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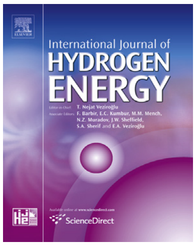

The possibility of an accidental scenario for marine transportation of fuel cell vehicle

Hydrogen releases from TPRD by radiant heat from lower deck

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ABSTRACT

In case fires break out on the lower deck of a car carrier ship or a ferry, the fuel cell vehicles (FCVs) parked on the upper deck may be exposed to radiant heat from the lower deck. Assuming that the thermal pressure relief device (TPRD) of an FCV hydrogen cylinder is activated by the radiant heat without the presence of flames, hydrogen gas will be released by TPRD to form combustible air-fuel mixtures in the vicinity. To investigate the possibility of this accident scenario, the present study investigated the relationship between radiant heat and TPRD activation time and evaluated the possibility of radiant heat causing hydrogen releases by TPRD activation under the condition of deck temperature reaching the spontaneous ignition level of the tires and other automotive parts. It was found: a) the tires as well as polypropylene and other plastic parts underwent spontaneous ignition before TPRD was activated by radiant heat and b) when finally TPRD was activated, the hydrogen releases were rapidly burned by the flames of the tires and plastic parts on fire. Consequently it was concluded that the explosion of air-fuel mixtures assumed in the accident scenario does not occur in the real world.

Introduction

Compressed hydrogen cylinders installed on the FCVs are each equipped with a TPRD—the device designed, at the detection of heat, to release hydrogen gas from the cylinder for its protection from bursting; the hydrogen releases are immediately burned by the flames existing around TPRD. This theoretical process gives an accident scenario shown in Fig. 1 for FCVs transported by a pure car carrier or a ferry boat having decks of steel structure. In this scenario, a fire accident breaks out in a lower deck, and heats up the FCVs parked on the upper deck.

Since FCVs are driven by human drivers onto a car carrier or a ferry, their fuel cylinders contain a certain amount of hydrogen when parked aboard. With the cylinder installed on the underbody portion of the vehicle, the TPRD of the cylinder may be activated by radiant heat in case of a fire accident on

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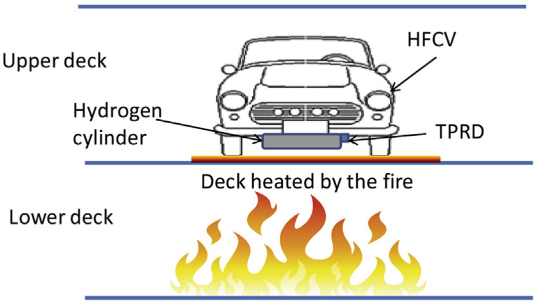

Fig. 1 – An accident sinario of hydrogen concentrations fire from lower deck.

the lower deck, resulting in the release of hydrogen from the cylinder.

Accordingly, the following accident scenario was drawn: If, at the time of TPRD activation by radiant heat, no fire is present in the deck where the FCVs are parked, the hydrogen releases will form combustible air-fuel mixtures which may cause explosion; however, if the exterior parts of the FCVs have already been self-ignited and aflame by the radiant heat from lower deck at the time of TPRD activation, the hydrogen releases will be burned immediately by the existing flames, so that explosion will not occur.

The present study was conducted to investigate the relationship between radiant heat and TPRD activation time and the possibility of the accident scenario with or without the spontaneous ignition of FCV exterior parts.

Performance test for TPRD by radiant heat

Test method

Many researchers have investigated the techniques of predicting the activation time of heat sensors for automatic sprinklers [1–3]. Nevertheless, while most of these studies involved heat detectors placed in thermal air currents, there were virtually no studies aimed to predict the heat sensor's activation time under radiant heat. The present study was therefore designed to experimentally determine relations between radiant heat and TPRD activation time. Table 1 shows the specifications of the sample TPRDs; their appearances are shown in Fig. 2.

All the four sample TPRDs are types used in automotive compressed hydrogen cylinders. Types A, B and C each incorporate in its stainless steel body a fuse metal that melts at its nominal activating temperature. Type D incorporates a glass bulb which contains a fluid and is ruptured at its nominal activating temperature by the thermal expansion of the fluid. A large portion of the glass bulb is embedded in TPRD's stainless steel body to protect from external impacts. Fig. 3 diagrams the test method, and Fig. 4 shows a photographic view of the test setup.

Table 1 – Specification of TPRD's.

TPRD name	Normal working pressure [MPa]	Type	Nominal activated temperature
#A	35 MPa	Fuse metal	104 °C
#B	35 MPa	Fuse metal	110 °C
#C	70 MPa	Fuse metal	110 °C
#D	35 MPa	Glass bulb	110 °C

The TPRD was pressurized by helium gas to more than 2 MPa. Radiant heat was applied to the TPRD from a cone-shaped heater, while the TPRD was thermally insulated from the installation stand by an intervening fiberglass plate. Four intensities of radiant heat was applied: 15, 30, 50 and 75 kW/m^2. The maximum heating duration was set at 1 h, and radiant heat intensity was calibrated by a heat flux meter before each heat application. The time (t_g) required from heat application to TPRD activation was measured, with the TPRD activation judged by reading the helium gas pressure. Additionally, the surface temperature of the TPRD body was measured by a K-type thermocouple (sheath diameter 0.5 mm) attached to the body surface by a heat-resistant aluminium foil tape.

Results

Fig. 5 shows the surface (body) temperature of TPRD at the time of its activation.

The TPRD body temperature at its activation proved to be higher than the nominal activation temperature among the fuse metal type TPRDs, but was lower in the glass bulb type TPRD. This was accounted for that in the fuse metal type TPRDs the radiant heat was transmitted from the TPRD surface to the fuse metal embedded inside the body through heat conduction process, while in the glass bulb type TPRD the radiant heat reached the glass bulb directly from an aperture in the TPRD body.

Fig. 6 shows the relationship between the applied radiant flux q_{ac} and TPRD activation time t_{ac}. In the case of a 15 kW/m^2 radiant heat, however, none of the four types of TPRDs was activated during the first 1 h.

The three fuse metal type TPRDs (types A, B and C) proved to have similar curve lines. The comparison of activation time indicated that the glass bulb type TPRD responded with slower activation than did the fuse metal type TPRDs when radiant flux was small, but the activation of the glass bulb type TPRD was faster than the other TPRDs when radiant flux was larger.

Fig. 7 shows the relationship between radiant flux and the reciprocal of activation time, where the average activation time of the three fuse metal type TPRDs is also compared.

As the figure above shows, there was a linear relationship between the reciprocal of activation time and radiant flux; furthermore, the performances of the three fuse metal type TPRDs were plotted virtually on the same straight line. The intersection point of this line and the horizontal axis indicated the maximum radiant heat at which TPRD remained inactive, or the critical radiation q_c. Then, Equation-(1) below holds, where t_{ac} is TPRD activation time, q_{ac} is radiant heat applied, and a is the reciprocal of the line inclination in Fig. 6.

$$\frac{1}{t_{ac}} = \left(\frac{1}{a}\right)\cdot(q_{ac} - q_c) \tag{1}$$

That is, a can be expressed by Equation-(2) below.

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