).

The Yield strength of a material is the stress level that will permanently deform it. Stress levels below the yield stress will cause the material to spring back to its original shape once the stress is removed (like a spring).

The SMYS is the pipe manufacturer's guarantee that the pipe produced has, at minimum, a given value of stress below which permanent yielding will not occur. For example, if a coupon were to be cut out of an X-65 pipe with a cross-section area of 1 square inch (a coupon ½" by 2"), and that coupon was to be stretched in tension with 60,000 pounds of force when the force is released, the coupon would return to its original shape.

This means that the pipe material remained in the elastic region of the stress/strain curve during the stretching. There may be parts of that pipe where 70,000 pounds of force would not permanently deform the material. Still, the pipe manufacturer is designing the pipe to have a "minimum" yield strength across the entire pipe, defined as having a yield stress level of at least 65,000 psi.

A Battelle Laboratories/Gas Research Institute study and an A.G.A. study have been used to know when leakage or rupture could occur.

An abridged paraphrased result of these studies is that pipes operating at or above 25% of SMYS may rupture due to mechanical impact, and pipes might rupture due to other defects, such as corrosion, when operating at or above 30% of SMYS. The level of 25% SMYS is considered to be the transition point where pipes may rupture due to pipe material damage/defect. For this reason, some transmission operators with uncertain confidence about their system integrity data have voluntarily chosen to operate their systems below 25% of SMYS.

These numbers are meant for pipelines at ambient temperature conditions. The numbers are very different if the pipe temperature is not ambient, i.e. a pipe or vessel experiencing a flame impingement will rupture-fail at much lower stress levels as high temperature weakens the pipe.

Also, a pipe material not designed for cold temperatures may fail in a brittle mode (rupture) at a much lower stress level (e.g., if LNG is injected into a carbon steel pipe, the carbon steel pipe becomes brittle below the Nil Ductility Temperature).

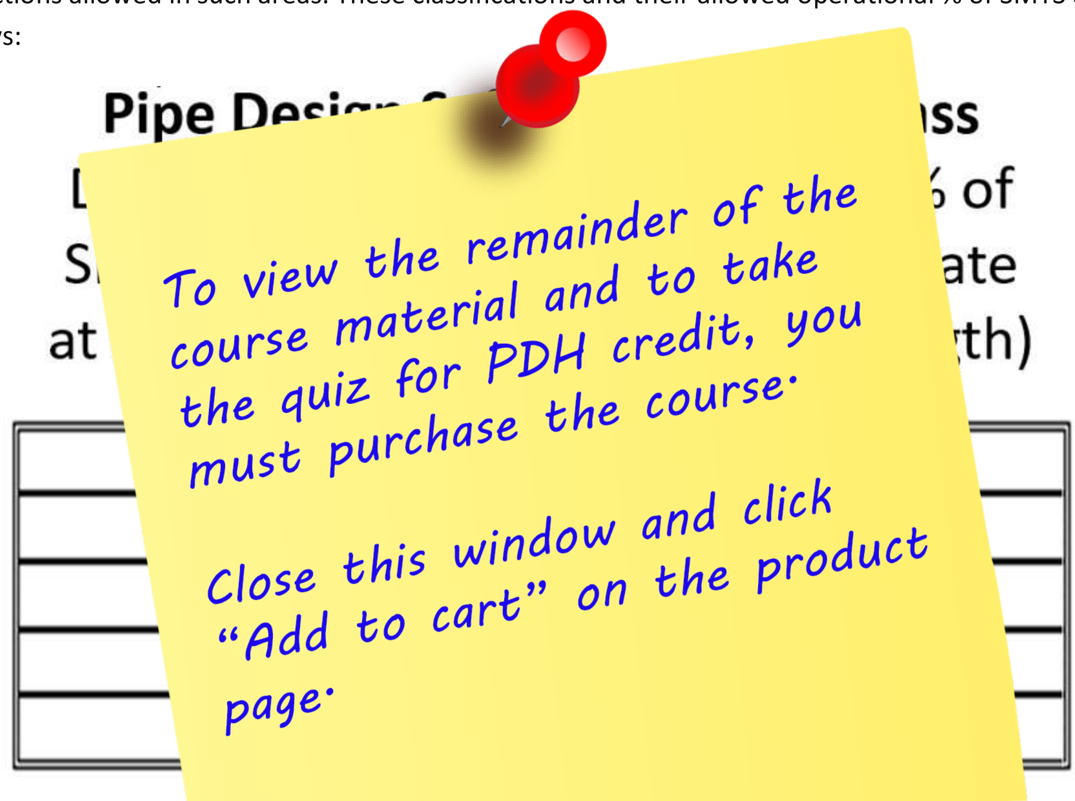
See the picture below of a brittle cookie that was dropped. If impacted at cryogenic temperature, the same would happen to non-cryogenic steel.

So, we still have not answered why a distribution pipeline will not rupture but a transmission pipeline may rupture. The answer lies in the definitions of distribution and transmission pipelines.

Under 49 CFR Part 192, a distribution pipeline operates under 20% of SMYS, and transmission pipelines operate at or above 20% of SMYS. A more complete definition of a transmission pipeline is as follows:

Transmission line means a pipeline, other than a gathering line, that: (1) Transports gas from a gathering line or storage facility to a distribution center, storage facility, or large volume customer that is not down-stream from a distribution center; (2) operates at a hoop stress of 20 percent or more of SMYS; or (3) transports gas within a storage field.

49CFR Part 192 also classifies areas based on population density and limits the % of SMYS and other restrictions allowed in such areas. These classifications and their allowed operational % of SMYS are as follows:



The calculation of the … S = (Pressure x Outside Diameter of Pipe)/ (2x Pipe Wall Thi… pipe with a 0.5" wall thickness operating at its MAOP of 1,170 psig would be operating at a stress of 28,080 psi. If the pipe were X-65 pipe, it would be operating at 43.2% of SMYS.

An approximation from my evaluation of PHMSA data, the quantities of U.S. transmission pipelines in each class area are abridged and paraphrased as follows:

- ~ 301,000+ miles in the U.S.
- ~ 78.6% is in a Class 1 area (offshore or 10 or fewer buildings intended for human occupancy in a 1-mile x 660' running section of pipeline
- ~10% is in a Class 2 area (11 to 45 buildings intended for human occupancy in a 1-mile x 660' running section of the pipeline)