Optimal Design of Cryogenic Insulation System for Large Liquefied Natural Gas (LNG) Storage Tanks Based on Operation Factors

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Abstract. Liquefied natural gas (LNG), as a recognized clean energy, has seen a rapid increase in global consumption in recent years. As the core equipment of the LNG receiving terminal, the large LNG storage tanks, its' cryogenic insulation system design is particularly important. The insulation system is mainly used to maximize the control of the daily evaporation of cold storage tanks, so as to achieve long-term storage of LNG in the tank. Its design is particularly important. At present, the internal design of the industry often only considers the construction conditions, without comprehensive consideration of operation, maintenance and other full-life cycle conditions. This paper analyzes and optimizes the design of the insulation system of large LNG storage tanks from the aspects of the performance of the insulation material itself, the construction period, pre-cooling start-up, operation and maintenance and other comprehensive operating factors. And taking the 30,000 m^3 LNG storage tanks as an example, through the analysis and comparison of some columns, obtained the optimal daily evaporation rate requirements of the insulation system, which can be used as a reference for the design of LNG projects during the construction period.

1. Introduction

With the upgrading of clean energy consumption and the need for dual-carbon targets, in recent years, natural gas consumption in China and other Asia-Pacific regions has witnessed explosive growth in recent years[1], and the construction of coastal LNG storage facilities in these regions will also enter the fast track. In addition, in order to meet the government's natural gas peak shaving and storage requirements in some inland areas, local urban gas enterprises will also build a large number of small and medium-sized LNG storage facilities in inland, rivers and a few coastal areas in the next few years.

As an important equipment in the storage process of LNG project, the operating pressure of LNG tank is -1.0~29.0kPa.G, and the design temperature of the inner tank is -162 ℃. Because the temperature difference between the inside and outside of the LNG tank generates heat input, and limited by the cryogenic insulation effect of the cryogenic insulation material, the low-temperature LNG in the LNG tank will be heated and gasified. If the heat leakage is serious, the production of boil-off gas (BOG) will increase sharply, increasing the energy consumption of the compressor treatment will also bring safety hazards, so the maximum allowable BOR of the design of the LNG tank is the most important indicator to measure the cryogenic insulation and cryogenic insulation effect of the tank.

At present, the design requirements for evaporation rate of 160,000m^3, 200,000m^3 and even larger LNG tanks are relatively mature, and the value of BOR is required to be 0.04%~0.05%/day under the working volume converted equivalent mass (wt), i.e. 0.04%~0.05wt%/day; For LNG tanks configured for 30,000~160,000 m^3 inland small and medium-sized LNG projects, there is currently no uniform requirement for the daily evaporation rate of domestic tanks, which is generally determined by the owner and the designer after consultation.

In terms of technical scheme research of cryogenic insulation system for large LNG storage tanks, in recent years, researchers such as Jeong-Soo LEE[2] of South Korea have successively carried out cryogenic insulation system research at the design and construction stage of LNG storage, while researchers such as Jiang Li[3] of China have carried out a large number of finite element analysis and design research during the construction process. At present, there is no unified standard requirement for the design of the maximum allowable daily evaporation rate (BOR), Generally, it is determined by the Owner and the Contractor after negotiation. In the design, only the construction conditions are considered, and the operation, maintenance and other full-life cycle conditions are not comprehensively considered.

Based on the current research status above, this paper analyzes and optimizes the design of the insulation system of large LNG storage tanks from the aspects of the performance of the insulation material itself, the construction period, precooling start-up, operation and maintenance and other comprehensive operating costs, and takes 30,000 m^3 of LNG storage tanks as an example to obtain the design requirements for the optimal daily evaporation rate of the insulation system, which can be

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used as a reference for the design of LNG storage tanks in the construction stage.

2. Evaporation mechanism and insulation structure of LNG storage tank

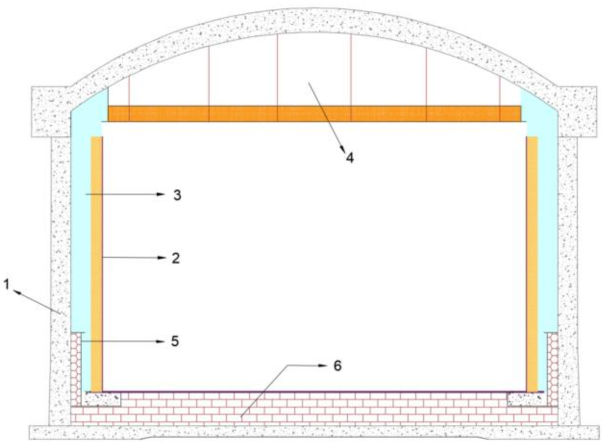
2.1. Evaporation mechanism of LNG storage tank

The main component of natural gas is methane (CH4), and its thermodynamic three-phase point is below 0 ℃. It cannot be "liquefied" by pressurization like LPG at room temperature, but only by reducing the temperature to -162 ℃. Therefore, LNG is different from gasoline, diesel, LPG and other hydrocarbons, and its volatilization can be reduced by pressurization. The cryogenic liquid inside the LNG storage tank is in the thermodynamic "saturated boiling state" of -162 ℃. Although the heat input energy is controlled by cryogenic insulation materials around the storage tank, there is still a steady stream of BOG gas[4]. The generated BOG gas is directly pressurized and exported through the BOG compressor, or sent to the Recondenser to mix with LNG with certain undercooling, and then pressurized and sent to the gasifier through the high-pressure pump. After gasification, it is exported through the pipe network[5].

2.2. Insulation structure of LNG storage tank

The main function of cryogenic insulation is to minimize the heat input of storage tank and control the evaporation rate of storage tank, so as to realize the function of long-term storage of LNG storage tank; At the same time, the function of the cryogenic insulation structure needs to protect the non low temperature components of the storage tank (mainly the outside of the storage tank) to keep it at the required ambient temperature, limit the damage of the foundation or soil at the bottom of the storage tank due to frost heaving, and prevent and minimize the condensation and icing of water vapor on the external surface of the storage tank. Figure 1 shows the structural diagram of 30,000m^3 LNG storage tank of a built LNG transfer station in China.

The type of LNG storage tank is full capacity tank, with the outer tank height of 25.3m and diameter of 45m. The outer tank is a prestressed concrete structure, the inner tank is 9% Ni low-temperature steel, and the inner and outer tanks are filled with cryogenic insulation materials[6]. The cold storage material of the bottom of the tank is 450mm thick foam glass brick material, which has a certain bearing strength. Besides holding the cooling effect, it also has the function of bearing the weight of the upper tank and the LNG liquid[7]. The cryogenic insulation of tank wall is composed of 300mm elastic felt and 700mm thick expanded perlite powder. The elastic felt is close to the inner tank wall plate and has certain resilience, which is used to absorb the extrusion pressure of perlite on the inner tank during the operation of the inner tank; The cryogenic insulation material of tank top ceiling is composed of 1.0~1.2m glass wool cryogenic insulation material.



1) Prestressed concrete outer tank; 2) 9% Ni steel inner tank; 3) Insulation layer of tank wall (inner elastic felt + outer expanded perlite); 4) Ceiling glass wool insulation layer; 5) TPS insulation layer (foam glass brick); 6) Bottom insulation layer (foam glass brick)

Figure 1. Structural diagram of typical LNG storage tank

3. Factors to be considered in the value of BOR in LNG tank design

According to the cryogenic insulation design experience of low-temperature storage tank, the larger the storage tank volume, the smaller the apportioned heat exchange area per unit volume of LNG[8]. Therefore, under the same cryogenic insulation thickness design, the larger the storage tank volume, the smaller the general BOR. According to the experience of tank construction at home and abroad:

(1) According to the construction experience of 1,000~20,000m^3 LNG storage tanks in most small liquid chemical plants and peak shaving stations in China, the general BOR requirement is 0.10~0.15wt%/day.

(2) The BOR of LNG storage tanks above 160,000 m^3 in LNG terminal is generally required to be less than 0.04~0.05wt% / day.

Generally speaking, the BOR design of LNG storage tank shall be finally determined after comprehensive consideration of cryogenic insulation effect, cryogenic insulation material cost during construction, construction configuration and operation cost of low-pressure BOG compressor. According to the above trend of the relationship between tank capacity and evaporation rate, it is tentatively assumed that the design BOR of 30,000 m^3 LNG tank is 0.05~0.10wt%/day. Later, the cost of cryogenic insulation materials and later operation costs under different BOR will be compared and analyzed.

4. Cryogenic insulation material cost of LNG storage tank under different BOR

Referring to the structural dimensions of 30,000 m^3 LNG storage tank in LNG transfer station in Figure 1 above, the cost of cryogenic insulation materials when the daily evaporation rate of storage tank is 0.05 wt%/day, 0.07 wt%/day, 0.08 wt%/day and 0.1 wt%/day respectively. The size, consumption and cost of cryogenic insulation materials for 30,000 m^3 LNG storage tank under each BOR are shown in Table 1, table 2 and table 3 respectively.

Table 1. cryogenic insulation thickness of various parts of LNG storage tank when BOR is 0.05, 0.07, 0.08 and 0.10 (wt%/day) respectively

Daily evaporation rate	Foam glass (tank bottom)	Elastic felt (tank wall)	Expanded perlite (tank wall)	Glass wool (tank top)
0.05%	0.90m	0.3m	1.20m	1.5m
0.07%	0.55m	0.3m	0.85m	1.2m
0.08%	0.45m	0.3m	0.70m	1.0m
0.10%	0.35m	0.3m	0.60m	1.0m

Table 2. Consumption of cryogenic insulation materials for LNG storage tank when BOR is 0.05, 0.07, 0.08 and 0.10 (wt%/day) respectively

Daily evaporation rate	Foam glass (m^3)	Elastic felt (m^3)	Expanded perlite (m^3)	Glass wool(m^3)
0.05%	1500(TYPE 800), 135(TYPE 1600)	1100	4408	2730
0.07%	920(TYPE 800), 85(TYPE 1600)	1100	3100	2190
0.08%	750(TYPE 800), 68(TYPE 1600)	1100	2545	1820
0.10%	590(TYPE 800), 50(TYPE 1600)	1100	2200	1820

Table 3. Cost of cryogenic insulation materials for LNG storage tank when BOR is 0.05, 0.07, 0.08 and 0.10 (wt% / day) respectively

Daily evaporation rate	Tank cryogenic insulation material cost(×RMB 10,000)	Proportion in tank investment cost percentage
0.05%	1250	8.9%
0.07%	870	6.2%
0.08%	740	5.2%
0.10%	670	4.8%

Remarks: the cost calculation of foam glass brick, glass wool, elastic felt and expanded perlite cold preservation materials refer to the recent domestic project prices.

5. Analysis of operation cost under different BOR of LNG storage tank

5.1. Cryogenic BOG compressor operation

The calculation of low temperature BOG compressor mainly considers the following BOG generation factors: heat leakage of storage tank, pipeline, tanker, ship loading, unloading, heat input of pump and atmospheric pressure change. The decrease of BOG is mainly caused by gaseous export. The difference between the sum of BOG generating factors and BOG reducing factors is the BOG design quantity.

In the BOG design capacity, the BOG generated by the daily evaporation of a 30,000 m3 LNG storage tank accounts for only about 5% of the total capacity of the LNG transfer station. It can be inferred that the daily evaporation of the storage tank has no direct impact on the selection of the low-pressure BOG compressor and will hardly increase the construction cost or use cost of the low-pressure BOG compressor.

5.2. LNG transfer station is not put into operation (Or no export condition)

According to the recent construction of LNG transfer station, it often occurs that the early resource market cannot be implemented or the supporting construction cycle of LNG transfer station is longer than that of storage tank. It is assumed that all BOGs in the whole site are vented within one month during start-up and commissioning, and an overhaul within 25 years of storage tank operation life (considering one month venting) is considered to compare the economic impact caused by different daily evaporation rates of storage tanks.

Table 4. conversion cost of tank venting evaporation and venting gas loss when BOR is 0.05, 0.07, 0.08 and 0.10 (wt%/day) respectively

BOR（wt%/day）	0.05%	0.07%	0.08%	0.1%
Daily evaporation (kg)	7178	9960	11376	14232
Conversion loss(×10^4 RMB)	120	170	191	240

According to the above analysis, taking into account the investment in cryogenic insulation materials, start-up, operation and maintenance costs of the storage tank, the comprehensive costs of 30000 m3 LNG storage tank under different BORs are shown in Table 5.

Table 5. Comparison of comprehensive expenses when the BOR is 0.05, 0.07, 0.08 and 0.10 (wt%/day) respectively (10^4 RMB)

BOR-wt%/day	Tank cryogenic insulation material cost	Converted cost of tank overhaul and venting before or after operation	The above two expenses are combined
0.05%	1250	120×2	1490
0.07%	870	170×2	1210
0.08%	740	191×2	1122
0.10%	670	240×2	1150

Therefore, considering the investment cost of cryogenic insulation materials during the construction period of LNG storage tank and the cost of BOG venting loss during the operation period, the maximum design value of storage tank BOR of 0.08wt%/day can be selected as the value requirement for the design BOR of 30,000 m^3 storage tank in the LNG transfer station. Under the BOR design requirements, the investment cost of cryogenic insulation materials of storage tanks accounts for about 5.2% of the EPC cost of storage tanks, which is in line with the proportion of the cost of cryogenic insulation materials of general LNG storage tanks in the EPC Construction Cost of storage tanks[9].

6. Conclusion

Through the research and analyzes the importance of reasonable setting of BOR value in design, and analyzes various factors to be considered in setting the BOR value of LNG storage tank. The main conclusions of this paper are as follows:

(1) For the large LNG storage tanks, there is no uniform requirement for the design value of the tank BOR in the industry, which should be considered after considering the cryogenic insulation effect, the cost of low-temperature insulation materials during construction, the configuration efficiency of BOG compressor, the loss of BOG emissions during commissioning and other factors in the operation period.

(2) Taking 30,000m^3 storage tank as an example, through comprehensive analysis in this paper, 0.08wt%/day can be selected as the maximum allowable BOR value requirement for LNG storage tank design. The relevant analysis process can be used as a reference for insulation design and evaporation rate selection of other large LNG storage tanks.

(3) In addition, for the peak-shaving LNG transfer station, because there may be no external transportation for a long time except for the winter supply guarantee period, the design can also consider that the BOR requirement value is relatively lower after discussion with the construction unit, so even if the investment cost of cryogenic insulation materials during the construction period is appropriately increased, it is very beneficial to reduce the long-term operation cost of the project (BOG compressor and other equipment).

Acknowledgments

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