[2024] 4th ELVHYS Workshop
2024.12.04.

Novel Insulation Systems for Liquid Hydrogen Tanks

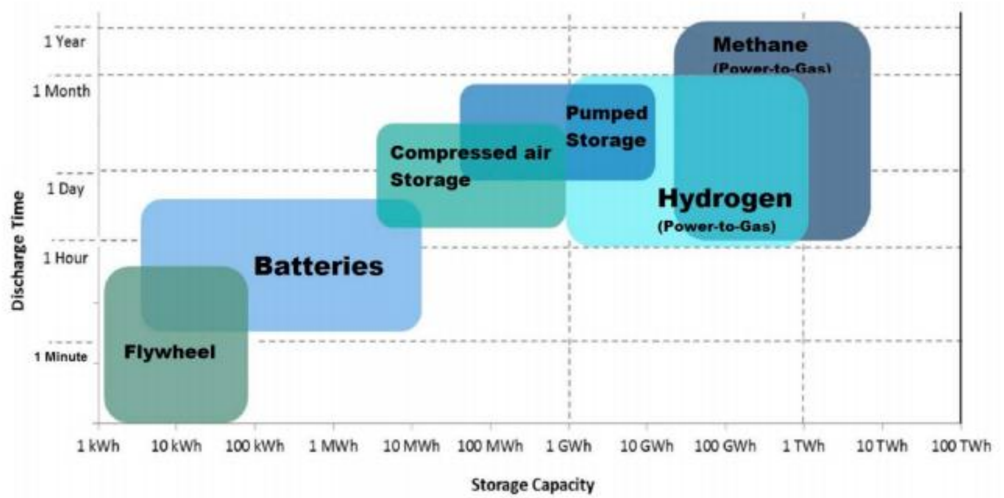
Gun Woo Kim, Hyun-Seok Kim, Dong-Hee Hong

This research was supported by Korea Research Institute of Ships and Ocean Engineering a grant from Endowment Project (PRS0310).

Hydrogen Energy System : Intro

Hydrogen Energy System

Hydrogen Society
(source : FIGARO USA Inc)



Source: School of Engineering, RMIT University (2015)

Energy capacity and discharge duration according to Energy Storage Tech

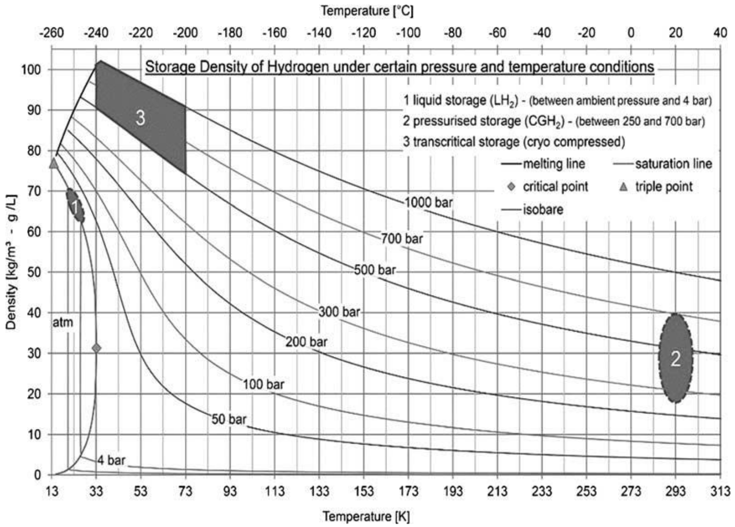
Due to the recent effects of extreme abnormal climate, interest in eco-friendly energy systems that do not produce global warming is increasing.

Hydrogen, recognized as an eco-friendly energy carrier, has high energy storage capacity and does not generate pollutants during transportation, storage, and use.

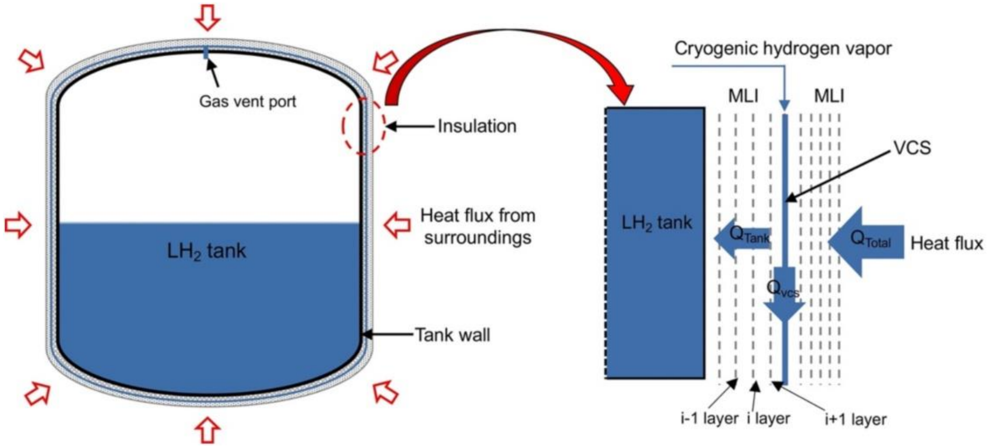
Liquid Hydrogen System

Pros and cons of liquid Hydrogen System

Liquid hydrogen
(source :The Lawrence Berkeley National Lab)



Liquid hydrogen Density-Temperature Graph
(source : Taccani et al., 2020)



Concept Design Example of Liquid Hydrogen Storage Tank
(source : Jiang et al., 2021)

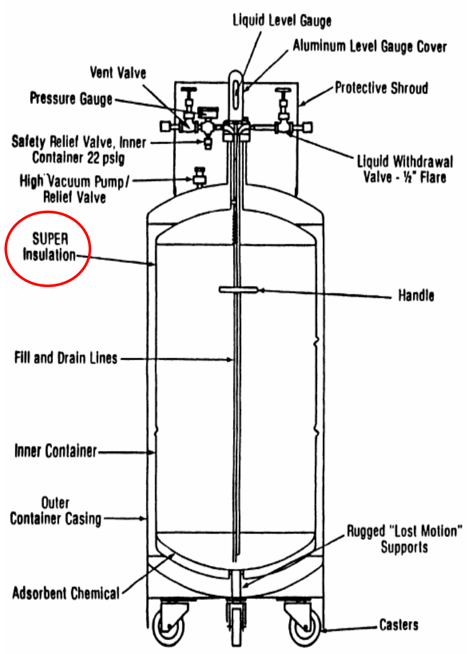
Hydrogen, a representative eco-friendly carbon-free fuel, has the disadvantage of requiring a large storage space due to its low energy density per volume.

Liquid hydrogen, which enables large-capacity hydrogen storage and transportation through the ocean, is a technology with high potential as it can ensure **high purity** and **safety** in the process of increasing the storage density of hydrogen.

However, the development of high-level insulation system design is required due to the cryogenic storage temperature of Liquid Hydrogen (20 K).

Liquid Hydrogen Insulation System

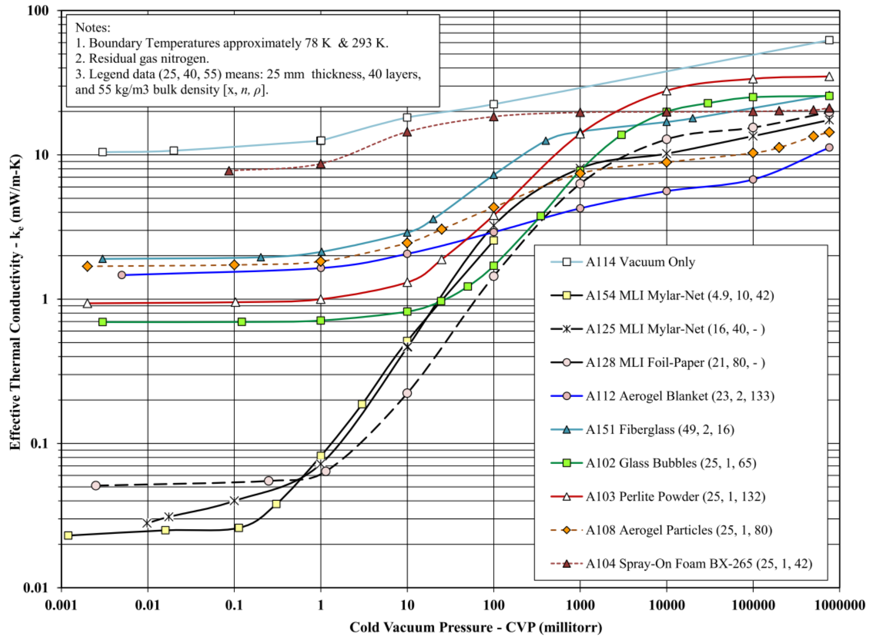
Cryogenic Insulation System : Vacuum+MLI



Super Insulation System
(source :Cryogenic Engineering)

50L Liquid hydrogen Tank

James E. Fesmire et al. / Physics Procedia 67 (2015) 1089 – 1097



Comparison of insulation performance by vacuum level and material

In General, a vacuum insulation layer is designed between the inner and outer containers to protect against penetration heat for cryogenic storage.

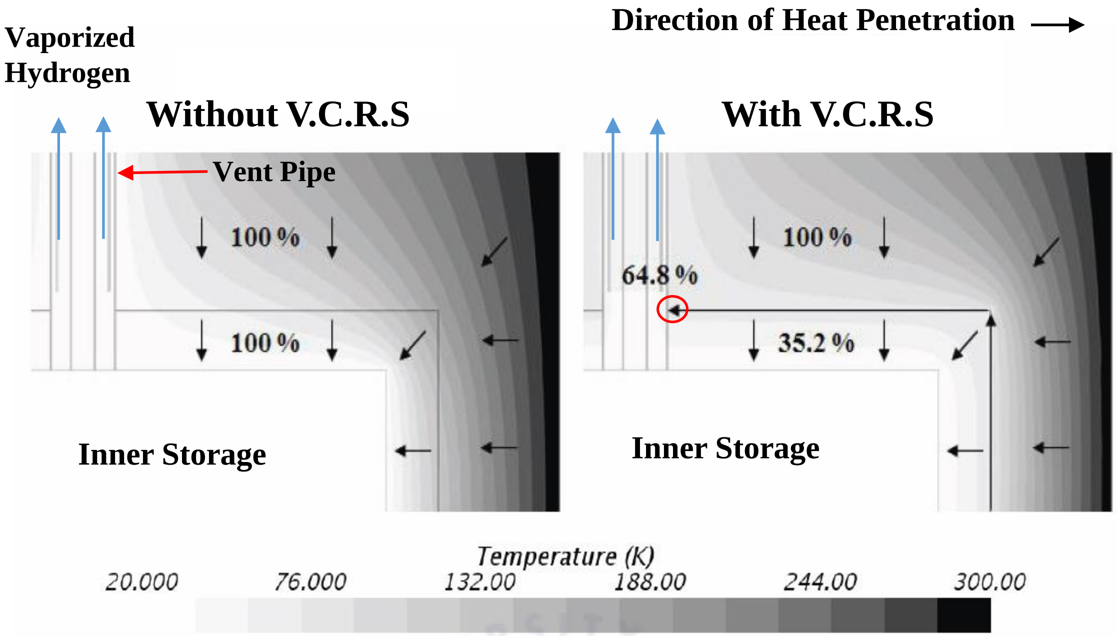
In case of our Liquid hydrogen Fuel Tank, 1 mtorr vacuum and multilayer Insulation with 25 Layer/cm was used for vacuum insulation layer.

Heat treatment and electrolytic treatment were applied to create the vacuum level, and it took one month to secure the vacuum level.

Liquid Hydrogen Insulation System

Vapor Cooled Shield (V.C.S)

5L Liquid Hydrogen Tank V.C.S System



V.C.S System operation Concept

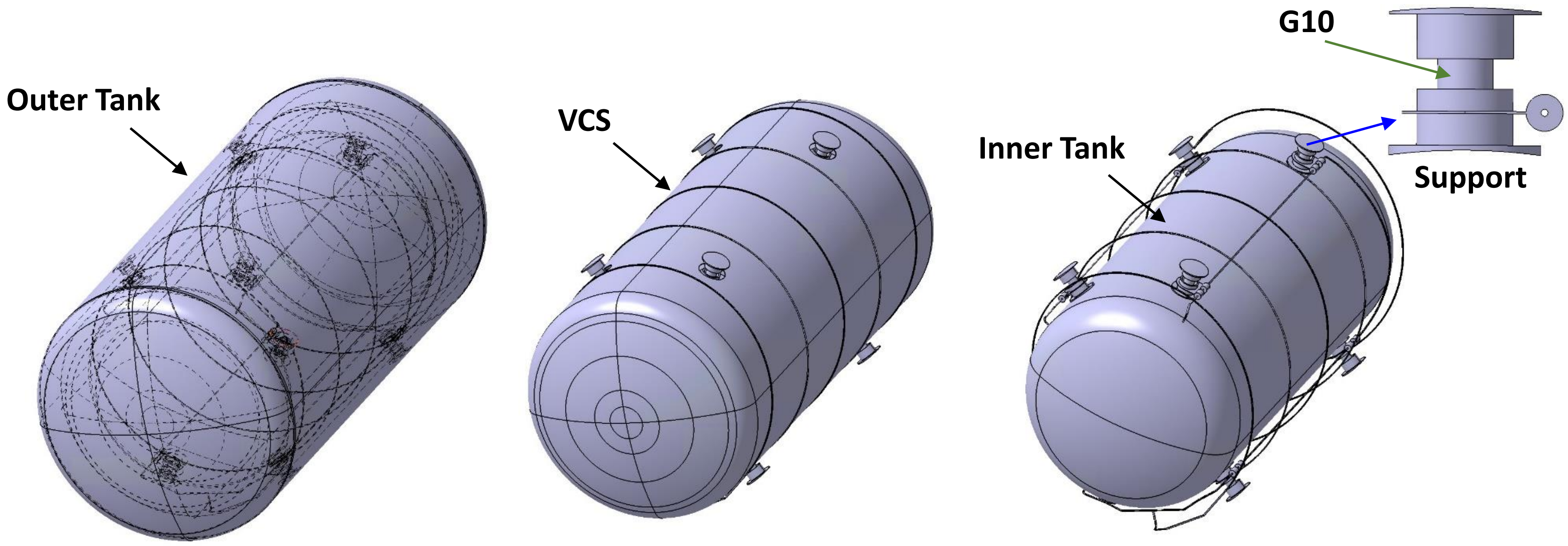
To provide additional insulation performance, the Vapor-cooled shield (V.C.S.) system was applied, which is a concept that reduces the amount of heat penetration into the internal vessel by transferring the heat to the boiled but still low-temperature gaseous hydrogen.

The heat transferred to the boil off hydrogen escapes along with the vaporized hydrogen as it vents out.

Similarly, additional insulation system was applied to prevent heat from being transmitted through the support structure (Support cooler).

Liquid Hydrogen Fuel Tank

CFD Simulation of 6 CBM Liquid Hydrogen Fuel Tank



Liquid Hydrogen Fuel Tank Model

First of all, we ask for your understanding that the liquid hydrogen technology has been designated as a national core technology of the Republic of Korea and thus the detail drawings and research results cannot be disclosed.

The design is in progress with the helix-shaped vent pipe welded to the support and VCS.

For the inner tank / outer tank / support, stainless steel material properties are used. For the central part of the support, G10 is used to minimize heat conduction.

Liquid Hydrogen Fuel Tank

CFD Simulation of 6 CBM Liquid Hydrogen Fuel Tank

$$\nabla \cdot \rho V = 0 , \rho = \frac{p}{RT}$$

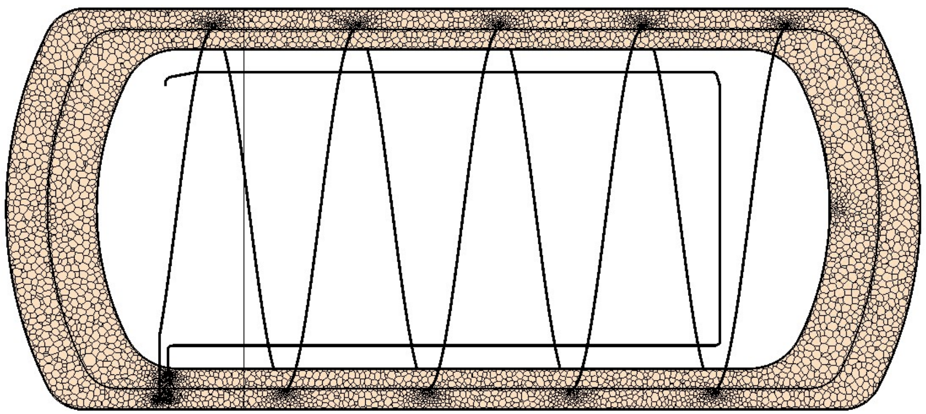
$$\rho V \cdot \nabla V = -\nabla p + \frac{\partial}{\partial x_j}[\mu(T)(\frac{\partial v_i}{\partial x_j} + \frac{\partial v_j}{\partial x_i})]$$

$$\rho c_p(T) V \cdot \nabla T = \nabla \cdot (k(T)\nabla T)$$

Mass Flow Inlet

$$\dot{m} = \frac{\dot{Q}_{Penet}}{h_{fv}}$$

Convection : 313.15 K
h = 3 w/m^2K



Constant Temp : 20 K

Commercial code StarCCM+ 15.04 Ver. Was used.

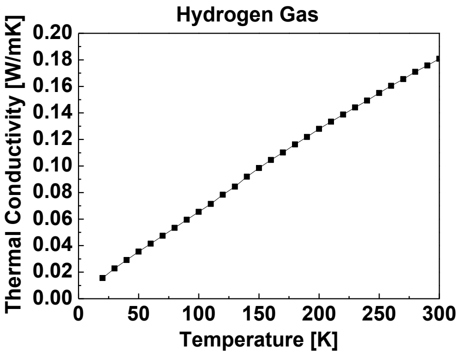
Natural convection heat transfer was considered for the external container, and a constant temperature was assigned to the internal container for a conservative analysis.

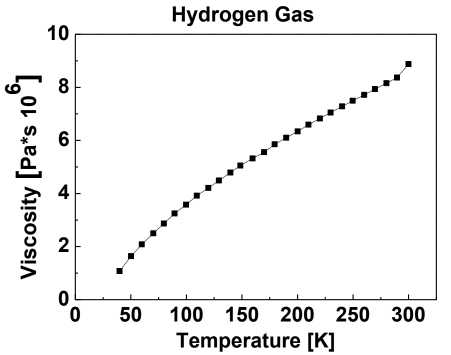
In the case of Vent Pipe, the mass flow rate is calculated and reflected based on the internal vessel penetration heat calculated for each iteration.

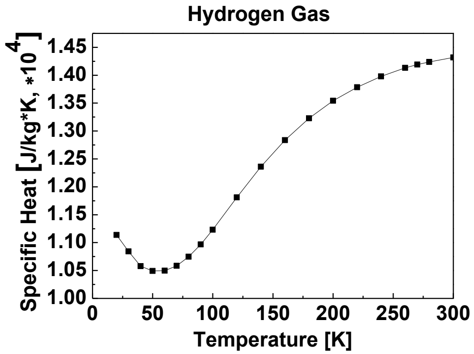
9.91 million grid Poly Mesh used

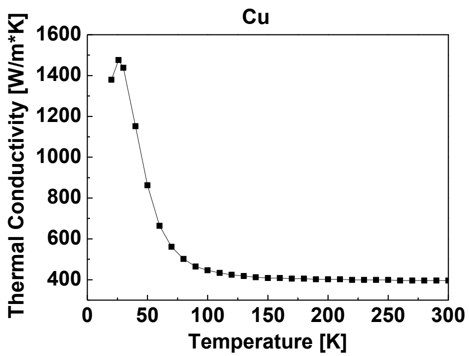
Liquid Hydrogen Fuel Tank

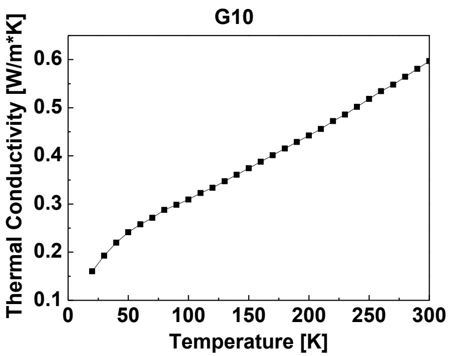
CFD Simulation of 6 CBM Liquid Hydrogen Fuel Tank

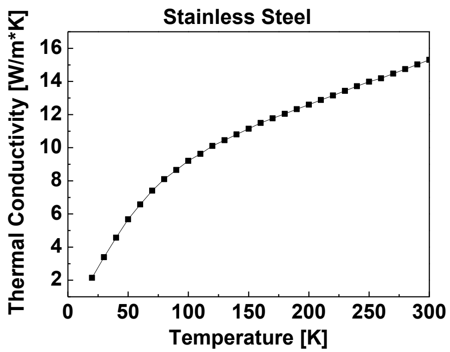


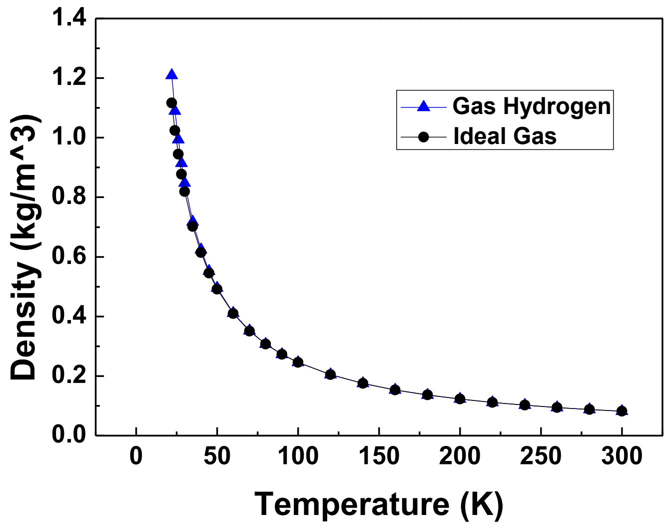








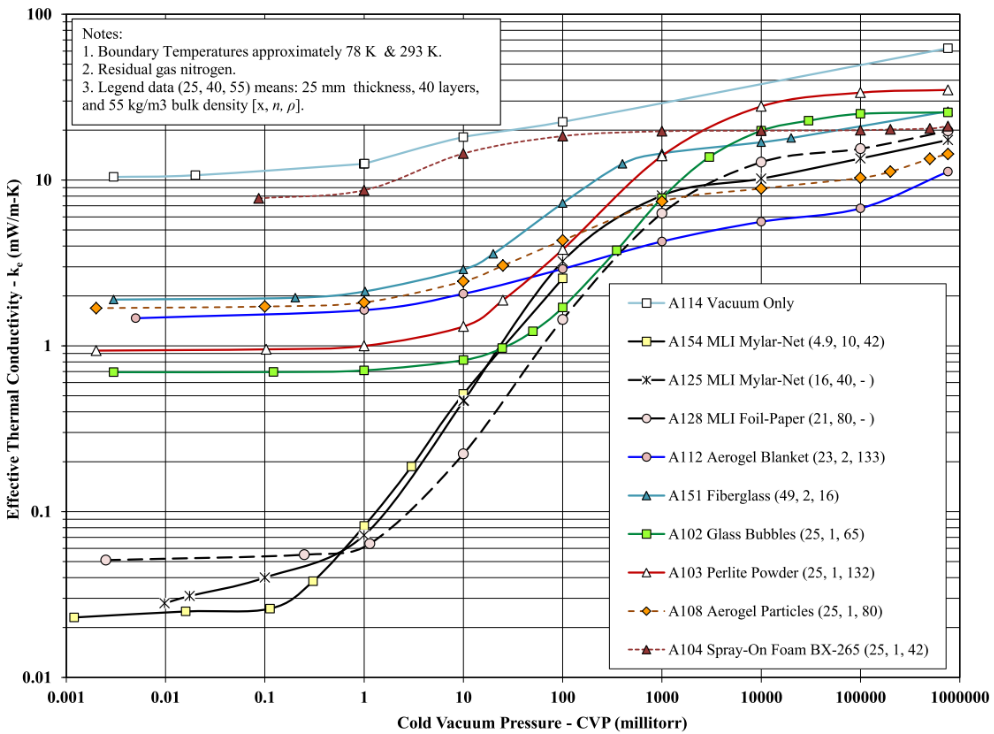




Liquid Hydrogen Fuel Tank

CFD Simulation of 6 CBM Liquid Hydrogen Fuel Tank

James E. Fesmire et al. / Physics Procedia 67 (2015) 1089 – 1097



Effective Thermal Conductivity was used to simulate the vacuum insulated area.

Effective thermal conductivity refers to the calculated thermal conductivity evaluated when all conduction/ convection/radiation heat transfer is converted to conduction.

In case of 1 mtorr MLI, Effective thermal conductivity 0.1 mW/m-K was used.

Additionally, Effective thermal conductivity 0.25 mW/m-K was also considered, assuming that the vacuum level was changed to 5 mtorr due to vacuum failure.

Liquid Hydrogen Fuel Tank

CFD Simulation of 6 CBM Liquid Hydrogen Fuel Tank

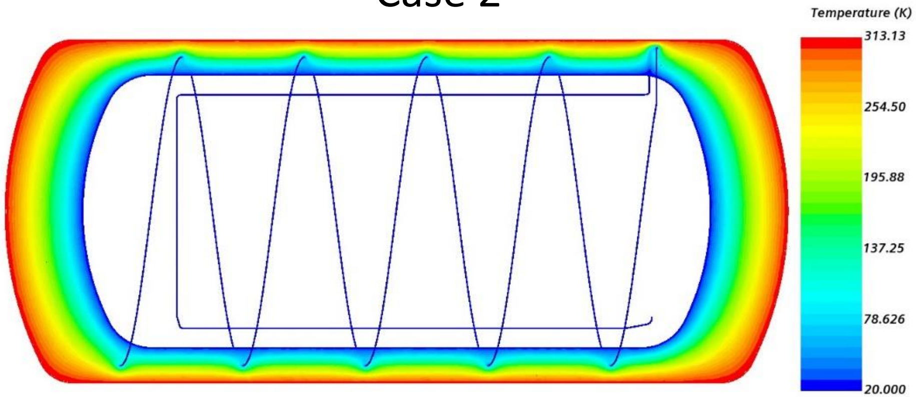
Case	A.T.C	VCS	Support Cooler
Case 1	$0.1\ \mathrm{m}W/mK$	X	X
Case 2	$0.1\ \mathrm{m}W/mK$	X	0
Case 3	$0.1\ \mathrm{m}W/mK$	0	0
Case 4	$0.25\ \mathrm{m}W/mK$	X	X
Case 5	$0.25\ \mathrm{m}W/mK$	X	0
Case 6	$0.25\ \mathrm{m}W/mK$	0	0

Liquid Hydrogen Fuel Tank

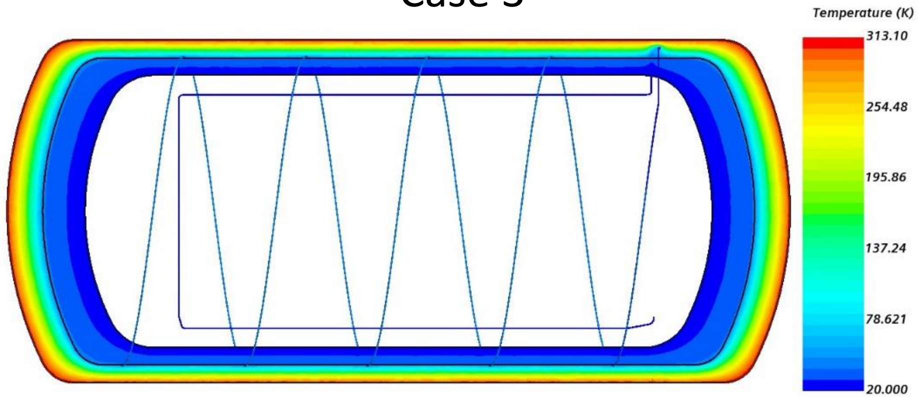
CFD Simulation of 6 CBM Liquid Hydrogen Fuel Tank

Case 1

Case 2

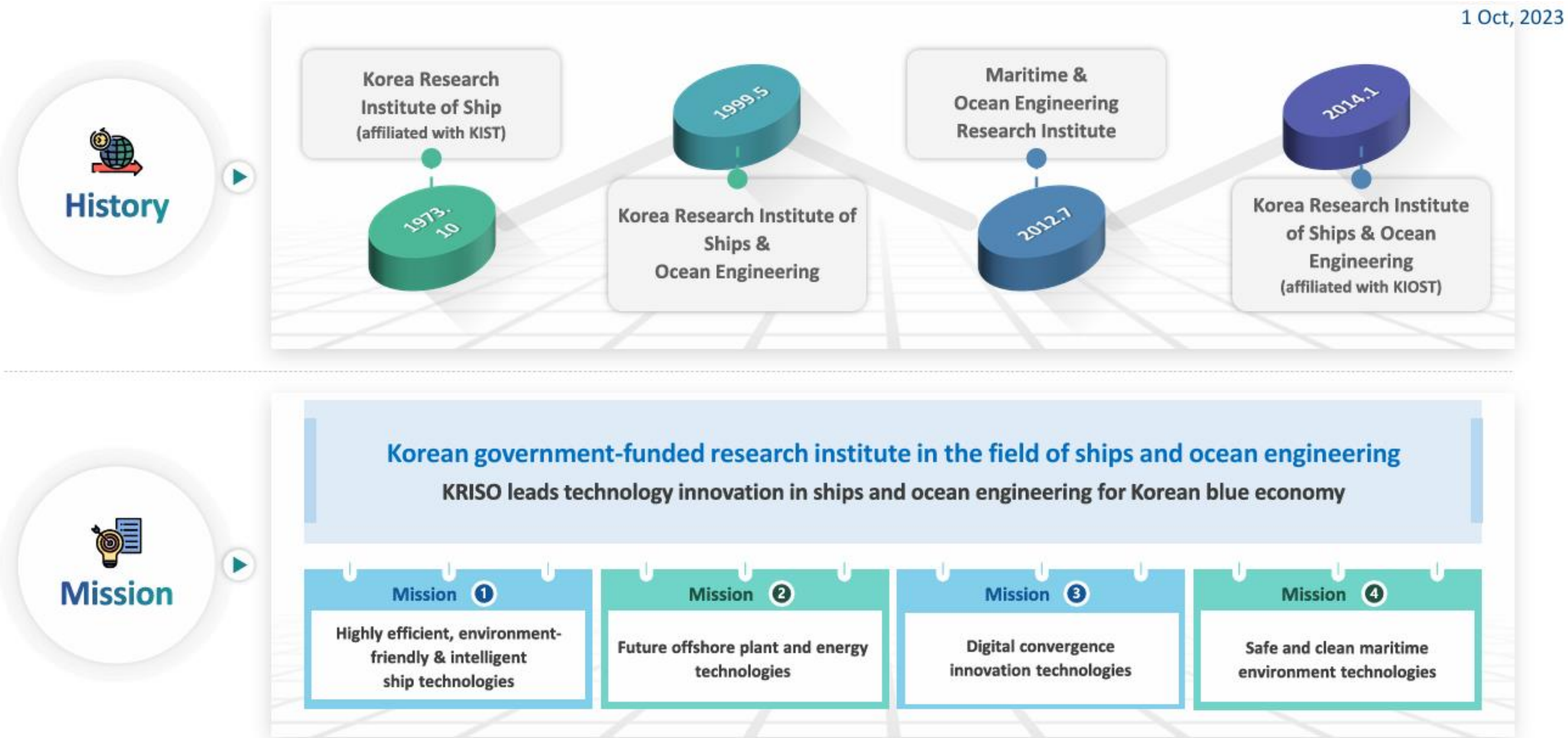


Case 3



KRISO Europe Center

Korea Research Institute of Ships & Ocean Engineering (KRISO)



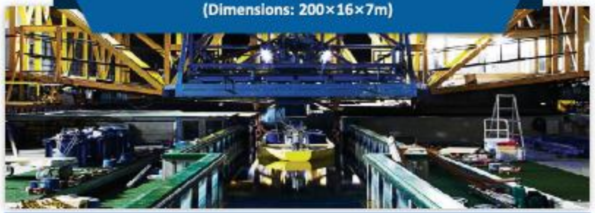
KRISO R&R

- Advanced Ship Technology
- Eco-friendly Ocean Development
- Digital Convergence & Innovation
- Maritime Safety & Environment

KRISO Europe Center

Korea Research Institute of Ships & Ocean Engineering (KRISO)

Towing Tank
(Dimensions: 200×16×7m)

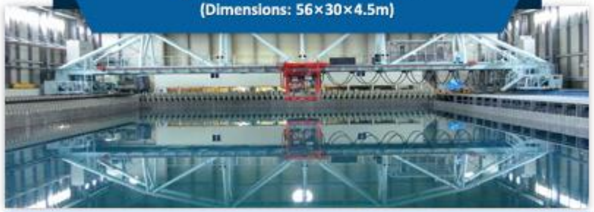


- **Since** '78. 3. (Korea's first one)
- **Functions** Test of propulsion and maneuvering performance for ships and submarines
- **Achievement** Tests for more than 2,000 model ships

Full Mission Bridge Simulator

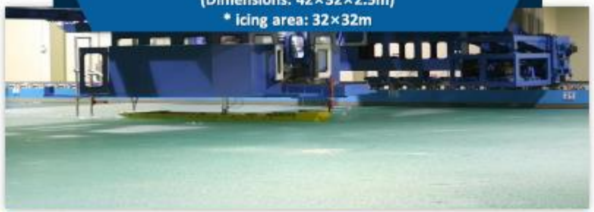
- **Since** '97.12.
- **Functions** Navigation simulation, analysis of traffic safety and maritime accident
- **Achievement** Naval Education and Training Command, cause analysis of maritime accidents

Ocean Engineering Basin
(Dimensions: 56×30×4.5m)



- **Since** '98.7. (Second largest one in Korea)
- **Functions** Simulation of realistic maritime environment, including waves, wind, and currents
- **Achievement** Maneuverability and stability tests for 350 ships and offshore structures

Ice Tank
(Dimensions: 42×32×2.5m)
* icing area: 32×32m



- **Since** '09.7. (World's largest one)
- **Functions** Secured design/shipbuilding/performance test technology for high value-added icebreakers
- **Achievement** Tests for the ice resistance of icebreaking research ship and capacity of extreme low temperatures of cold room

Large Cavitation Tunnel
(Dimensions: 60×22.5×6.5m)
* Sectional area: 12.5×1.8×2.8m

- **Since** '09.10 (Second largest one in the world)
- **Functions** Evaluation of fluid capacity in relation to ship-propeller-rudder interactions and cavitation tests of propellers
- **Achievement** Design and tests for high value-added merchant ship, high speed vessels, Korean submarines propeller

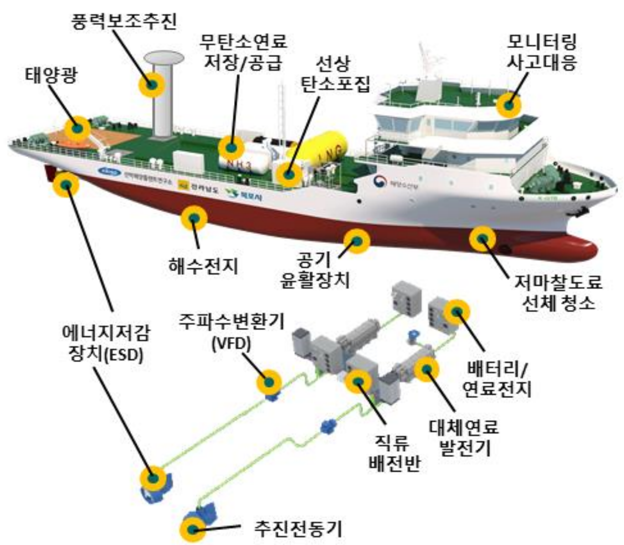
Deep Ocean Engineering Basin
(Dimensions: 100×50×15m)

- **Since** '18.11. (World's largest one)
- **Functions** Performance evaluation and verification of ships and offshore structures in deep sea environment
- **Achievement** Reproduction of the deep sea environment and development of technologies for offshore plant

KRISO Europe Center

Korea Research Institute of Ships & Ocean Engineering (KRISO)

Design Specifications	Value
Ship Name	K-GTB
Inspection	K.R.
Design Velocity	Max. 12.5 Knots
Range	900N.Miles
Length O.A.	82.6 m
Length B.P.	74.0 m
Breadth	18.0 m
Draft	3.6 m
GT	2,600 ton
Displacement	3,700 ton
Propulsion	Electric, 1,100 kW, 2 set
Main Generator	LNG DF 1,500 kW , 2 set



KRISO Europe Center

KRISO Europe Center : Mission

KRISO is going to establish a **Research Base in Europe** for initiative of the major technologies and the international standards in the fields of *advanced maritime mobility and sustainable use and development of the oceans*.

In addition, KRISO is preparing a program to build up young and professional human resources in collaboration with KIRD (Korea Institute of Human Resources Development in Science and Technology).

Keywords: Decarbonization, Digitalization, Advanced Maritime Mobilities, Sustainable Use & Development of the Oceans, Foster Program of Human Resources, International Cooperation

Korea will be an Associated Member of Horizon Europe in 2025!

KRISO
KOREA RESEARCH INSTITUTE OF SHIPS & OCEAN ENGINEERING

KRISO will be in Europe for closer cooperation with European partners!

KRISO 선박해양플랜트연구소
KOREA RESEARCH INSTITUTE OF SHIPS & OCEAN ENGINEERING