Hydrogen Vehicle Fuel Systems – Localized Fire Protection Considerations

Milestone 3

LOCALIZED FIRE TEST PROCEDURE

Submitted To:

Transport Canada
Road Safety

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1.0 INTRODUCTION

For liquid-fuelled vehicles, whether a fire occurs at one end of the fuel tank, or engulfs the fuel tank has never been a direct safety issue. The fuel tank will basically fail in the same manner regardless of the location or intensity of the fire. However, the use of pressure vessels to carry compressed gas as a vehicle fuel, introduces a new safety issue involving exposure to fires.

The experience involving fuel systems used on-board compressed natural gas vehicles provides an invaluable insight into the performance requirements for compressed hydrogen fuel systems. For compressed natural gas (CNG) vehicles, the leading single cause of fuel tank ruptures is fire. In CNG vehicle fire incidents where it was possible to document the events leading up to a rupture, it was determined that the fire was focused on a portion of the tank remote from the location of the thermally-activated pressure relief device (TPRD).

To operate under all conditions of fill within a fuel tank, TPRDs must be thermally-activated designs. Pressure-activated TPRD designs will usually only operate when the tank is at its working pressure when exposed to fire conditions. Similarly, there are combination TPRD designs that require exposure to both elevated temperatures and elevated pressures to function. CNG fuel tanks should only be protected using thermally-activated TPRD designs.

Typically the TPRDs are located on the valve end of the tank. Even using a TPRD design that is considered very sensitive to heat, bonfire tests of individual tanks have shown that the TPRD must be within the area of flame impingement to activate. Recent documented CNG fuel tank failures involving localized fires are as follows:

- NK Type 2 cylinder on transit bus in South Korea – December 2007
  - VTI glass bulb TPRD
- Lincoln Type 4 cylinder on Honda Civic in Seattle – March 2007
  - GFI in-valve fusible trigger TPRD
- Dynetek Type 3 cylinder on transit bus in Saarbrucken – May 2003
  - Emer fusible metal plug TPRD
- Pressed Steel Tank Type 2 cylinder on Ford Crown Victoria in Wisconsin - September 2002
  - Superior fusible link in-valve TPRD

The above failures involved various cylinder types, various vehicle types, and different pressure relief device designs.

Fire tests involving vehicles have shown that the location of TPRDs on the tank is not important if the tank is protected from direct flame impingement. For example, in tests performed at Powertech for the Japan Automobile Research Institute, tanks installed within an enclosed trunk compartment were “baked” by an external fire. As a result, the TPRDs (VTI glass bulb design) had time to sense the heat and activate before either pressure rise occurred in the tank, or the composite reinforcement could deteriorate.

While the automotive industry has performed some fire testing involving liquid-fuelled vehicles, there is very little data available concerning the performance of compressed gas fuel systems in vehicle fires. For CNG vehicles, it is known that fire tests have been performed by both Ford and Honda, for the purpose of recreating the cause of the tank failures that have occurred in their vehicles. As a result of these tests, both Ford and Honda recalled their vehicles to install protective barriers on the rear seat, to prevent fires in the passenger compartments from burning through to the CNG storage tanks and allowing direct flame impingement in localized areas.

Data from the Ford and Honda fire tests on CNG vehicles remains unpublished. For hydrogen vehicles, the automotive industry remains generally unaware of the possibility of localized fires causing tank failure. No automotive manufacturer is known to have performed fire tests involving vehicle bodies with hydrogen fuel systems. However, one automotive manufacturer has performed “Tire Fire” tests on a vehicle. The unpublished results confirm that localized fire conditions could exist on storage tanks.

2.0 APPROACH

Based on industry fire tests of gasoline-fuelled vehicles (see the report on “Milestone 2 – Vehicle Fire Condition”), and unpublished OEM fire test data, a localized fire test condition has been identified by one OEM [see Figure 1].

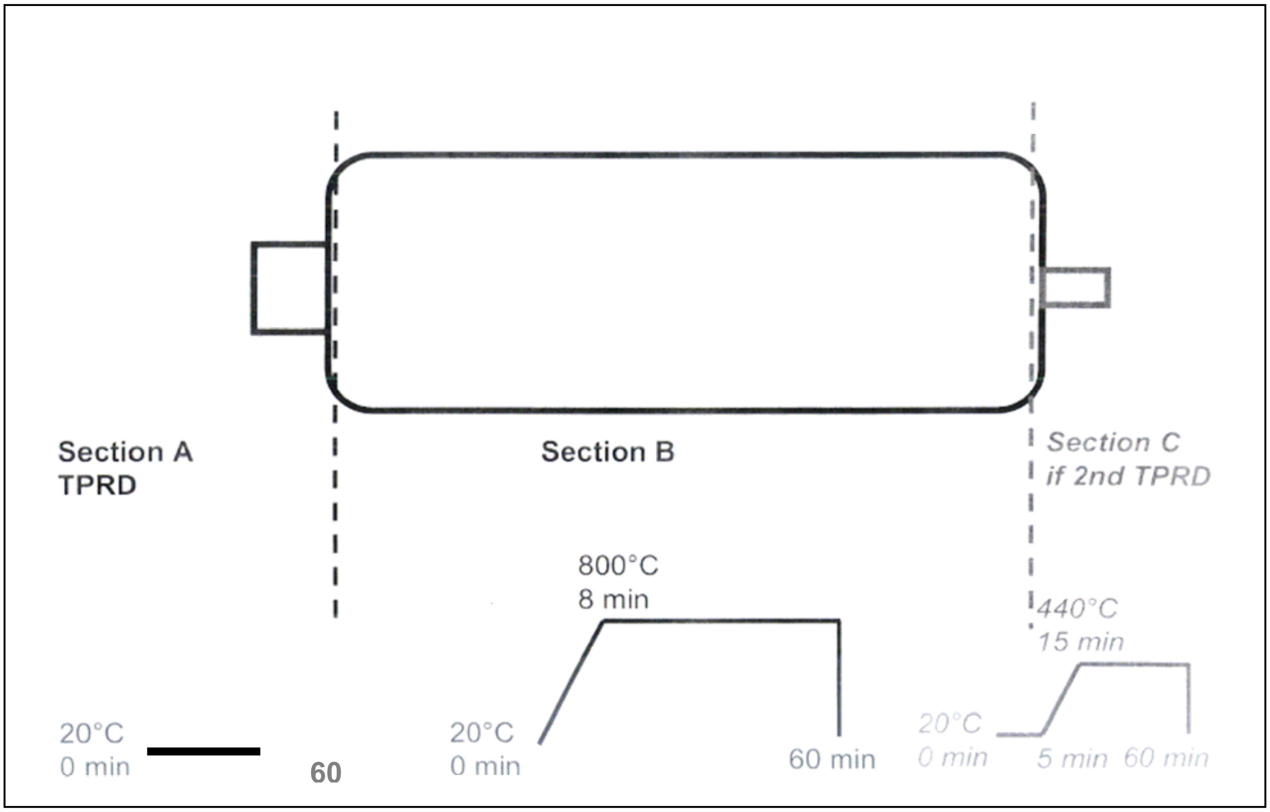

Figure 1 – Temperature-time profiles for a localized fire test condition

The temperature profiles indicate that under extreme conditions, maximum temperatures of up to 800^0C could be achieved in less than 8 minutes on some part of the tank. (Note that 800^0C observed in vehicle fires is much hotter than the 590^0C to 650^0C specified in bonfire tests). Temperatures of around 440^0C would be achieved elsewhere on the tank over a 15 minute time period, while another region of the tank would not experience any significant temperature increase.

Depending on the design of the vehicle fuel system, and the source of the fire, the 3 different temperature regimes could occur in a sequence different from that described in Figure 1. For example, in the event of a tire fire involving a tank mounted cross-wise in the vehicle, the tank

would achieve maximum temperature at the end closest to the tire fire, followed by medium temperatures on the tank sidewall, and no temperature on the end opposite the tire fire.
Since most tank designs employ TPRDs attached to valves located on the ends, then the worst-case fire test involve the highest fire temperature in the sidewall, the medium temperature at one end, and the low temperature at the opposite end. To compound the severity of the test, if only one TPRD is used to protect the tank, then that TPRD should be located in the ambient temperature end of the test. This is therefore the test condition illustrated in Figure 1.

In addition to quickly generating very high temperatures, the localized fire test method must be capable of generating reproducible results using very close control of the required temperature profile on different areas of the tank. The test unit must be relatively low cost, as destruction during testing will be a possibility.

3.0 WORK PROGRAM

A number of preliminary tests were performed to determine how to achieve the 800^{0}C test temperature for the tank sidewall. Direct flame impingement is not an option, since flame temperatures vary radically during a test, making a reproducible test condition impossible. Experiments were therefore conducted using hot flue gases from a propane burner, but it was found that the propane exhaust did not achieve (or sustain) the required temperature.

To provide a uniform, consistent temperature on the tank surface, the approach of placing the tank on a heated metal surface was tried. A steel cradle was manufactured from a half-pipe, of the same diameter of the tank being tested. The underside of the steel cradle was then heated by an open flame. Temperatures were then measured on the inside surface of the cradle (the surface in contact with the composite tank).

Initial tests determined that heating using propane, and oxy-acetylene, was unable to achieve the temperature within the specified timeframe. It was then determined that a combined flame of oxygen and propane could easily achieve and maintain the required test temperature. The prototype test set-up is illustrated in Figures 2 and 3.

Figure 2 – Cradle supporting tank.

Figure 3 – Torches heating underside of steel cradle.

To prevent wind effects, it was found necessary to install a secondary shield around the cradle. In addition to preventing the torches from being affected by the wind, the shield allows exhaust gases to flow unaffected in the annular space around the half-pipe cradle, providing a consistent heat input. The shielding is illustrated in Figures 4 and 5.

Since the ends of the tank require much lower temperatures that can be generated in a relatively long period of time, then exhaust gases can be used for this purpose. Accordingly, a torch fuelled by propane is positioned at the valve end of the tank. Figure 2 provides a view of the torch positioned beneath the valve end.

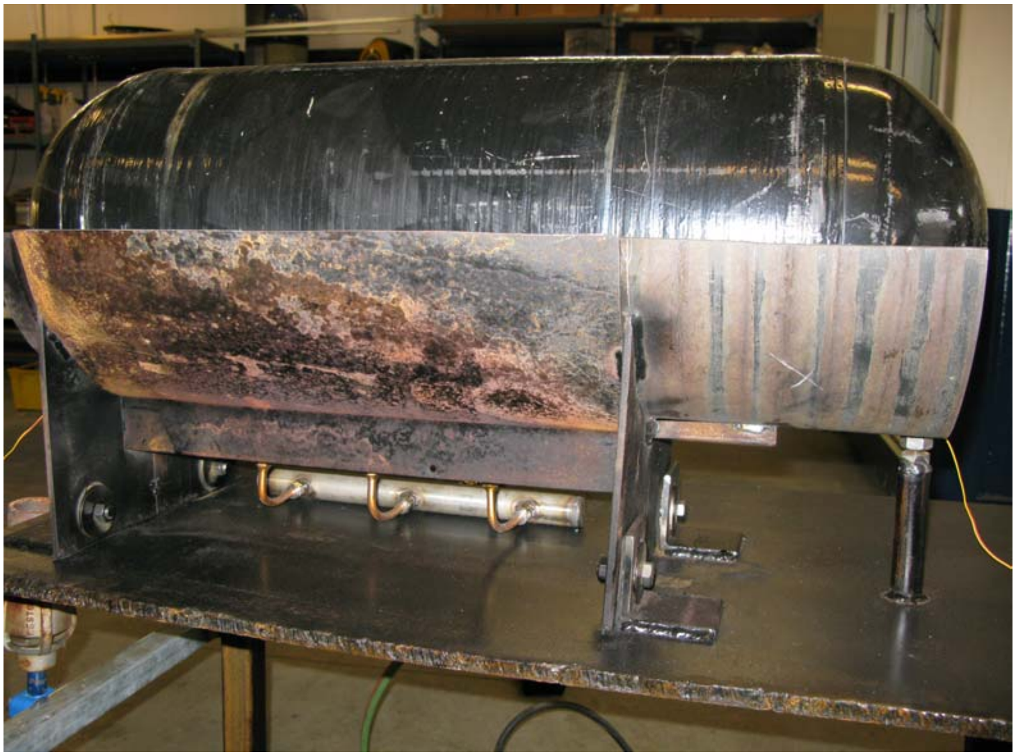

Figure 4 – Shielding on one side (note torches are not visible).

Figure 5 – Note annular space between cradle and shielding for exhaust gases.

4.0 PROPOSED TEST METHOD

The test method can be any approach that meets the time-temperature profiles described in Figure 1. The method developed at Powertech involves the following procedure:

1. A steel cradle the length of the tank sidewall, and of the same radius of the tank, is constructed. The cradle encompasses 50% of the tank circumference. The steel thickness shall be sufficient to resist warping or deformation when exposed to an 800°C temperature for sustained periods of time.

2. Thermocouples are attached to the inside surface of the cradle at 3 locations (at both ends and at centre location).

3. The base of the steel cradle is heated uniformly using any heat source that will gradually increase temperature and reach and maintain 800°C (+/- 5°C) at one of the 3 thermocouple locations 8 minutes after the start of the test. Care shall be taken to prevent heat from the heat source from affecting the ends of the tank.

4. The end of the tank exposed to ambient air conditions shall have a thermocouple attached to the tank or valve surface, as appropriate. Metal shielding of the thermocouple is not required for testing in ambient air conditions.

5. On the opposite end of the tank, a thermocouple shall be attached to the tank or valve surface, as appropriate. The thermocouple shall be protected from direct flame impingement by a steel shield. The opposite end of the tank shall then be heated to a temperature of 440°C (+/- 5°C). This heating shall commence 5 minutes after commencement of sidewall heating. The 440°C temperature shall be reached after 10 minutes, or a total 15 minutes after the test commenced on the sidewall.

6. The opposite end of the tank is heated using any heat source that can provide a temperature of 440°C on the thermocouple. The metal shielding shall either conform to the profile of the end dome, or encircle the valve, as appropriate.