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## Performance test and analysis of the developed emergency release system for liquefied hydrogen installed in loading systems

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# Performance test and analysis of the developed emergency release system for liquefied hydrogen installed in loading systems

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**Abstract.** As a form of future energy, hydrogen is attractive because it produces no carbon dioxide when it is combusted. To transport and store hydrogen, liquefying hydrogen is effective because of its compactness and lighter weight than other types of transportation technology. The emergency release system (ERS) is one of the most important types of equipment in the loading and unloading operation between terminal and vessel. We conducted analysis of the pressure drop of developed ERS for liquefied hydrogen to assess the performance on pressure drop. We also calculated and measured the effect of the diffusion of liquefied hydrogen during the disconnection operation of ERS.

## 1. Background

Global warming is a serious problem in the world. The Paris Agreement was adopted by consensus by all of the 196 parties to reduce greenhouse gas emissions. The members promised to reduce their carbon output as soon as possible and to do their best to keep global warming to well below 2 degrees C. In Japan, On December 26, 2017, the Ministerial Council on Renewable Energy, Hydrogen and Related Issues decided on a “Basic Hydrogen Strategy” to achieve a world-leading hydrogen-utilizing society. It is described that a liquefied hydrogen supply chain is to be demonstrated by world-first liquefied hydrogen carrier in 2020 and commercialized around 2030.

To realize a liquefied supply chain, a loading arm is necessary to transfer a liquefied hydrogen between the cargo carrier and terminal. The loading arm systems incorporates ERS to disconnect smoothly and safely so that the carrier separates from the jetty soon in the case of emergencies such as earthquakes or tsunamis.

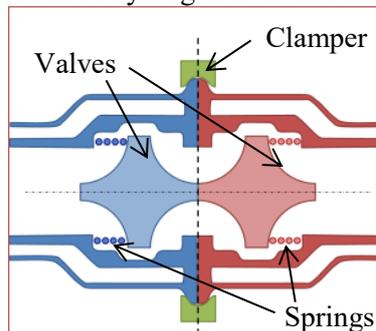
Figure 1 shows a conceptual drawing of the developed ERS for liquefied hydrogen. The check type ERS mainly consists of two valve bodies, two springs, and a clamper. When connected by a clamper, each side of the valve and spring push one another and form a space between the casing and valve



body where liquefied hydrogen flows. The disconnecting operation starts from the opening of the clamper. Soon after that, the two valves are separated, and the springs on each side push each valve to shut the flow path. The main feature of the check type is that it doesn't have a shaft to operate the valves. This means that heat ingress from the shaft can be avoided. This merit is important in treating liquefied hydrogen, which evaporates much more easily than LNG.

The check type has the demerit of a high pressure drop, because of its narrow flow path. It affects the spec of the transfer pump and a diameter of the piping. Therefore, we calculated flow distribution using Computational Fluid Dynamics, CFD.

Another concern is the effect of diffusion of liquefied hydrogen during the disconnection process. Liquefied hydrogen located between two valves can be dispersed to the atmosphere. Therefore, we measured and calculated the concentration of hydrogen after disconnection.



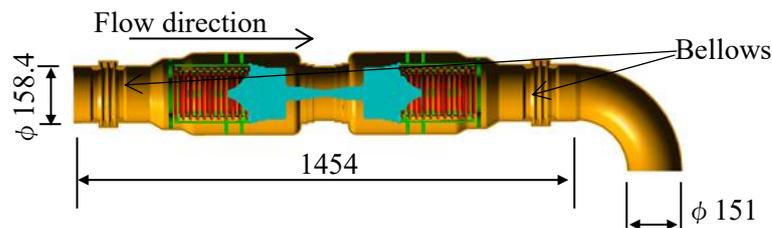
**Figure 1.** Outline structure of check type ERS.

## 2. Analysis on pressure drop by CFD

### 2.1. Analysis model and conditions

Figure 2 shows the calculation model. The main components that affect pressure drop are modelled, such as the valves, springs, and guide pipes. We also modelled bellows at each side to absorb thermal displacement during the cool down process. This will also affect pressure drop in some degree.

There are twenty million meshes; all meshes are formed by hexa mesh. We used CFD software, FLUENT (version 17.2), and analyzed flow rate distribution at the static state. Outlet pressure is defined as atmospheric pressure because it doesn't affect the value of pressure difference on ERS. The main analysis conditions are shown in Table 1. Velocity inlet is set based on supposed operation.



**Figure 2.** Calculation model of the check type ERS.

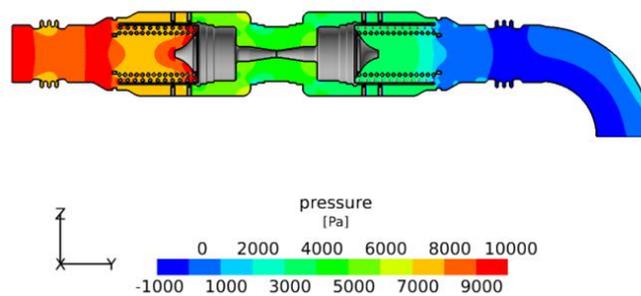
**Table 1.** Analysis conditions.

Application	FLUENT (version 17.2)
State	Steady state
Adopted turbulence flow model	Realizable $k-\varepsilon$ model
Calculation scheme	SIMPLE algorithm
Inlet flow cord and flow velocity	Velocity inlet, 5.64 (m/s)
Outlet flow cord, pressure at outlet	Pressure outlet, 0 (PaG)

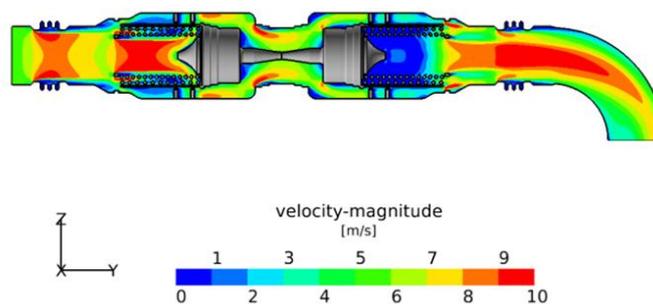
## 2.2. Calculation results

Figure 3 shows the calculation results of pressure distribution. Figure 4 shows the distribution of flow rate. We recorded a total ERS pressure drop of  $9.89\text{E}+3$  Pa. Considering the total pressure drop of the piping between the terminal and vessel, the value doesn't have a serious affect. However, we must be careful when designing the piping and selecting the pump.

To discuss how to reduce the pressure drop, we checked the flow rate distribution. In Figures 3 and 4, a large pressure drop occurs upstream from the first valve body. A high flow rate is massed at the centre of the valve body. This means the springs and guide pipe are preventing uniform flow in the radius direction. Therefore, suitable selection of a spring to secure the flow path is important. We can also see a large pressure drop area at the downstream edge of the second spring. This means that the parts to fix the spring make the diameter where fluid passes narrow. It may be effective to provide space in the above parts.



**Figure 3.** Distribution of calculated pressure in the ERS.



**Figure 4.** Distribution of flow velocity in the ERS.

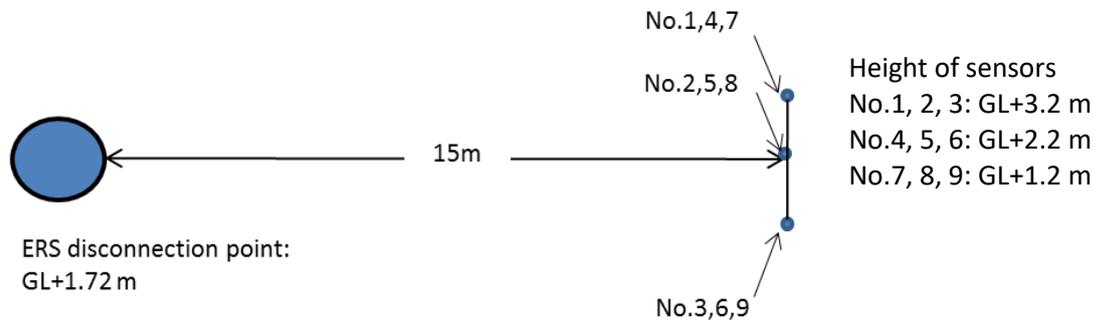
## 3. Hydrogen concentration after disconnection

### 3.1. Measurement of hydrogen concentration in the atmosphere

This test was conducted at the JAXA (Japan Aerospace Exploration Agency) rocket test facility in Noshiro city in Japan. We installed the prototype of the developed ERS as shown in the previous figure vertically, purged the air inside the prototype using helium, and supplied liquefied hydrogen from the storage tank. Liquefied hydrogen was supplied from the pipes connected at the upper and lower positions. Boil-off gas is sent to the vent stack installed at the test facility via the piping. Disconnection is carried out by opening the clamber.

Figure 5 shows the layout of the sensors for hydrogen concentration. We assembled the tower using pipes and installed sensors in each part of the tower indicated in figure 5. The distance from the prototype to the tower is 15 m considering the measured value of concentration indicated within the range of the sensors, from 0 to 40000 ppm. The adopted sensors, FIS-FH2-HY11, were contact

burning-type and produced by FIS corporation. The three axis ultra-sonic vane anemometer, Gill Wind Master, resolution limitation 0.001m/s and 0.1 degrees, was installed near the prototype.



**Figure 5.** Location of installed concentration sensors.

### 3.2. Numerical analysis of hydrogen diffusion

3.2.1. *Concept of the software "Phast"*. We calculated hydrogen diffusion behaviour utilizing Phast software developed by the Det Norske Veritas group. Phast is used by more than 800 global organizations to analyse flammable, explosive, and toxic hazards and has been upgraded over 30 years. It has been validated through comparison with experimental data of hydrogen gas diffusion [1], [2].

Atmospheric diffusion model included in Phast assumes that a material is basically dispersed from one point, and its plume diffuses under a steady wind condition. Gas concentration distribution is calculated based on Pasquill's equation modelled concentration distribution as Gaussian distribution, which is shown as equation (1):

$$C = \frac{Q}{\pi u \sigma_y \sigma_z} \exp -0.5 \left( \frac{y^2}{\sigma_y^2} + \frac{z^2}{\sigma_z^2} \right), \quad (1)$$

where  $C$  is the gas concentration at any  $x$  point [volume fraction],  $Q$  is the flow rate of dispersed fluid [ $\text{m}^3/\text{s}$ ],  $u$  is the wind speed along the  $x$  axis [ $\text{m}/\text{s}$ ], and  $\sigma_y$ ,  $\sigma_z$  [m] are the standard deviation for gas concentration in the  $y$  and  $z$  axis directions, respectively.

Concentration distribution along the  $y$  axis at any  $x$  point,  $f(y)$ , is assumed to be Gaussian distribution shown as equation (2). Distribution along the  $z$  axis,  $f(z)$ , can be expressed as well.

$$f(y) = \exp \left( -\frac{y^2}{2\sigma_y^2} \right). \quad (2)$$

The Phast model expands beyond Pasquill's model in the following points:

- The model of dispersion of the plume includes movement and vaporization of liquid drops of dispersed liquefied gas.
- Heat exchange between the atmosphere and plume consider changes in temperature and phase.
- The atmospheric stability proposed by Pasquill [3] and the density of the plume also affect the values of  $\sigma_y$  and  $\sigma_z$ .

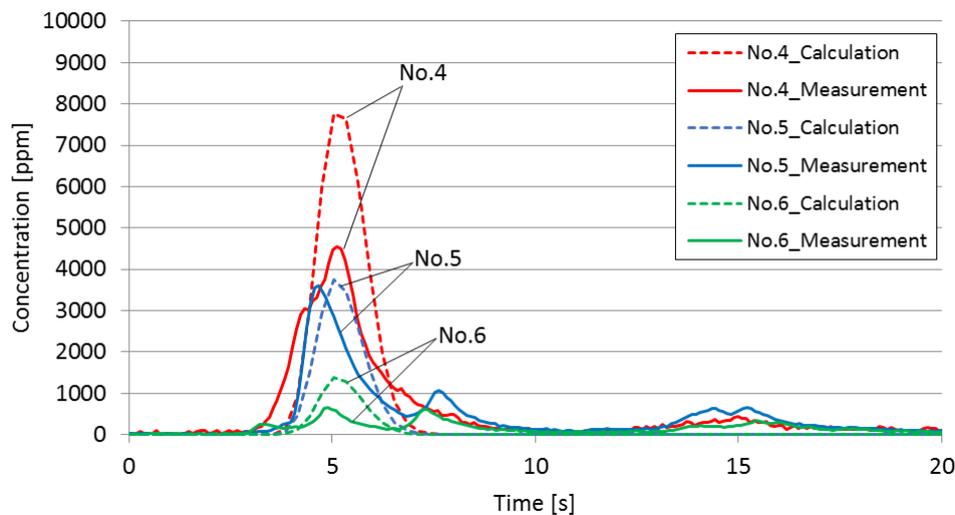
3.2.2. *Analysis condition*. Table 2 shows the analysis condition in this study. This is determined based as much on the experimental condition as possible. The adopted Pasquill stability class was D, based on the stability class table [3]. Pressure and wind speed was the measured average value in the test.

Table 2. Calculation condition

Material	Hydrogen
Volume and pressure	0.005 ( $\text{m}^3$ ), 0.19 (barG)
Process conditions	Saturated Liquid
Scenario type	Catastrophic Rupture
Wind Speed and Pasquill Stability	4.14 (m/s), D
Relative Humidity and temperature	0.935, 30 (degC)

### 3.3. Comparison experimental data with numerical analysis

Figure 6 shows the comparison measured data of sensors No. 4, 5, and 6 with calculation results at corresponding places. Measured data is corrected by the measured hydrogen concentration before the disconnection. All the calculation results overestimated the peak value of concentration, while accurately estimating the time of peak concentration. Overall, experimental results showed broader shaped lines than the calculation results. This is thought to be mainly because a degree of liquefied hydrogen stays on the surface of a valve of the ERS lower part for a few seconds, because the valve was at the temperature of the liquefied hydrogen just before disconnection. Additionally, a time change of wind speed and direction may be the reason for broad concentration lines.



**Figure 6.** Hydrogen concentration measured by sensor No.4.

## 4. Summary

To confirm the performance of the world's first emergency release system for liquefied hydrogen and to improve performance in the future, we first calculated the distribution of pressure drop and flow rate in the prototype using CFD. We found what parts seriously affect pressure drop and the information will be effective in improving ERS in the future. Secondly, we simulated and measured the concentration of diffused hydrogen after disconnecting the prototype. This indicated that the simulation is able to predict the distribution and time dependency of hydrogen concentration very well.

## Acknowledgments

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