The Study of LNG Leakage Monitoring in Tank

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Abstract—**Liquefied Natural Gas (LNG) is a kind of clean energy. Also, many LNG Tank and LNG-powered vessels have been designed and built around the world. However, LNG introduces the potential risk of leakage and explosion accidents. Thus, it is necessary to conduct safety assessment on the layout of typical facilities during the initial design stage. In this paper, we tested with proposed FOC (Fiber Optic Cable) for cryogenic circumstance, and DTS (Distributed temperature Sensing) system. The proposed FOC which is composed by Stainless Steel Tube, Steel, and PE Soft Jacket with polyimide material is found to be efficient for LNG harsh temperature. The proposed LNG tank monitoring system with the proposed FOC can detect the occurrence of the location, temperature, and alarm of LNG tank leakage. It provides linear continuous temperature monitoring in real time along its long distance tank as well as pipeline during loading, offloading and cool down cycles. The purpose of this study is to lead to monitoring of LNG leakage by inducing a gradual temperature change without deformation in the LNG storage tank. In addition, it is checked whether the cryogenic temperature can be detected, and the cables capable of cryogenic monitoring are tested together with the suggested cable damage degree. This study is divided into three major studies. It is a function of detecting the temperature in the tank at cryogenic temperature, maintaining the temperature change gradually to prevent the LNG tank from being deformed when LNG is inserted in the tank, and detecting the rigidity of the cable. The data were analyzed by testing the data with average temperature, time to reach temperature and loss of cable in terms of cable stiffness. Corresponding monitoring taken on time will reduce the disaster degree of accidents to the least extent.**

Keywords—**fiber optic cable, liquefied natural gas tank, distributed temperature sensing, monitoring system**

I. INTRODUCTION

Natural gas consumption is increasing in the future [1, 2]. This energy carrier has been increasing for last decades, and the broad development of the LNG (Liquefied Natural Gas) sector has been noticeable in the search for new supply directions by natural gas customers [3]. And Natural gas is favored, in many countries, over other fuels such as coal because of its relatively high quality and cleaner burning character which thus reduces pollution to the environment [4]. Liquefied natural gas (LNG) is a better form for the long distance transportation and storage of natural gas [5,6]. LNG is produced by cooling natural gas with liquid nitrogen to more than −160 ℃ under the normal pressure [7]. The resultant volume of the LNG will be 1/600 that of the original natural gas. Thus, LNG is the format for natural gas transportation and gas storage. The LNG industry and trade increased rapidly in recent years [8-10]. In this study, it is an LNG cryogenic tank test for leakage detection. The tank test is conducted using the cryogenic cable proposed in the previous study, the manufactured tank, and the DTS system. As the Nitrogen gas to be inserted into the manufactured tank, Nitrogen gas similar to LNG gas was injected to monitor the gas outflow. The manufactured tank has a height of 0.8 m and a diameter of approximately 1m at the bottom. The length of the installed optical cable was approximately 36m or longer, and a dummy cable was connected for temperature accuracy. The proposed FOC which is an optical cable to sense the temperature is composed of polyimide material and Type-3 (Stainless Steel Tube/Steel/PE Soft Jacket) cable structure. For LNG, it was tested whether it was possible to monitor the occurrence of leakage at a cryogenic temperature of −160℃ or higher. In the carried out tank test, it was possible to monitor the occurrence of leakage even at a cryogenic temperature of −196 ℃ or higher. This study is divided into three major studies. It is a function of detecting the temperature in the tank at cryogenic temperature, maintaining the temperature change gradually to prevent the LNG tank from being deformed when LNG is inserted in the tank, and detecting the rigidity of the cable. The data were analyzed by testing the data with average temperature, time to reach temperature and cable loss in terms of cable stiffness.

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II. TANK LEAKAGE MONITORING SYSTEM

A. Designed FOC (Fiber Optic Cable)

We designed the structure (3-Types) and cladding materials (among Gold, Acrylate, Aluminum, and Polyimide) based on several experiments, for LNG Monitoring System. In the study of the material and structure of optical cables, two major experiments were conducted. These are the temperature chamber test and the cryogenic test. In the temperature chamber, the temperature is raised from −10.9 ℃ to 41.3 ℃, and the values of loss rate, temperature accuracy, and temperature transferability are analyzed. Polyimide and Acrylate showed good results in the study of materials reaching −10 ℃, and polyimide could get +40 ℃ faster than other

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materials. In structural studies using polyimide materials as a common material, Type-3 (Stainless Steel Tube/Steel/PE Soft Jacket) cable structure is effective for LNG leak monitoring. In chamber test, the first step is set the temperature of the temperature chamber to −10℃, and set the chamber temperature to −10℃. Trace is saved every 10 seconds until the temperature of the chamber reaches −10℃ and Fluke contact thermometer reference temperature is −10℃. The second step is maintaining the temperature at −10 ℃ for 10 minutes and save trace. The third step is set the chamber temperature to 40℃ and trace data is stored in units of 10 seconds when the chamber. Also, temperature is between −10℃ and 40℃ and Fluke contact thermometer reference temperature is 40℃. The last step is maintaining the temperature at 40℃. In addition, when reaching 40℃, the temperature is maintained for 10 minutes and the trace is saved.

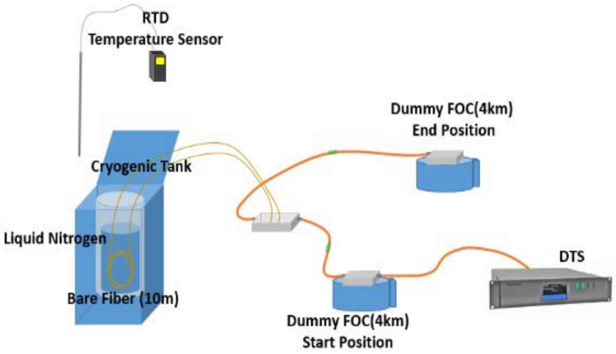

Figure 1. The cryogenic experiment

In cryogenic experiment, the cryogenic temperature, connect the DTS and insert Nitrogen into the cryogenic tank. After Nitrogen is filled, the temperature accuracy is monitored using RTD (Resistance Temperature Detector) temperature sensor to check the temperature accuracy. The starting point and the ending point of the cable are connected to each other by 4km of a dummy cable (Fig. 1).

Benefit of designed FOC, it provides continuous temperature monitoring in the real time along its long length, so it could offer a real time monitoring during loading, offloading and cool down cycles. The proposed LNG Tank monitoring system using the proposed Fiber Optical Cables, which are developed FOC Material as well as FOC Structure. Also, DTS can be installed in LNG tank to detect gas leaks to prevent major disasters, and can be applied to various fields using linear sensors.

B. *LNG Tank Leakage Experiment*

The manufactured tank is tested by injecting nitrogen from three nozzles.

The main purpose makes it efficient Cool-Down. This experiment is to verify the gradual temperature change, the gradual temperature change in the tank bottom and side, and the durability as well as robustness of cryogenic FOC (Fiber Optic Cable) (Fig. 2).

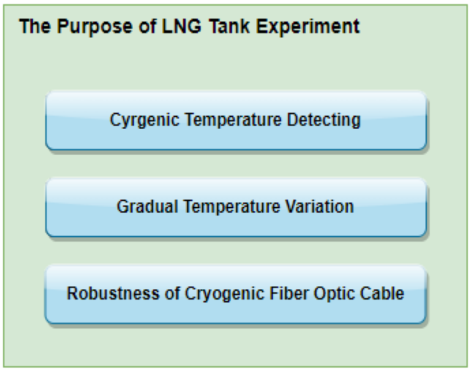

Figure 2. The purpose of LNG experiment

The comparison at the position of D and the position of E is a comparison of the maximum and minimum values of the temperature difference between the contacted and the non-contact of the nitrogen solution (Fig. 3).

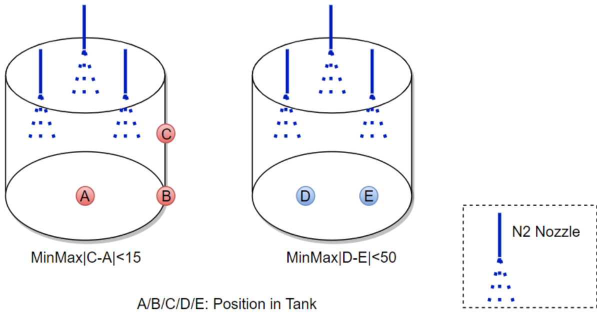

Figure 3. Temperature Control in each position during Nitrogen Insertion

Each temperature difference must not exceed 50 ℃ in absolute value. If a temperature difference of 50 ℃ occurs, distortion of the welded part of the tank may occur. The positions of A and C are intended to measure the temperature difference between the side and the bottom of the tank. In the case of the tank, nitrogen is inserted while controlling the temperature and pressure of less than 15 ℃ to prevent the tank from being warped or deformed due to the temperature difference between the side and the bottom.

Figure 4. Interior tank

Figure 5. Exterior tank

1) Cool-down

Drying stage to remove moisture to execute cool-down, purging stage to create an environment where explosion occurs by replacing the inside of the tank (Figs. 4 and 5) with inert gas in an oil tanker or tank It is divided into a cool-down stage, which is a processing stage (Fig. 6).

Figure 6. Cool-Down Processing

The general conditions for inserting LNG gas into the tank are as follows. The target cooling rate of the inner tank is 3°C/h, up to 5°C/h, and the maximum temperature difference between two adjacent shells or bottom thermocouples 30°C. Also, for membrane tanks, the following cooling rate is −10 ℃/h, the target cooling rate for the membrane up to 15 ℃/h, and the maximum temperature difference between two adjacent wall or floor thermocouples is 50 ℃.

2) Tank structure

The manufactured tank has a height of 0.8m and a diameter of approximately 1m at the bottom Fig. 7. The length of the installed optical cable was approximately 36m or longer, and a dummy cable was connected for temperature accuracy. The FOC length is checked on the DTS monitoring system. The DTS settings for detecting pipeline leaks are as follows.

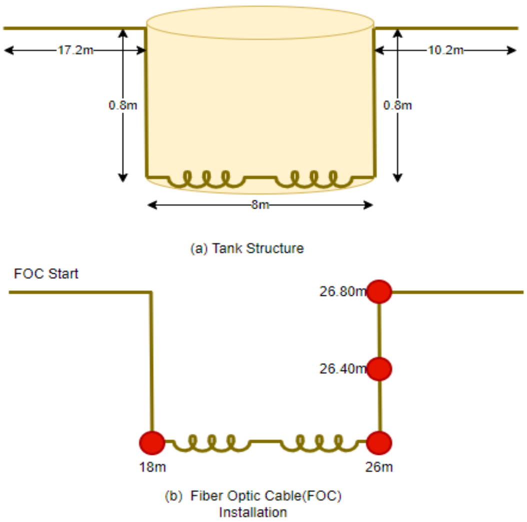

Figure 7. Tank Structure and FOC Installation

3) Cryogenic tank test

The cryogenic tank test is divided into three stages. It is divided into inserting nitrogen, adjusting the pressure while inserting nitrogen, and a step of stabilizing the temperature.

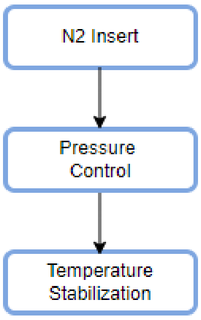

Figure 8. Cool-down tank cryogenic test step

First, when nitrogen is inserted into the tank, the pressure is controlled by inserting it for 30 minutes and stopping the insertion for 10 minutes (Fig. 8).

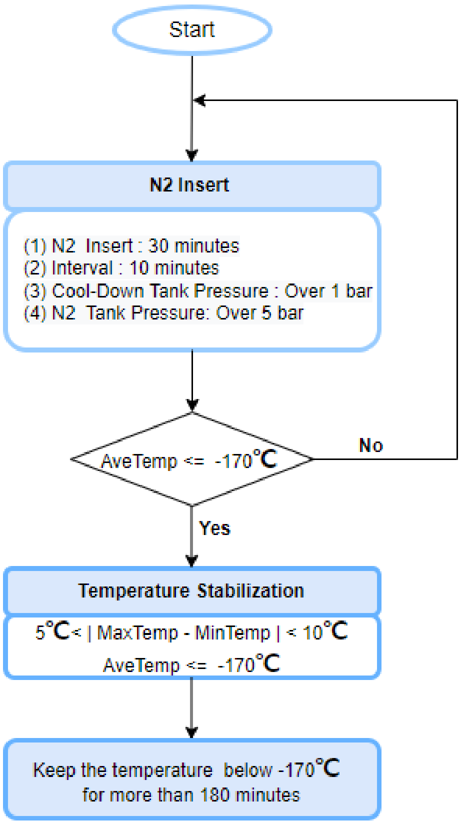

Figure 9. Experiment Processing

Repeat the test by adjusting the pressure to 1 bar or more in the cool-down tank and 5 bar or more in the nitrogen tank to be inserted. Repeated insertion is continued until the temperature is below −170 ℃, and when the temperature is below −170 ℃, the range of the maximum and minimum temperature values is maintained in the range of 5 ℃ to 10 ℃. The temperature of the down tank was maintained at a temperature of 180 ℃ or more and −170 ℃ or lower. The −170°C threshold as a reference here is a value obtained from several cool-down tank tests Fig. 9). DTD setting parameter is below (Table I).

TABLE I. DTS SETTING PARAMETER

No.	Parameter	Value
1	Total FOC Length(cm)	3600
2	Sampling Interval(m)	0.50
3	Spatial Resolution(m)	0.50
4	Measure Time(sec)	10
5	The Number of Check Points	3601

III. RESULT

In the cryogenic tank test result, the cables are laid in the tank as curled rather than aligned. Therefore, the cryogenic phenomenon occurred at −220℃ or more depending on the cable laying at the 18 m point.

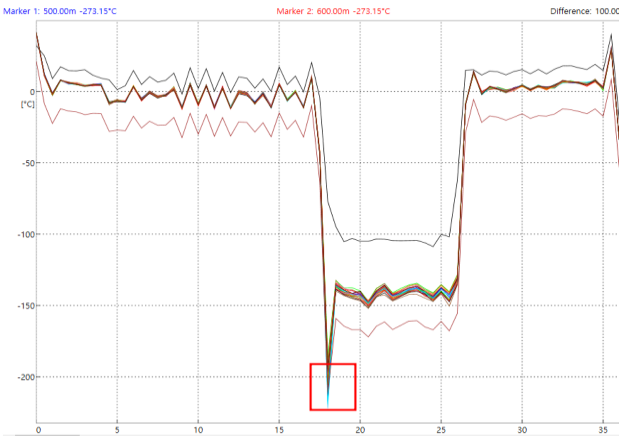

Figure 10. Peak phenomenon(−220 ℃) occurred at 18m

In the LNG tank test, the test analysis analyzes the data in four ways: temperature detection at cryogenic temperature, gradual temperature change, cable rigidity, and cable peculiarities (Fig. 10).

A. Detect at Cryogenic Temperatures

The cryogenic temperature at the bottom of the tank was detected at 22m to 24m, and the temperature average (Fig. 11), Standard Deviation (STD)(Fig. 12), and cable loss (Loss) (Fig. 13)were analyzed. The analyzed data shows that the temperature detection in the cryogenic state shows a cryogenic state with an average temperature of −140 ℃ or higher in the 22m to 24m section, and an even distribution of 7.5 or more in the temperature STD. However, as a singular phenomenon, the average temperature at the 22m point shows a cryogenic state of −142 ℃ or higher, and the standard deviation of the temperature is 8.19 or higher compared to other points, which is relatively large. At 23.5m, the standard deviation of temperature was the smallest, and the cable loss was 0.085, which is less than the standard deviation of 0.09 at other points.

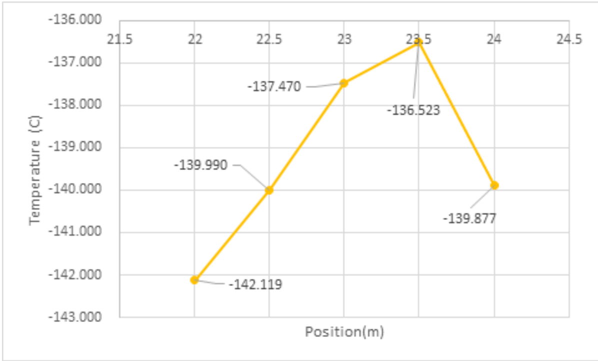

Figure 11. Average temperature from 22m to 24m

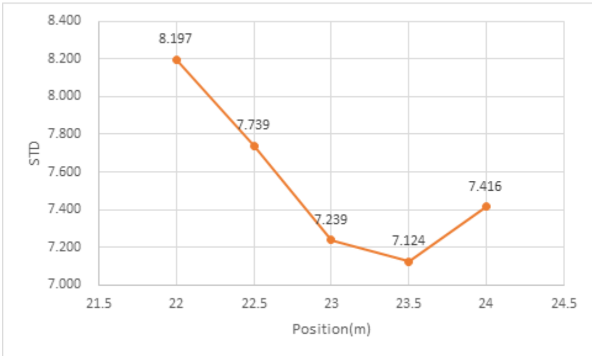

Figure 12. STD from 22m to 24m

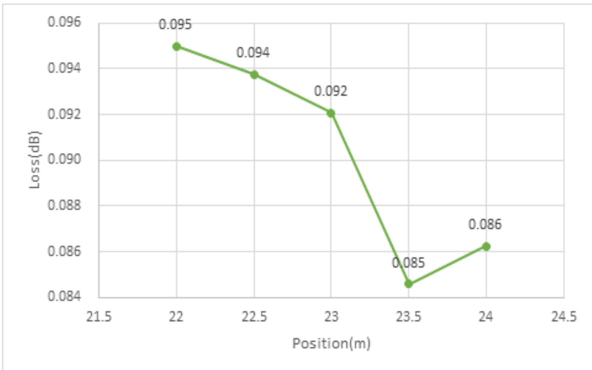

Figure 13. FOC Loss from 22m to 24m

B. Gradual Temperature Change

Analyze the time span and temperature STD for cryogenic temperature at 17.5m and 18m to 26m, and the average and temperature STD at 26.5m. Data for gradual temperature change are analyzed at 17.5 m and 26.5m. Each average temperature is −37.8℃ at 17.5m and −8.17℃ at 26.5m. The points 17.5m and 26.5m are the sides of the tank, and there is a possibility that nitrogen can be directly exposed by the three nozzles (Table II). This situation may cause the data on both sides to be expressed as relatively different values. From the 18m point to the 26.5m point, the temperature drops by an average of −1.15 ° per 60 seconds until the temperature change from −170℃ to the 26m point. change may be different compared to other parts. For this phenomenon, STD at 18m and 26m are 38.29 and 21.35, which are larger than the average STD of 15.9 at other locations.

TABLE II. STD AND AVERAGE TEMPERATURE OF 17.5M, 26.5M

Temperature	Position	
	17.5m	26.5m
Average Temperature (℃)	-37.801	-8.170
STD	8.138	4.908

C. Durability

Durability analyzes the temperature average, STD, and cable Loss values at the point of 21m to 25m. In order to analyze the rigidity of the cable, the average temperature from the 21m point to the 25m point is −139.19℃, and STD of this part is also evenly distributed as 7.63. In addition, the cable loss, which expresses the robustness of the optical cable, is an average of 0.089, which is not higher than the general average loss value (Fig. 14).

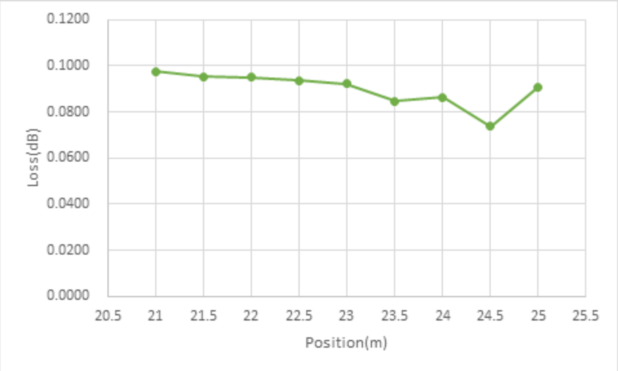

Figure 14. FOC Loss from 21m to 25m

D. Cryogenic Peak

A peak occurs at 18m and analyzes the temperature average, STD, and cable loss (Fig. 15). Analyze the temperature change at 18 m at the point where the cryogenic peak occurs and the data change from the 22 m point to the 24m point at the bottom of the tank shown in the gradual temperature change data. In the average temperature change, −196℃ at 18m point and −139.19℃ average temperature at 22m~24m point. Also, the standard deviation is 26.78 at 18m and 7.53 at 22m to 24m, indicating an unstable state in temperature change at 18m. In terms of cable loss, the loss at the 18m point was 0.105dB, which was larger than the value of 0.09.

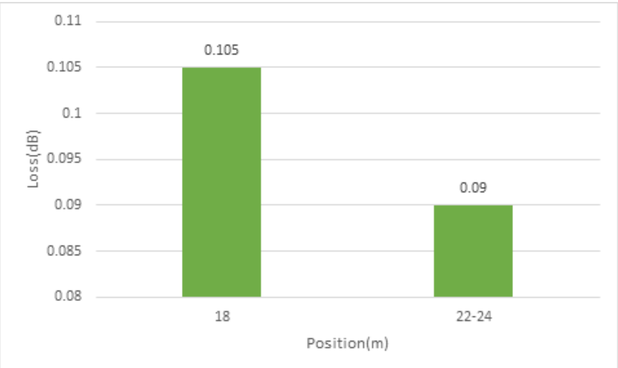

Figure 15. The loss of peak point(18m) and between 22m and 24m

IV. CONCLUSION

In this experiment, the tank test is conducted using the situation DTS in the tank and the proposed cable using tank manufacturing. The purpose of the tank test is to test the temperature sensing at cryogenic temperatures, the overall temperature change, and the robustness of the optical cable at cryogenic temperatures.

In this study, the average temperature, standard deviation, and cable loss were analyzed and the proposed method showed 0.092dB of both average temperature and loss at −196℃ even at cryogenic temperature −196℃ at the location of gradual temperature change (22m–24m) and at 18m, the ideal peak point. In terms of the cable's robustness, the optical cable loss value was 0.089 on average, indicating a robust cable compared to the general loss value. As a future study, it is necessary to further study the leak detection according to the FOC installation method, and to efficiently exact the ala value by analyzing each data value.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Ahri Lee and Sukyong Song conducted the research; Seungjun Han and YunSeob Han analyzed the data; Ahri wrote the paper; all authors had approved the final version.

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