

PILOT LNG STORAGE TANK FOR R&D PURPOSES AT KOGAS

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1. INTRODUCTION

Korea Gas Corporation (KOGAS) decided to develop Liquefied Natural Gas (LNG) storage tanks by its own technology in 1996. The projected storage tanks, commercial full containment 9% Ni type and above ground membrane type, have the capacity of 140,000 m³ respectively. To localize the design technology, a Pilot LNG storage tank with the capacity of 1,000 m³ needed to be first designed and built.

R&D division of KOGAS had carried out this project until June 2002, and successfully developed the design of those LNG storage tanks. With the developed design of full containment 9% Ni type LNG storage tank, KOGAS has applied to No. 6 to No. 10 tanks in Tongyoung LNG receiving terminal and No. 11 to No. 14 tanks in Pyungtaek terminal. Also, KOGAS had successfully developed and built a Pilot LNG Storage tank and its facilities for the research and development purposes.

The construction of the Pilot LNG storage tank, above ground membrane type tank having a capacity of 1,000 m³, and its facilities started in September 2000 and the commissioning of the tank completed in December 2001. They were constructed at an existing Incheon LNG receiving terminal, which is the largest terminal in KOGAS. Figure 1 shows the Pilot LNG storage tank and facilities.

The purpose of this Pilot system is to verify the qualification of various cryogenic installations and equipments such as the membrane and insulation developed by KOGAS, and assure the performance of other equipments such as the cool-down temperature sensors and strain gages which measure the deformation of membrane behavior, and also carry out various kinds of test related with LNG behaviors.

Moreover, the Pilot LNG storage facilities enable us to carry out comprehensive tests over a long period of time, and to obtain an experience and know-how of operating LNG plant. They also provide us with the core technologies in engineering design, especially in developing the membrane containment type LNG storage tank.

This paper focuses on the outline of the Pilot LNG storage facilities and the study plan that will be performed in the future.

2. DESCRIPTION OF PILOT LNG STORAGE TANK

The Pilot LNG storage tank was designed and constructed according to the requirements of API 620, BS7777, and RPIS(Recommended Practice In-ground Storage tank) [1, 2, 3] and it has been

successfully operating for 14 months. During this period, we once performed a cyclic test of cooling-down and warming up of the tank.

The Pilot LNG storage tank, which has a capacity of 1,000 m³, consists of membrane inner tank, pre-stressed concrete outer tank and gas-tight dome roof with suspended ceiling deck. The diameter of the inner tank is 14.18 m and the full height of the tank is 15.71 m. The pilot tank has a dike with a diameter of 26.5 m and an elevated base slab with an air gap of 1.5 m. The normal operating pressure of the tank is 150 mbarg, whereas maximum and minimum operating pressures are 350 mbarg and 50 mbarg. The boil-off rate (BOR) is less than 0.53% per day of the liquid volume corresponding to the maximum operating level.

LNG and BOG for the pilot tank is delivered from and sent to the Incheon LNG receiving terminal, therefore the operating pressure of the pilot tank depends on the BOG pressure of the Incheon LNG receiving Terminal.

2.1 Pilot tank main features

Tank Design Data

- Design Type	Above ground, Membrane, Suspended Deck
- Gross Liquid Capacity	1,300 m ³
- Normal Working Capacity	1,020 m ³
- Design Temperature of Product	-170 °C
- Design Pressure	-5 ~ 450 mbarg.
- Operating Pressure	50 ~ 350 mbarg.
- Operating Level	1.5 ~ 8.81 m
- BOG rate	0.53 vol%/day
- LNG Pump	50 m ³ /h x 2, 15bar

Inner Tank Features

- Diameter	14.18 m
- Shell Height	10.92 m

Outer Tank Features

- Diameter	15.71 m
- Height	14.21 m
- Wall Thickness	0.6 m



Figure 1: 1,000 m³ Pilot LNG storage facilities

2.2 Description of Inner Tank

The inner tank that stores LNG was constructed with the use of membrane of the 2mm thick stainless steel 304 and insulation panels of 204mm thick polyurethane foam, which had developed by KOGAS R&D division.

KOGAS' membrane is provided with corrugations to absorb thermal contraction and expansion caused by LNG temperature. For the development of membrane, theoretical analysis and experimental studies had been performed to investigate the strength of the membrane and the reaction forces at the anchor points.

To ensure the stability and fatigue strength of the corrugated membrane which subjected to the cryogenic liquid pressure and thermal loading, the stress analysis was performed by using nonlinear FEM code.

Also, a lot of experiments had been performed to investigate the deformation and strength of the membrane. All experiments had been conducted on the basis of RPIS, and we found the results are fully satisfied with the RPIS standards.

One example of these case studies is shown in Figure 2. For fatigue test, specimens were extracted from the corrugated part and performed fatigue test under the room temperature and -165°C .

Using displacement control, constant strain was repeatedly applied to specimen until the specimens were fractured, and the failure cycles for the specimen could be obtained. Also, we measured strain on the strain concentrated areas by using strain gages.

As Figure 2 indicated, we recognized that the corrugated part had enough fatigue life when we compared the ASME Best fit curves [4] of base metal with corrugated part.

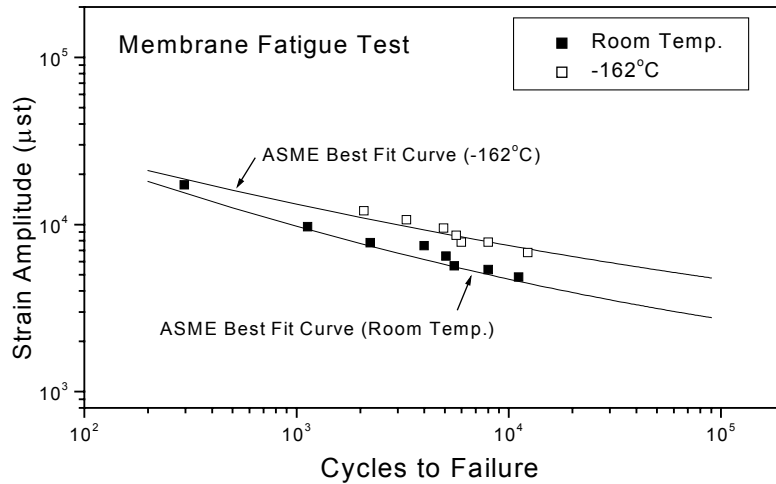


Figure 2: Fatigue test result of membrane

To measure the behavior of membrane during the tank operation, 150 stain gauges with thermal couples were installed on the side wall membrane, and 90 others were installed on the bottom membrane. The collected data from the attached 240 strain gages were used to compare analytical values with real values. Those data were very helpful to understand the membrane behaviors, optimize the membrane shapes, and scale up membrane size.

Figure 3 shows the principal strain behavior at the same moment.

1. It can be easily seen from the Figure 3 that the membrane containment was well cool-downed with constant temperature drop and the principal strain showed stable behavior up-to - 80°C.

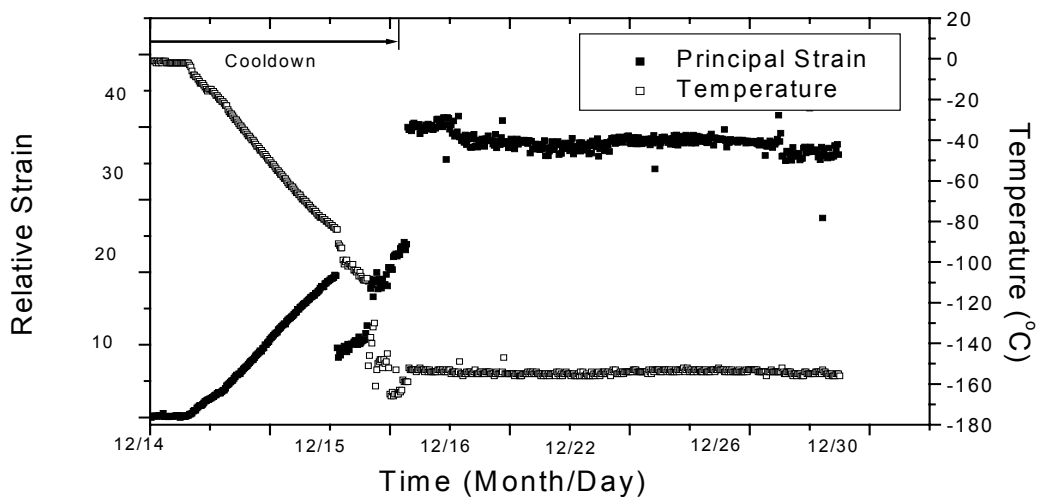


Figure 3: Principal strain behavior during cool-down and LNG filling

2. The temperature of membrane containment dropped rapidly because the filling of LNG was

started after the membrane containment reached at a certain low temperature level.

3. Because the Wheatstone bridge wasn't stable when LNG contacted with the membrane containment in a moment, measured values weren't constant at that time. But measured values recovered stable status when LNG was filled in the membrane containment at a certain level.

The insulation materials developed by KOGAS have sufficient strength to withstand the work loads and low thermal conductivity so as to fulfill the requirements of heat leak. Theoretical analysis had been performed to investigate the strengths, density, and thermal conductivity of insulation materials at each grade.

Also, experimental studies had performed to investigate above items. All experiments had conducted on the basis of ASTM [5], and we found the results were fully satisfied with the ASTM. When we compared KOGAS insulation materials with previous insulation materials, the performance of KOGAS insulation materials is superior to existing commercial insulation materials. Recently, KOGAS has installed KOGAS insulation materials to Pilot LNG storage tank and several other tanks in Incheon terminal(No. 13 to No. 18 in-ground tanks). One example of these case studies is shown in Table 1. T is transverse direction of specimen and L is the longitudinal direction of specimen in the Table 1.

Grade		A	B	C	D	E	F	G	H	I	J
Density [kg/m ³]	≧	46	52	62	77	87	94	102	110	118	128
Compressive Strength at 20°C [kg/cm ²]	≧T	1.7	2.2	3.0	4.4	5.4	6.3	7.3	8.4	9.7	11.1
Tensile Strength at 20°C [kg/cm ²]	≧L	2.5	3.0	3.9	5.4	6.5	7.3	8.3	9.3	10.2	11.8
Bending Strength at 20°C [kg/cm ²]	≧L	2.8	3.5	4.9	7.4	9.4	10.9	12.7	14.7	16.8	19.7
Shearing Strength at 20°C [kg/cm ²]	≧T	1.8	2.1	2.8	4.1	5.0	5.7	6.5	7.3	8.3	9.5
Linear Expansion Coefficient [×10 ⁻⁵ m/(m·°C)]	≧L	6.5	6.5	6.5	6.5	6.5	6.0	6.0	6.0	6.0	6.0
Thermal Conductivity [kcal/(m·hr·°C)]	≦	0.0183	0.0184	0.0187	0.0192	0.0197	0.0201	0.0205	0.0210	0.0216	0.0224
Thermal Conductivity [kcal/(m·hr·°C)]	≦	0.022	0.022	0.023	0.023	0.023	0.025	0.025	0.025	0.025	0.025
Closed Cell Content [vol%]	≧	90									
Inflammability	≦	Burning time ≤ 120 seconds, Burning length ≤ 60 mm									
Water Absorption [g/100cm ²]	≦	3.0									
Thermal Shock Test		No Crack									

Table 1: Physical Properties of KOGAS Insulation Material

In order to study the performance and the filling effects of each filling device, four different types of LNG filling devices, ring spray nozzle, top filling (straight type and splash-straight type), mixed filling(perforated type), and bottom filling(straight type, perforated type, and slit type), had installed on the inner tank. Six cool-down sensors were installed on the suspended deck and side wall, and 10 cool-down sensors were installed on the bottom of the tank.

2.3 Description of the Outer Tank

For the analysis of the outer tank, KOGAS used the commercial program calling “LUSAS” and other design programs developed by KOGAS. The analyses we carried out were as follows:

1. Linear 2D with Axis-symmetric model which applied dead load, pre-stressed load, water load, LNG load, and live load.
2. Linear 3D with Non Axis-symmetric model which applied wind load, OBE(0.1g), and SSE(0.2g) loads.
3. Thermal analysis with Axis-symmetric 2D model which applied temperature.
4. Dynamic analysis with stick model which applied OBE and SSE.

Figure 4 shows outer tank design procedure.

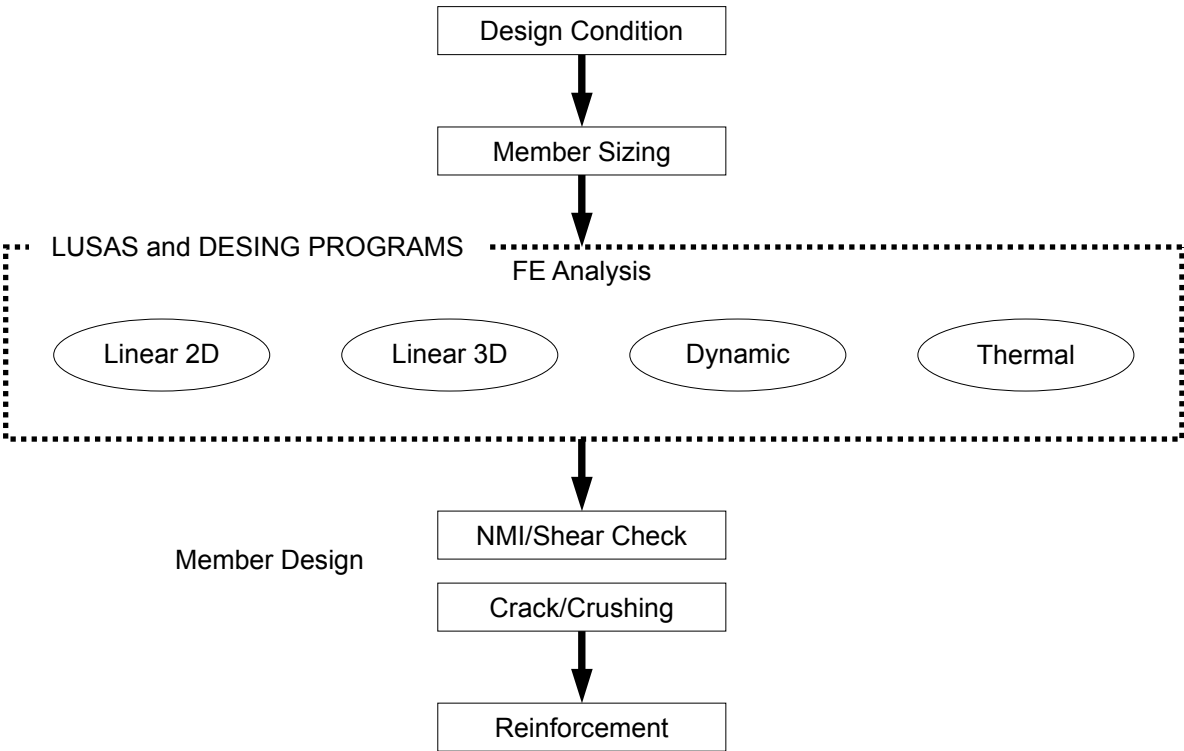


Figure 4: Outer tank design procedure

The outer tank consists of an entirely closed monolithic concrete structure – bottom slab, wall ring beam, and roof. The circular bottom slab of the outer tank has a total diameter of 16.38 m and constant thickness of 0.7 m. The cylindrical wall is made of pre-stressed concrete and has a total

height of 12.51 m up to the bottom of the ring beam. A ring beam of 1.5 m height and of 0.9 m thickness made of pre-stressed concrete completes wall. The function of the ring beam is to pick up the compressive forces resulting from the dome roof structure.

The dome roof structure consists of a concrete roof, steel roof, and suspended deck. The steel roof was assembled as a dome type on the bottom slab and was lifted by compressed air and fixed on the side wall. The dome roof is a reinforced concrete structure foamed as a sphere segment with an inner sphere diameter of 14.18 m and has from 0.4 m to 0.6 m thickness. The concrete roof and steel roof were designed independently for the steel concrete multiplex layer structure.

The steel roof is influenced by deformation of the concrete roof because the rigidity of the concrete roof is greater than that of steel roof. As a result, the deformation of the concrete roof represents that of the entire roof when the steel roof is pressed to the concrete roof by inner pressure.

The suspended deck was manufactured and suspended under the steel roof by means of rods before roof air-raising is executed. The suspended deck is made of aluminum of thickness 5 mm. Six layers of glass wool were covered on the suspended deck for insulation.

The wall and ring beam are pre-stressed in hoop direction. The tendons are anchored at buttresses. The tendons are post-tensioned and bonded with the concrete by a grouting injection.

At the inner surfaces of the wall cryogenic non-pre-stressed reinforcement with a yield strength of over 460 Mpa was used. At the outer surfaces of these members and at the inner and outer surfaces of the bottom slab and the roof hot rolled high yield re-bars of grade 400 was installed.

37 pedestals (0.9 m x 0.9 m x 1.2 m) were installed for the absorption of seismic loads.

3. PILOT LNG PLANT

Pilot LNG plant is not operated independently but linked with the existing process lines and utility facilities of Incheon terminal. Table 2 indicates the tie-in location and linked lines.

Tie-in Location	Linked lines
Entry Point 1	LNG Unloading, Flare Line
Entry Point 3	LNG Send-out, BOG Disposal, NG Send-out (Make-up Gas), LP Steam, LP Condensate, Oily Water, Potable Water
Entry Point 2	Fuel Gas, Instrument Air, Plant Air, LP Nitrogen, Fire Water, Emulsifier, Industrial Water

Table 2: The tie-in location and linked lines

The process line of pilot LNG plant consists of LNG unloading line, LNG send-out line, BOG line, Flare line, and Make-up gas line. LNG unloading line of pilot LNG plant is linked with the recirculation line of Incheon terminal. Also, BOG and Send-out lines of pilot LNG plant are connected with BOG and send-out lines of Incheon terminal.

The produced gas caused by over-pressure in the pilot tank sends to the flare line of Incheon

terminal and burns it up. Make-up gas line of pilot LNG plant is linked with high pressure NG line of Incheon terminal so as to prevent the production of negative pressure in the pilot tank.

The pressure of pilot tank can be controlled by Pressure Control Valve which is installed on BOG line. The send-out pressure (15 kg/cm²) of pilot plant is higher than the LP header pressure(12 kg/cm²) of Incheon terminal. The Pilot LNG plant has its own utility system (N₂ and air), whereas fuel gas, industrial water, and fire fighting systems are linked with Incheon terminal.

Electric utilities are received 6.6 KV from the 13th substation of Incheon terminal and use 440V, and 220V through the own transformer. The Pilot LNG plant has its own UPS(Unlimited Power System). Control system consists of the own DCS(Distributed Control System) and the own ESD(Emergency Shut Down system). The control room of Incheon terminal can monitor the pilot plant.

4. CONCLUSION

Through the development and operation of the pilot LNG storage tank, KOGAS has accumulated various knowledge and experiences on engineering design, construction, commissioning and operation for commercial LNG storage tank. On the basis of engineering and experimental data obtained from the pilot LNG storage tank, KOGAS R&D division already had completed the full design of a typical membrane containment type LNG storage tank having a net capacity of 140,000 m³ on June 2002.

In point of fact, KOGAS has the capability of designing for both membrane containment type and full containment type of LNG storage tanks. Such efforts and results will increase the competitiveness of KOGAS in the areas of conceptual design, basic and detailed design, seismic and structural analysis for LNG storage tanks.

With the use of pilot LNG storage tank, KOGAS is going to secure the optimum design capability along with the performance test and improvement of self developed membranes and insulations. Also, numerous LNG behavior trials will be carried out in the 1000 m³ storage tank. The next step is to develop the technology that can optimize the operation of LNG storage tanks and minimize the forming of BOG during the summer, where the LNG should be stored for a long period of time.

Also for a long-term project, KOGAS plans to develop the technology that can dramatically extend the remaining life of LNG storage tanks by acquiring technology that can estimate and predict the remaining life of LNG tanks.

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