Simulation of liquid level, temperature and pressure inside a 2000 liter liquid hydrogen tank during a truck transportation

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OUTLINES

1. INTRODUCTION
2. GOVERNING EQUATIONS
3. ANALYTICAL MODEL
4. TERMAL ANALYSIS
5. OSCILLATION AND TERMAL ANALYSES
6. SAMMARY

1. INTRODUCTION

Sustainable/renewable energy such as solar energy, wind energy and tidal energy is greatly attractive as an alternative energy source.

Using electrolysis technique, sustainable energy can be changed to hydrogen, which is an ultimate energy source because of chemical reaction with only water.

Liquid Hydrogen (20.3 K, high density)

Production of H_2

Transport of H_2

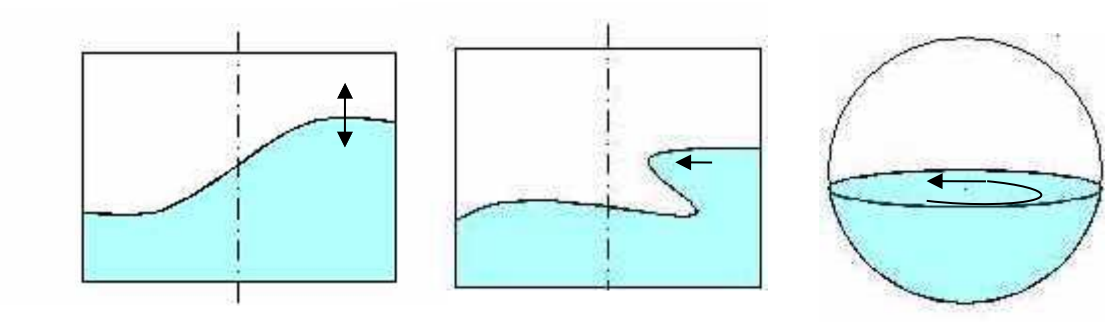
Use of H_2

Background

Liquid hydrogen (LH_2) is expected to be the ultimate energy medium for the worldwide storage and transport of large amounts of H_2.

To establish LH_2 worldwide storage and land/marine transport, it is important to develop LH_2 tanks/carriers.

The complex sloshing conditions inside an LH_2 tank during transportation have been estimated:



LH_2/LNG:

Density; ca. 1/6

Viscosity; ca. 1/8

Objectives

Synchronous measurements of LH_2 level, temperature and pressure inside a 2000 liter tank were carried out during a truck transportation:

an LH_2 level exceeding 1200 mm

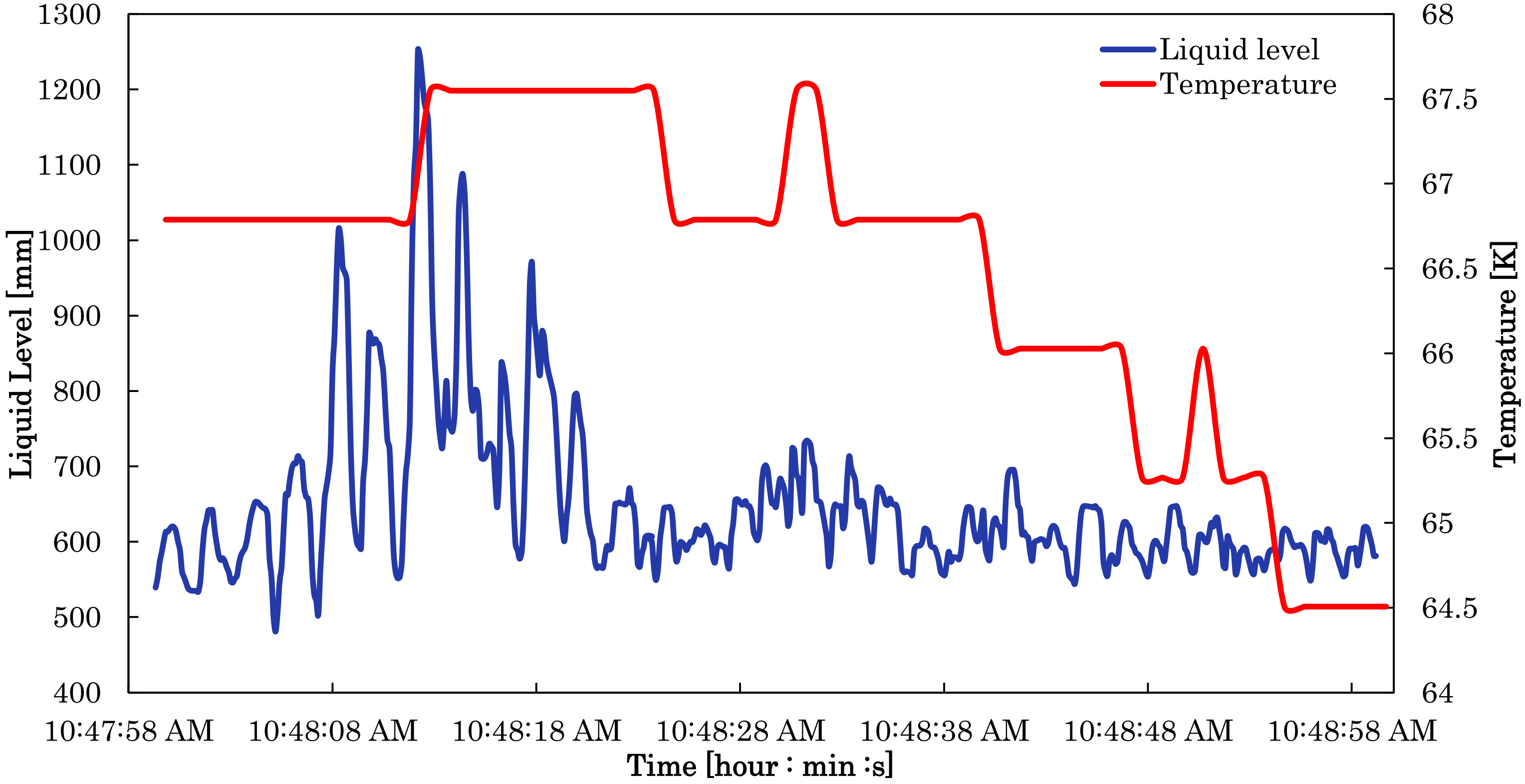
average period of oscillation of 2 s

decreasing temperature and pressure after truck started

Objectives of this work is to make a simulation model of sloshing of LH_2 inside a 2000 liter tank during a truck transportation using a multipurpose software ANSYS CFX.

Background

Truck transportation test of 2000 L LH_2 tank*



Average period of oscillation: 2.0 s

Max liquid level: 1252 mm

Temperature: 67.5 K → 64.5 K

***Takeda *et al.* : Proc. ICEC24-ICMC2012**

OUTLINES

2. GOVERNING EQUATIONS

i) Equation of continuity

$$\frac{\partial}{\partial t}(r_\alpha \rho_\alpha) + \nabla \cdot (r_\alpha \rho_\alpha \vec{U}_\alpha) = 0 \qquad \textbf{(1)}$$

ii) Equation of motion

$$r_\alpha \rho_\alpha \left[\frac{\partial \vec{U}_\alpha}{dt} + (\vec{U}_\alpha \cdot grad)\vec{U}_\alpha \right] = -grad(r_\alpha p_\alpha) + r_\alpha \mu_\alpha \Delta \vec{U}_\alpha + \vec{f}_\alpha \qquad \textbf{(2)}$$

iii) Buoyancy

$$F_\alpha = (\rho_\alpha - \rho_{ref})g \qquad \textbf{(3)}$$

2. GOVERNING EQUATIONS

iv) Volume fraction

$$r_\alpha = \frac{V_\alpha}{V} \quad (4)$$

v) Equation of state (Rediich Kwong model)

$$p_\alpha = \frac{RT_\alpha}{v_\alpha - b} - \frac{a(T_\alpha)}{v_\alpha(v_\alpha + b)} \left(a = a_0 \left(\frac{T_\alpha}{T_{\alpha c}} \right)^{-0.5}, \quad a_0 = \frac{0.42747 R^2 T_{\alpha c}^2}{p_{\alpha c}}, \quad b = \frac{0.08664 R T_{\alpha c}}{p_{\alpha c}} \right) \quad (5)$$

vi) Equation of specific heat at constant pressure

$$C_{\alpha,p}^0 = R_\alpha \left(a_{\alpha,1} + a_{\alpha,2} T_\alpha + a_{\alpha,3} T_\alpha^2 + a_{\alpha,4} T_\alpha^3 + a_{\alpha,5} T_\alpha^4 \right) \quad (6)$$

2. GOVERNING EQUATIONS

vii) Equation of heat energy

$$\frac{\partial}{\partial t}(r_\alpha \rho_\alpha e_\alpha) + \nabla \cdot (r_\alpha (\rho_\alpha \vec{U}_\alpha e_\alpha)$$
$$= \nabla \cdot (r_\alpha \lambda_\alpha T_\alpha) + r_\alpha \tau_\alpha (\nabla \vec{U}_\alpha)^2 + S_{E\alpha} + Q_\alpha \qquad (7)$$

viii) Equation of phase generation density

$$\dot{m}_{\alpha,\beta} = \frac{k_\alpha (T_\alpha - T_s) - k_\beta (T_s - T_\beta)}{L} \qquad (8)$$

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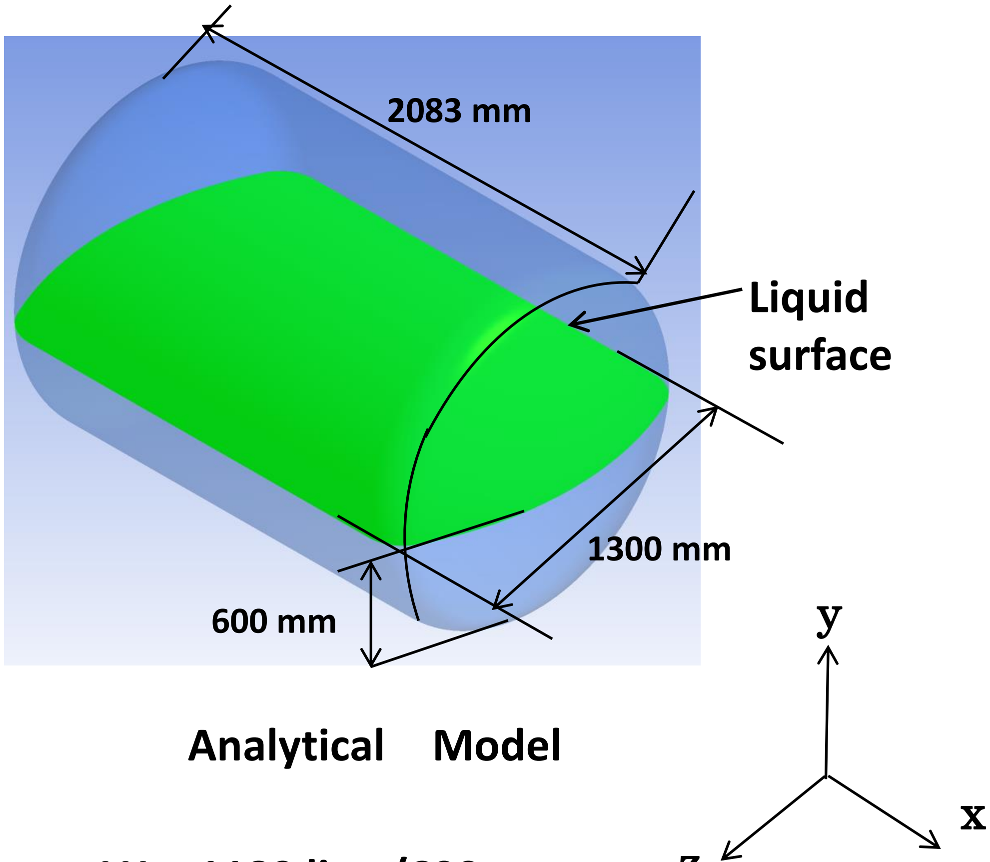
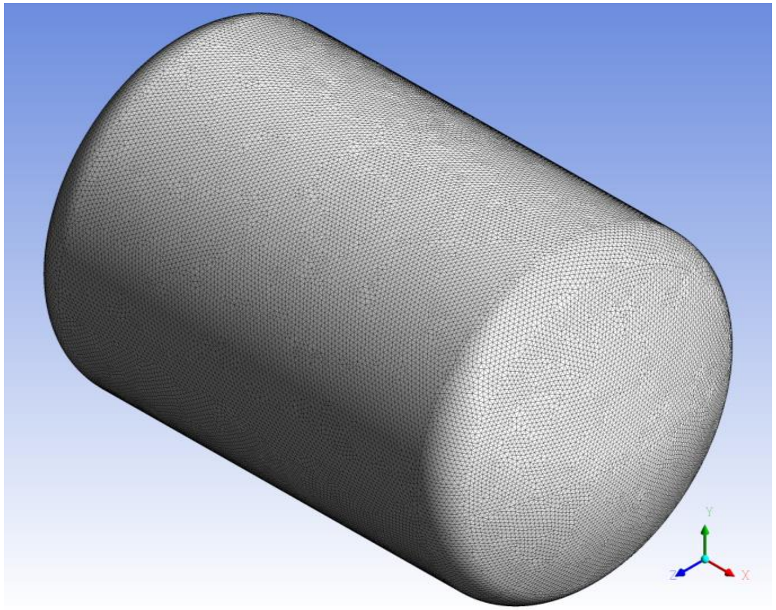
3. ANALYTICAL MODEL

(1) 2000 liter tank



Analytical Model

LH_2 : 1189 liter/600 mm
Smooth initial surface position



Mesh Configuration

Number of meshes: 1.66×10^6
Coniguration: tetrahederal
Maximum size: 16.5 mm

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4. THERMAL ANALYSIS

(1) Outlines

(a) Analysis condition

Evaporation and convection of saturated LH_2 (20.3 K) was negligible.

(b) Initial condition

Temperature of GH_2 was set 20.3 K.

LH_2 level was set 600 mm.

(c) Boundary condition

Uniform heat leak from wall of the tank was set 17 W, which was obtained through the experiment.

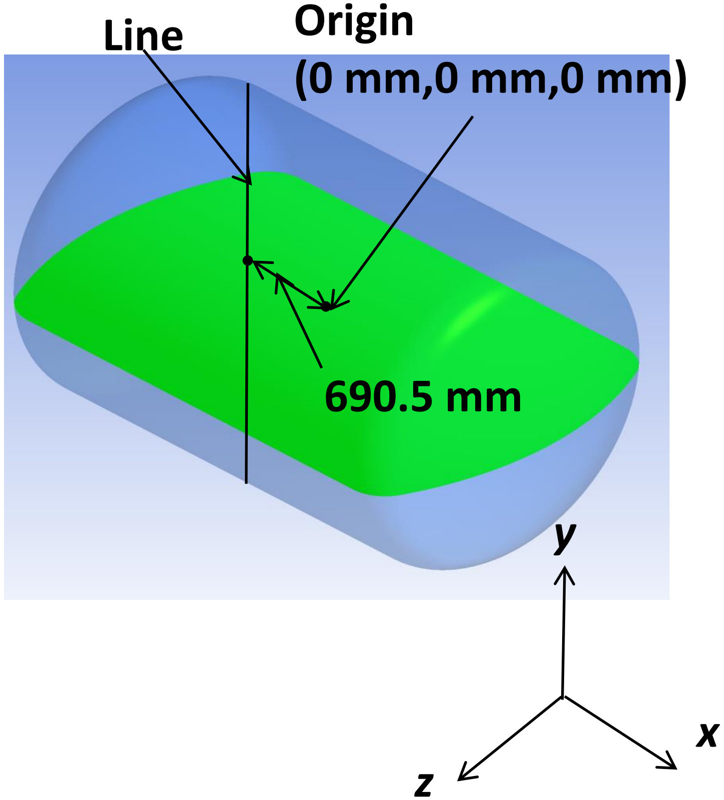
4. THERMAL ANALYSIS

(1) Outlines

(d) Indication of numerical results

1) Temperature distribution of GH_2 in the tank at z = 0 mm plane and x = -690.5 mm plane, where the origin was defined as the center of gravity.

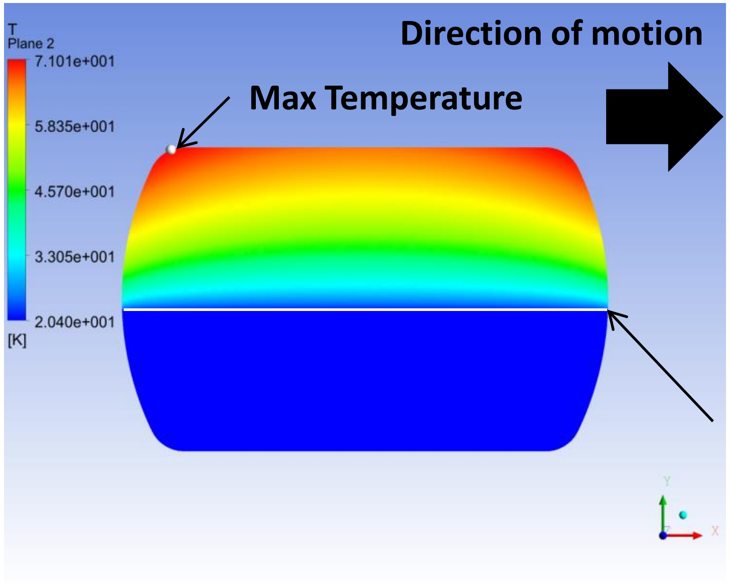
2) Temperature distribution along the line located in z = 0 mm and x = -690.5 mm, where the liquid level and temp. sensor was installed.



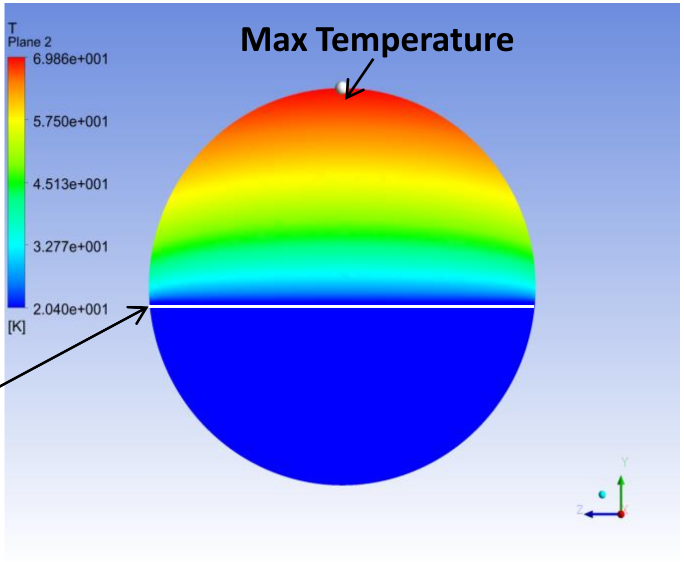
4. THERMAL ANALYSIS

(2) Numerical results

(a) Temperature distribution in the tank



Liquid surface



Side section at *z* = 0 mm

Maximum temperature: 71.0 K

Vertical section at *x* = - 690.5 mm

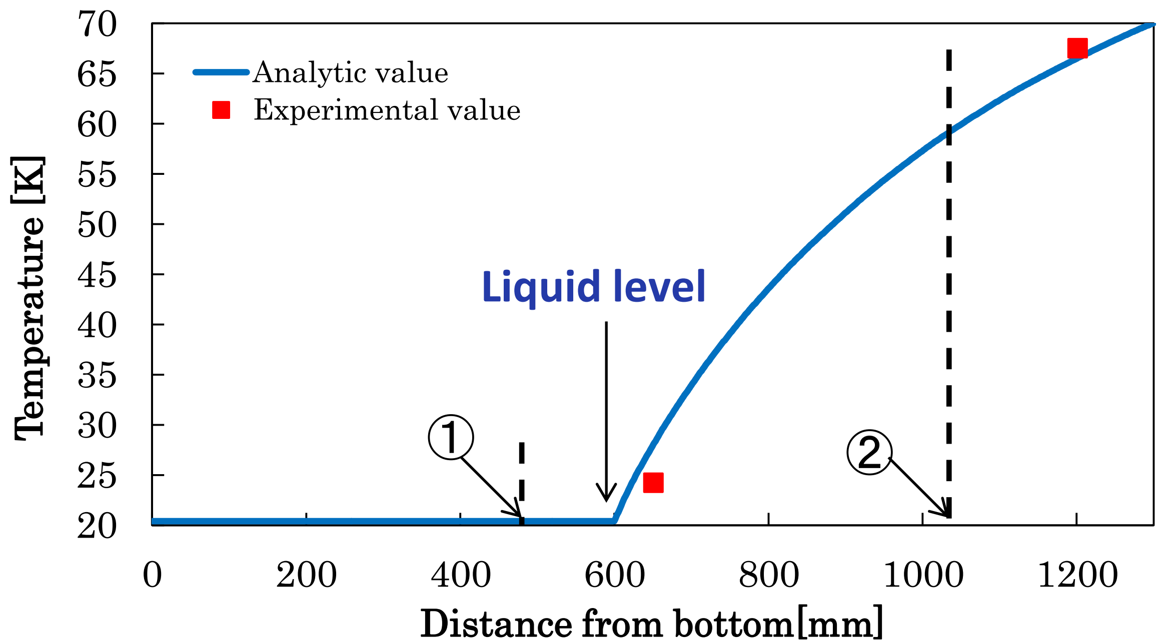
Maximum temperature: 69.8 K

Maximum temperature in the tank: 71.0 K

4. THERMAL ANALYSIS

(2) Numerical results

(b) Temperature distribution along the line



① Temperature at 650 mm from bottom (50 mm from surface)

Experiment: 24.2 K, Analysis: 28.0 K

② Temperature at 1200 mm from bottom (600 mm from surface)

Experiment: 67.5 K, Analysis: 66.5 K

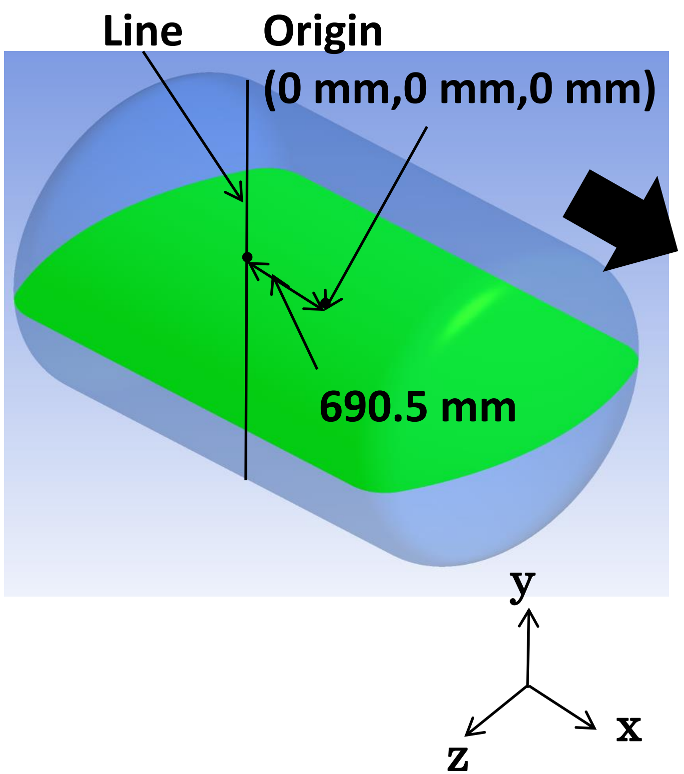
OUTLINES

5. OSCILLATION AND TERMAL ANALYSES

(1) Outlines

(a) Analysis condition

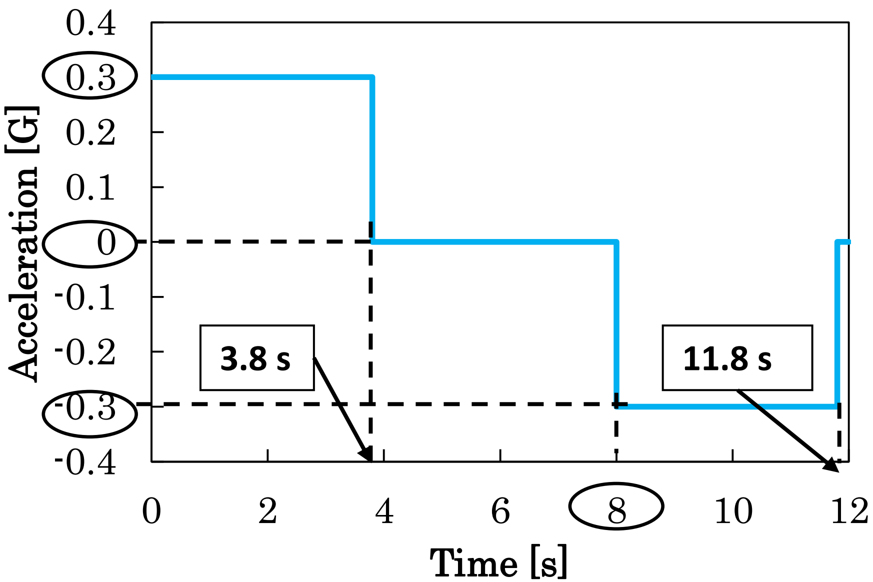
- Temperature and pressure of GH_2 can change.
- Evaporation of LH_2 and heat leak of 17 W.
- Time step of 0.01 s and total time of 12 s.
- Horizontal vibration: see next view graph.



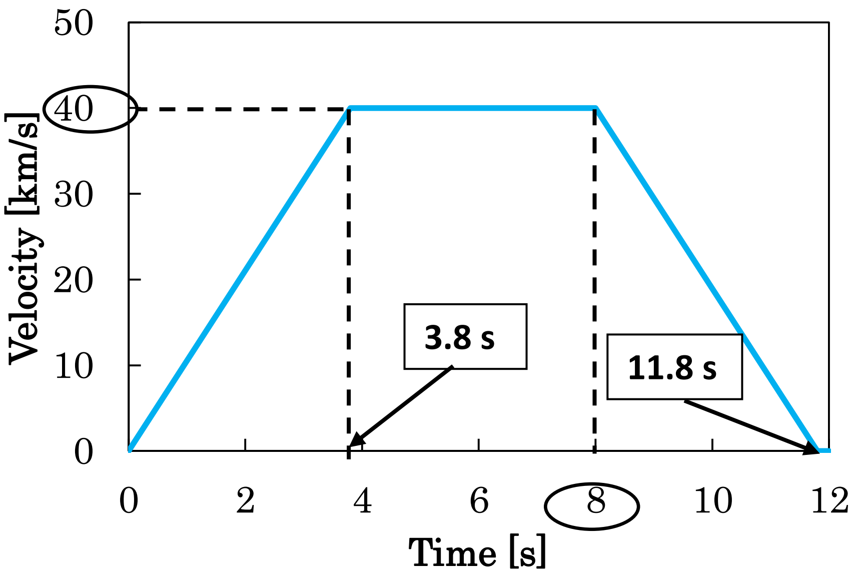
(Machine time: 15 d)

5. OSCILLATION AND TERMAL ANALYSES

(1) Outlines: (a) Analysis condition



(a) Acceleration



(b) Velocity

5. OSCILLATION AND TERMAL ANALYSES

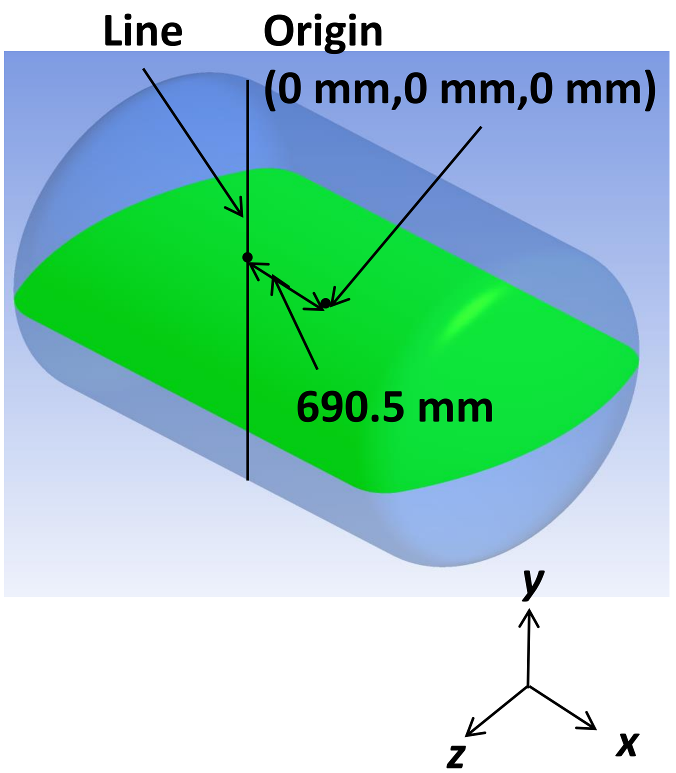
(1) Outlines

(b) Initial condition

- Numerical results of thermal analysis under the static condition.

(c) Boundary condition

- Uniform heat leak of 17 W from wall of the tank, which was obtained through the experiment.



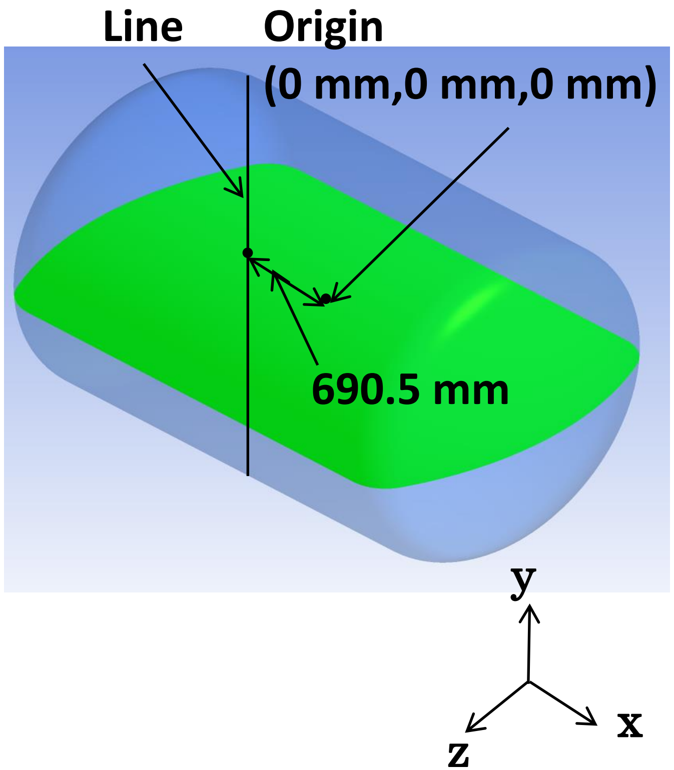
5. OSCILLATION AND TERMAL ANALYSES

(d) Indication of numerical results

- **Simulation:**
  1) LH_2 surface oscillation
  2) Temperature distribution

     Side section at z = 0 mm

     Vertical section at x = - 690.5 mm

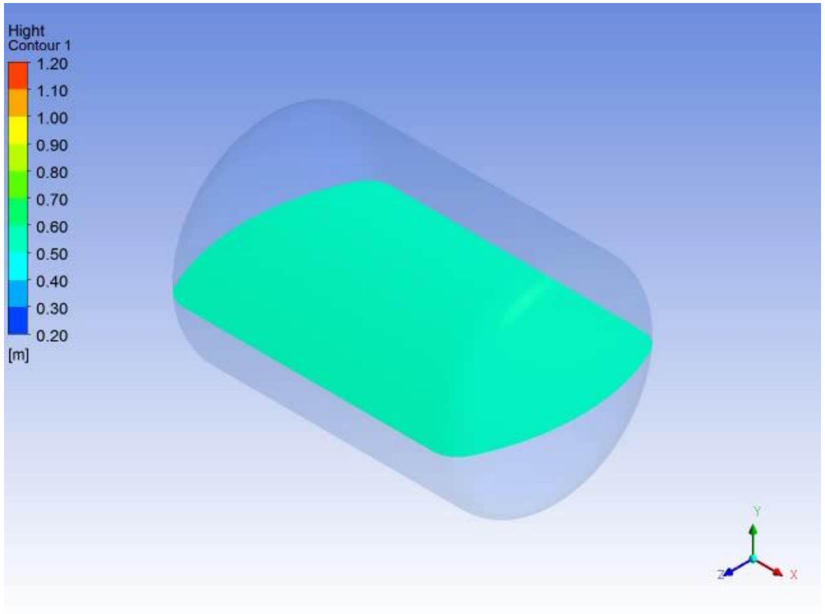


- **Numerical results:**
  1) LH_2 Level and temperature of GH_2 at 1200 mm from bottom on the line.
  2) Average temperature and pressure of GH_2 in the tank.

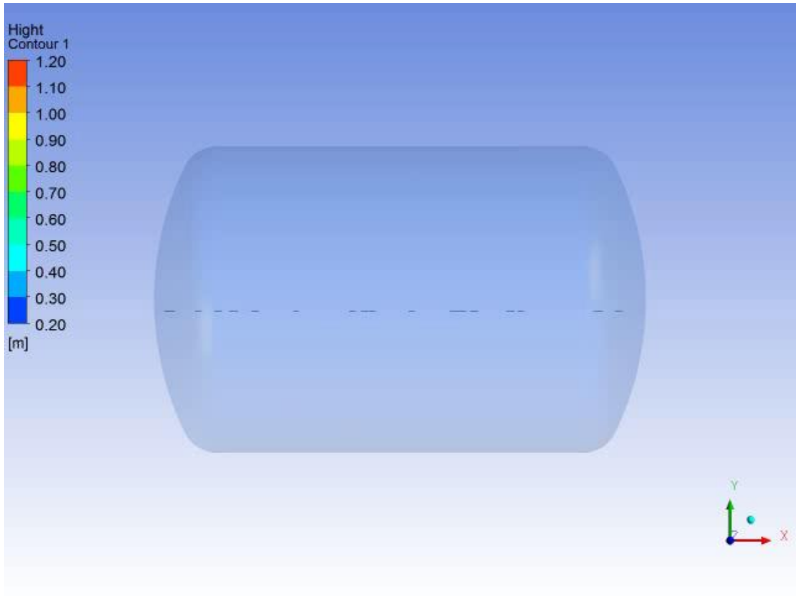
5. OSCILLATION AND TERMAL ANALYSES

(2) Simulation

(a) LH_2 Surface oscillation



3D model

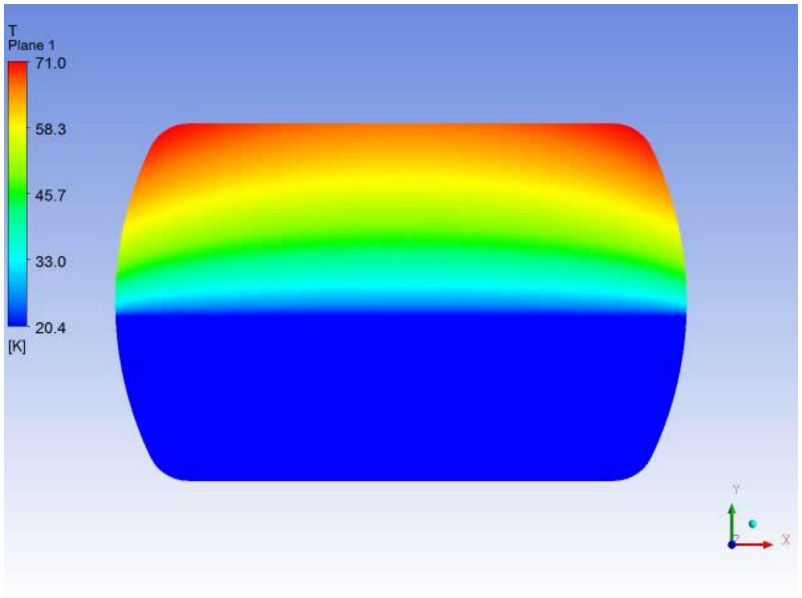


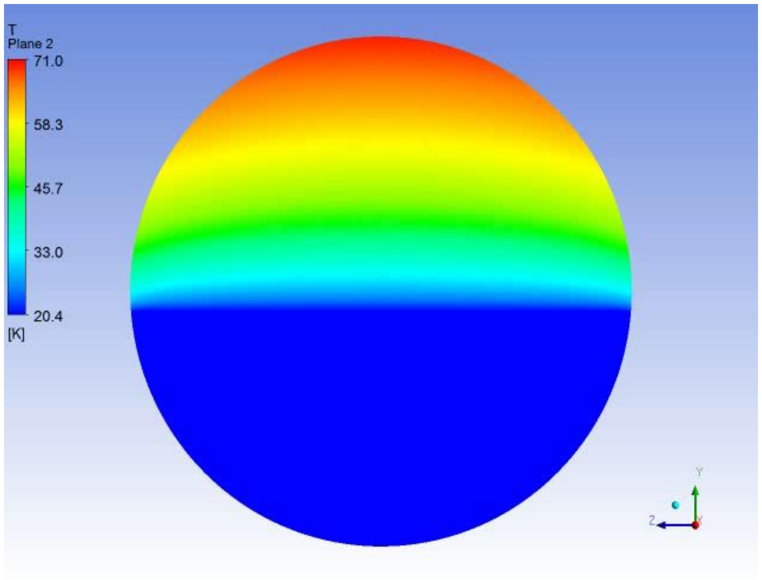
Side View

5. OSCILLATION AND TERMAL ANALYSES

(2) Simulation

(b) Temperature distribution



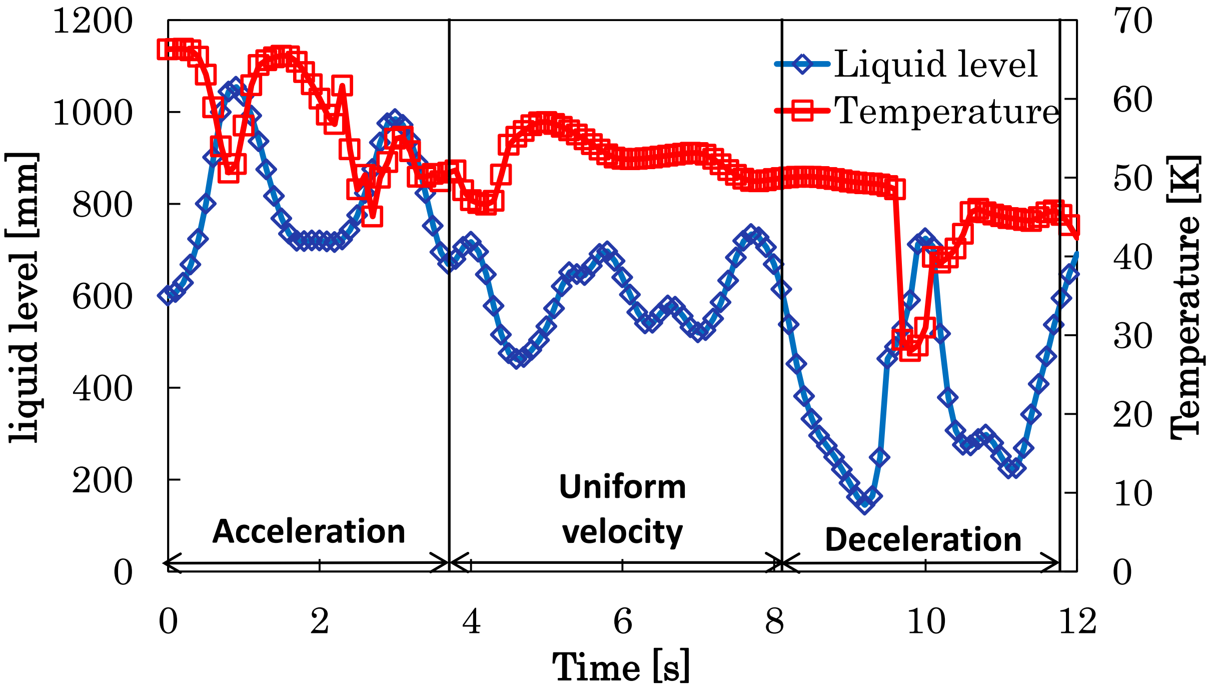


Side section at *z* = 0 mm **Vertical section at *x* = - 690.5 mm**

Maximum temperature in the tank: 71.0 K → 47.6 K

5. OSCILLATION AND TERMAL ANALYSES

(3) Numerical results : (a) LH_2 level and temperature of GH_2 at 1200 mm from the bottom on the line

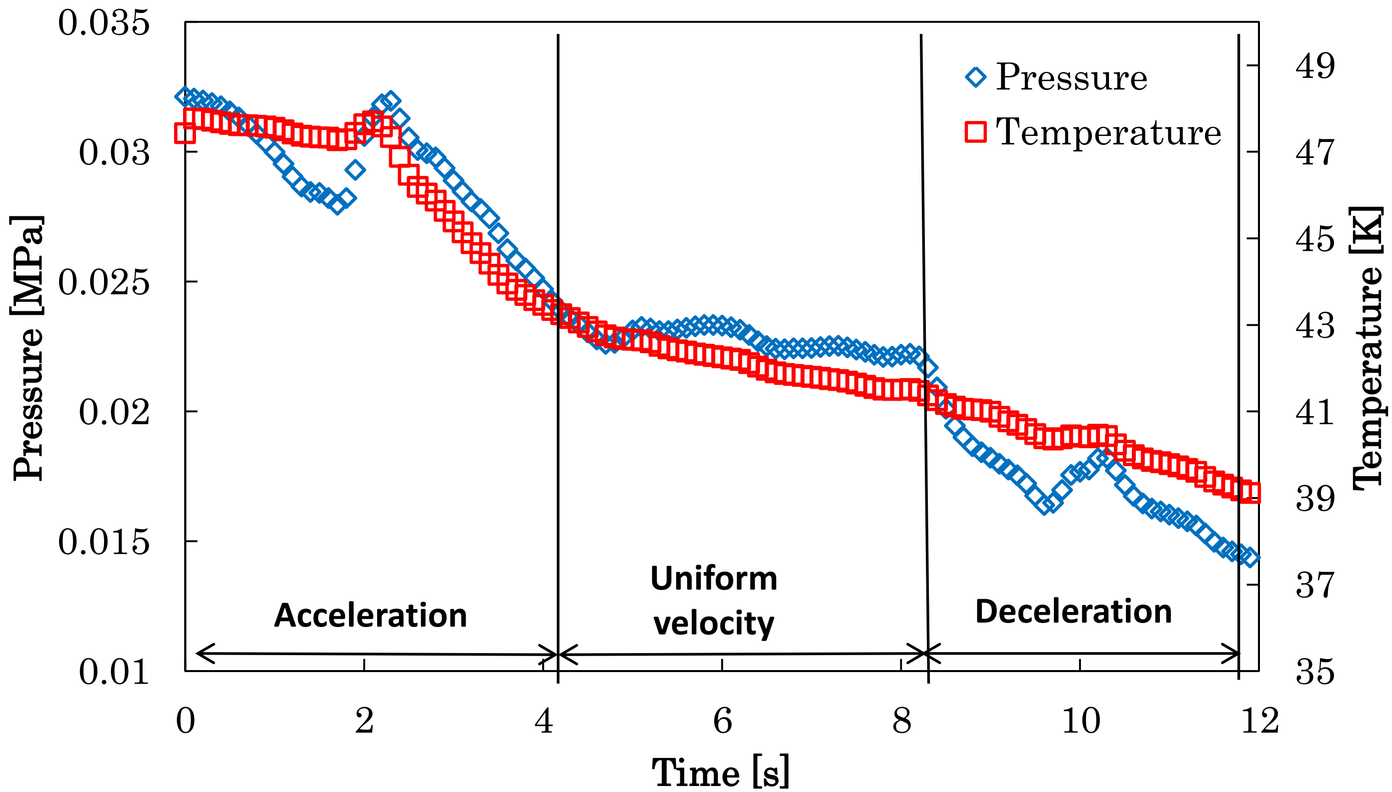


Average period of oscillation: 2 s ⟷ 2.0 s (Exp.)

Max liquid level: 1054 mm ⟷ 1252 mm (Exp.)

5. OSCILLATION AND TERMAL ANALYSES

(3) Numerical results: (b) Average temperature and pressure of GH_2



Temperature: 47.8 K → 39.1 K

Pressure: 0.032 MPaG → 0.014 MPaG

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6. SAMMARY

- (1) Simulation of LH_2 surface oscillation, temperature and pressure inside a 2000 liter tank during truck transportation were carried out using an ANSYS CFX.
- (2) Periodic oscillation of LH_2 level, maximum LH_2 level over 1000 mm and decreasing average pressure with decreasing average temperature inside the tank were demonstrated successfully.
- (3) Oscillation and thermal analyses of a large LH_2 tank of 1250 m^3 for marine transportation will be carried out as a future work.

- **Thank you for your attention !**