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RESEARCH RESULTS

FRA OFFICE OF RESEARCH, DEVELOPMENT & TECHNOLOGY

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PERFORMANCE OF TANK CAR PRESSURE RELIEF DEVICES UNDER FIRE CONDITIONS

SUMMARY

The Federal Railroad Administration (FRA) conducted a series of fire tests on one-third scale models of a non-pressure tank car to evaluate the performance of Pressure Relief Devices (PRDs) under fire conditions. PRDs help to limit the pressure buildup in tank cars under fire conditions, thereby reducing the potential for a tank explosion.

Based on a review on operating and accident conditions, and PRD characteristics, the research team developed a test matrix, designed a suitable fire test setup, prepared test specimens, and executed the test effort.

The test series included:

- Between August and October 2018, an initial series of tests with water as lading were conducted at Underwriters Laboratories (UL) in Northbrook, IL, to confirm test and instrumentation setup and baseline PRD performance.
- In August 2019, a subsequent series of tests using ethanol, a flammable liquid, as lading were conducted at the Federal Institute for Materials Research and Testing (Bundesanstalt für Materialforschung und -prüfung [BAM]) in Germany (see Figure 1).

Figure 1. Test tank engulfed in fire

Preliminary results of the testing include:

- The test series were successful in exposing the PRDs to realistic fire conditions and evaluating their subsequent performance. The instrumentation functioned effectively, capturing key elements of interest to safety researchers including the mass of lading released, release and reclosing pressures, and extent of temperature stratification. In addition, the test setups allowed the researchers to observe and record PRD behavior under conditions of gaseous and liquid flow, and two-phase flow (i.e., a mix of gas and liquid), providing valuable data for future safety analysis, modeling, and validation.
- The PRDs largely performed as expected under fire conditions, releasing and reclosing effectively, while allowing multiple release events to be recorded.
- For the water tests, the release and reclosing pressures were largely in line with preset values.
- For the ethanol tests, the PRDs release near the preset value, then subsequent releases were at lower pressures, suggesting that exposure to burning ethanol was affecting the stiffness of the control springs. However, releasing at values lower than the preset values is generally considered safe. It was also clear that the releasing flammable material was contributing to the fire conditions being experienced.
- The temperature stratification observed on the lading surface was small for both tests. Additional review of data is ongoing.

BACKGROUND

Tank car derailments, especially those with crude oil and ethanol lading, have resulted in significant fires with resultant explosions, thermal tears, and fireballs. Fluid pressure buildup under fire conditions combined with loss of strength in the steel due to elevated temperatures can lead to catastrophic failure of tank shells. To protect first responders and the public under such conditions, it is critical to control the energy associated with hazardous materials releases. Certain rail tank cars carrying hazardous materials are required to survive a 100-minute, fully engulfing pool fire without catastrophic failure. In general, this requirement is met through using thermal protection and PRDs. The PRDs help limit the pressure buildup in the tank cars, thus reducing the potential for tank explosion. The expectation is that PRD will result in smaller quantities of hazardous material being released while avoiding the potential for catastrophic failure.

While the performance of PRDs under fire conditions is crucial to assuring the safety of hazardous material transportation, PRD performance under real fire conditions has not been tested or verified. The intent of this program was to evaluate PRD performance under those conditions.

OBJECTIVES

The objective of this test program was to investigate the performance of multiple PRD configurations when exposed to fire conditions. This was accomplished through:

- Subjecting one-third scale tanks with a full-size PRD to an engulfing pool fire
- Documenting PRD performance with respect to opening pressure, reclosing, and evacuating the tank
- Documenting tank and lading conditions through tank pressure, wall and lading temperatures, and expelled lading mass
- Determine the level of temperature stratification of the tank lading
- Understand the impact of PRD capacity and orientation, on PRD performance

The plan included initial tests with water lading to confirm test and instrumentation setup, as well as overall success of the test protocol. A final set of tests was conducted with a flammable lading, ethanol, shown in Figure 2).

Figure 2. Pre-test photo with steel shield and insulation for ethanol testing

METHODS

Based on a review of accident conditions, and PRD types/capacities that are nominally used in tank car service, two different PRD capacities and three different PRD orientations were selected for the test effort. As shown in Figure 3, the lower capacity PRD (10,000 standard cubic feet per minute [scfm]) was used at the top (0 degree) position, representing a condition wherein the car has derailed upright. Under this condition, one expects largely gaseous flow through this PRD, and the lower capacity PRD is appropriate.

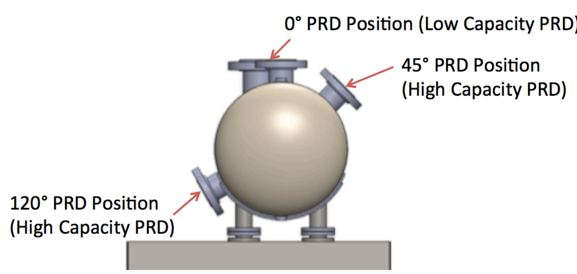

Figure 3. End view of the tank showing PRD orientations

The 45-degree position represents a condition of a partial rollover, wherein the PRD will initially vent liquid and transition through a two-phase flow to a gaseous release once the liquid level has reduced below the PRD line. Given the potential for liquid and two-phase flow, a high capacity PRD (32,000 scfm) was used at this location.

The 120-degree position represents a more complete rollover, with liquid flow being expected until the tank is near empty, and a high capacity PRD was tested in this orientation. All PRDs are rated for 75 psig, which is common in flammable liquid service. Key PRD parameters are summarized in Table 1.

Parameters	Value
Lading used in Testing	Water, Ethanol
Low Flow PRD	11,000 scfm
High Flow PRD	32,000 scfm
Liquid Level in tank	97-98%
Initial Discharge Pressure	Design 75psi
	Actual 70-79psi
Final Discharge Pressure	35-70psi
Tank Capacity	621 Gallons
Shell Thickness	3/4 inch
Shell Material	(ASTM) SA-516 Gr70

Table 1. Summary of PRD's and tank parameters

The test vessel was about a one-third scale model of a DOT-117 tank, but with a thicker shell for an additional factor of safety, and was intended to be used for multiple tests. It is worth repeating that the focus of the test is to analyze PRD performance, and not the tank performance. The test vessel is made of carbon steel with an outside diameter of 36 in., length of 156 in., and wall thickness of 0.75 in. The capacity is 621 gallons and the empty weight is 3,400 pounds.

The test vessel was designed to accommodate PRDs of varying capacities installed at any one of three different angular positions. It was also fitted with a manway for the purpose of instrumenting the tank interior.

For the water and ethanol tests, multiple levels of additional security including secondary and tertiary pressure relief mechanisms, fire shutoff options, and personnel distancing methods were adopted to ensure that these high-energy tests could be conducted safely.

The tanks and PRD's were instrumented for all tests. The tanks were internally instrumented with pressure transducers and thermocouples located in the liquid and vapor spaces. A float inside the tank was instrumented with thermocouples to measure the temperature stratification near the liquid surface. Externally, the tank's shell and PRD's were instrumented with thermocouples. Four directional flame thermometers were used to measure the fire temperatures. Load cells located under the tank provided measurement of tank and lading weight, from which the amount of lading expelled through the PRD, could be deduced.

The test tanks were filled to about 97 percent water capacity for both series of tests. An array of fuel jet nozzles were used in both series of tests to create the engulfing fire, with heptane fuel used for the water tests, and propane fuel used for the ethanol tests.

RESULTS

In each test, the engulfing fire heated and pressurized the lading, leading to PRD activation. For all the tests, the initial release from the PRD happened near the 75-psi set pressure. Upon opening, the PRD typically expelled a portion of the lading, reducing the pressure and reclosing. The fire continued to burn and the PRD release cycle was repeated.

In the case of the water tests, subsequent releases also occurred near 75 psi. In the ethanol tests, subsequent releases occurred at lower pressures, as seen in Figure 4. This is likely due to the flammable lading being lit as it exits the PRD, and the resulting heat input softening the PRD springs. Generally, the reduced release pressures are not considered a safety risk.

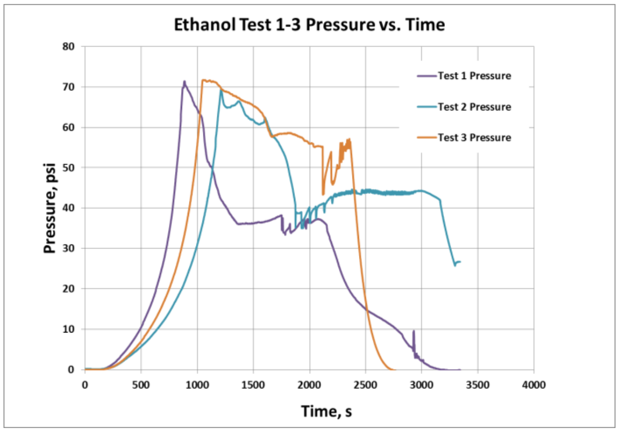

Figure 4. Measured pressure vs. time PRD release, Tests 1–3

It was seen from both the water and ethanol tests that the 0-degree PRD position, largely released gaseous lading, retained most of the lading inside the tank. In contrast, the 120-degree test mostly released liquid, and therefore expelled most of the liquid, retaining little. The PRD at the 45-degree position fell in the middle.

CONCLUSIONS

The primary conclusion of the effort was that the PRDs largely performed as expected under fire conditions, releasing and reclosing effectively, allowing multiple release events to be recorded. Test conditions were effective in providing a realistic fire exposure to the PRD and the desired performance data was successfully collected. The layer of temperature stratification appeared to be fairly thin and without significantly higher temperatures than the rest of the liquid lading.

FUTURE ACTION

Given the significant quantities of data collected, a detailed review of the data is underway and will be reported in the future. The need for additional testing is also being considered.

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