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Research and Application of Commissioning Technology for LNG Tank Zero Discharge Commissioning

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Abstract: Before cooling, the LNG tank is filled with nitrogen. During the test run, the tank will be gradually cooled from normal temperature to - 162 C. A large amount of BOG with high nitrogen content will be discharged to the torch in a short time, resulting in a great waste of resources. This paper discusses the difficulty of BOG recovery in LNG tank cooling by studying the conventional methods of LNG tank commissioning. Full nitrogen replacement and "BOG+LNG" tank cooling process are adopted before commissioning. The utilization efficiency of cold energy in receiving station is improved, the flow rate of BOG in receiving station is reduced, and the B in cooling process of LNG tank is realized. BOG zero emissions. The results showed that: (1) nitrogen in LNG tank could be fully replaced by "top intake and bottom exhaust" replacement method; (2) BOG + LNG cooling process could cool the tank, and effectively reduce the BOG flow rate in the cooling process of LNG tank to meet the processing capacity of receiving station and realize zero BOG emission in the cooling process of LNG tank. The technology of LNG tank zero emission commissioning has great reference value for the tank cooling of new storage tanks or receiving stations with the capacity of gasification and outward transportation. At the same time, "top intake bottom exhaust" nitrogen replacement, "BOG + LNG" cooling process has certain enlightenment for optimizing LNG tank design.

Keywords: LNG Tank, Pre-cool Down, Nitrogen Purge, BOG Zero Emission, Dynamic Simulation

1. Introduction

Since the first phase of Guangdong Dapeng LNG (liquefied natural gas) project was put into operation in 2006, the construction of China's coastal LNG receiving station has reached a peak [1]. Up to now, 11 LNG receiving stations have been put into operation, 32 atmospheric LNG tanks of 16 *104m^3 have been put into operation, and more than a dozen large storage tanks are about to be put into operation or under construction. LNG tanks need to be gradually cooled to -162°C, before being put into use. Each 16* 104m^3 atmospheric pressure LNG tank will consume about 2200m^3 of LNG, and the BOG generated during the cooling process will be basically emptied, resulting in a lot of waste. In this paper, through optimizing the cooling process of the tank, using the "top intake and bottom exhaust" method to replace nitrogen ahead of time, through the "BOG + LNG" cooling process (guide to self-evaporating low-temperature BOG into the receiving station, using LNG spray temperature control tank progressive pre-cooling, until the completion of cooling small filling LNG). It is of great significance to reduce the BOG flow rate in the cooling process of storage tanks, satisfy the working condition requirements of receiving stations, realize the zero emission of BOG in the cooling of storage tanks and save the commissioning cost for the newly added storage tanks in the LNG receiving stations which have been put into operation in China.

2. Traditional LNG Tank Cooling Process and BOG Recovery Difficulties

LNG tank cooling process is mainly through LNG spraying the tank full of nitrogen gas, cooling the tank wall and tank bottom at a cooling rate of 3-5°C/h, until the tank bottom temperature detector detection temperature cooled to - 155°C below, the tank began to small flow rate of slow liquid, and establish a certain level of BOG generated in the cooling process. The temperature gradient at the bottom of the tank or at any two adjacent detection points on the tank wall should not exceed 30°C, and the temperature gradient at the bottom of the tank and the surface of the tank wall should not exceed 50°C [2-3]. The pre-cooling process of the tank is shown in Figure 1 below. There are the following difficulties in realizing zero emission in LNG tank cooling: (2) The tank is filled with nitrogen before cooling, and the high nitrogen content in BOG during cooling affects the process system. (2) the consumption of LNG is large during the cooling process of tank, and more BOG is produced in short time. (3) the normal process of receiving station can not deal with the large amount of BOG produced during the cooling process of storage tanks. Therefore, it is necessary to solve the problems of high nitrogen content in BOG and large BOG production in a short time to implement zero emission of LNG tank cooling.

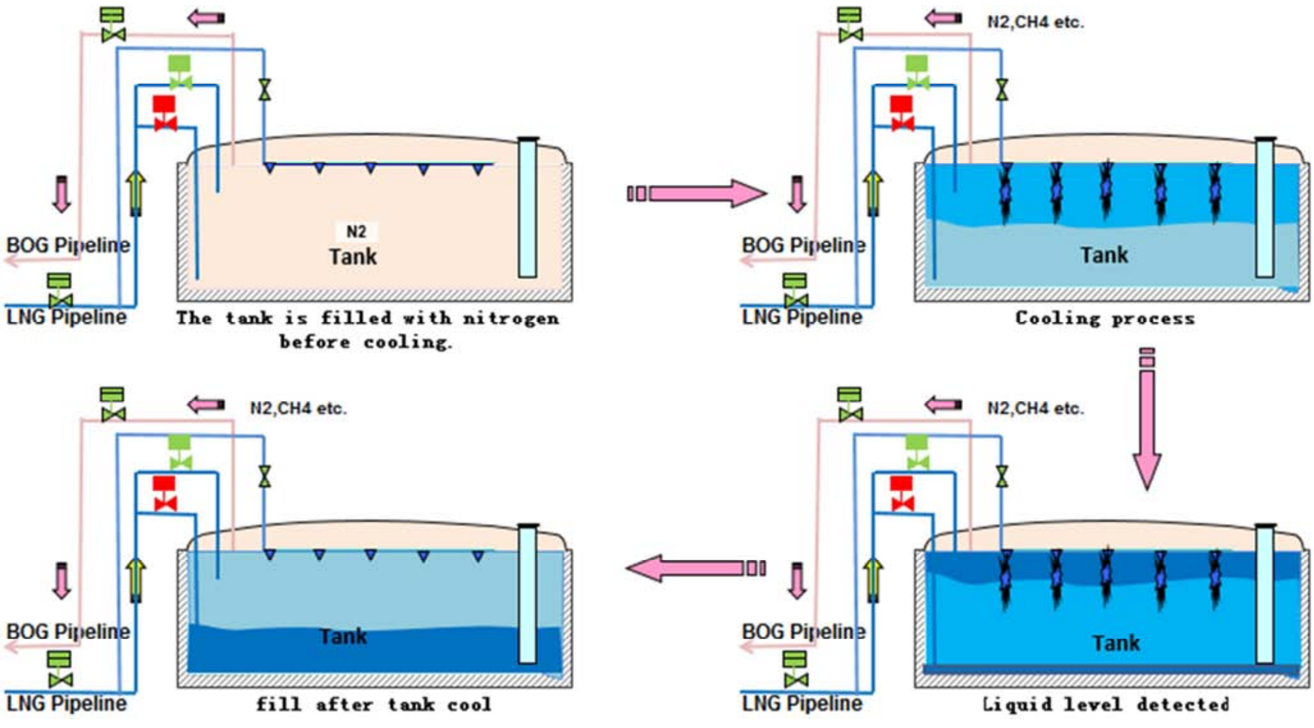

Figure 1. *Cooling process of large tank.*

3. Key Technologies of Zero Discharge for Commissioning of LNG Tanks

3.1. Top Air Intake Bottom Exhaust Nitrogen Replacement

3.1.1. Conception and Thinking of Nitrogen Replacement

The traditional way of tank cooling does not consider the nitrogen displacement completely, but uses the BOG of unloading pipeline to replace or not to cool the tank directly. As a result, the nitrogen content in the BOG is high when the tank is cooled, and the residual nitrogen is gradually reduced after the tank is cooled and put into use for a period of time. Combined with the density characteristics of methane (the main component of LNG) and nitrogen [4] as follows: Table 1 and LNG tank piping arrangement [5], the following nitrogen replacement scenarios are proposed:

(1) Using the density properties of methane and nitrogen, normal temperature natural gas (BOG) is injected from the top of the tank through a process pipeline into the normal temperature tank, as shown in Figure 2 below.

(2) Controlling the tank to be in a stable state, the nitrogen is expelled through the nitrogen blowing pipeline at the bottom of the tank, as shown in Figure 2 below:

(3) Closely monitor the nitrogen outlet combustible gas, the nitrogen containing combustible gas into the torch until the replacement qualified

Table 1. *Density of methane and nitrogen at different temperatures of 117kpa.*

T°C	-140	-120	-100	-80	-50	-20	0	10	20	30
CH_4 kg/m³	1.74	1.5	1.32	1.19	1.02	0.89	0.83	0.8	0.77	0.74
N_2 kg/m³	2.98	2.59	2.29	2.05	1.77	1.56	1.44	1.42	1.34	1.3

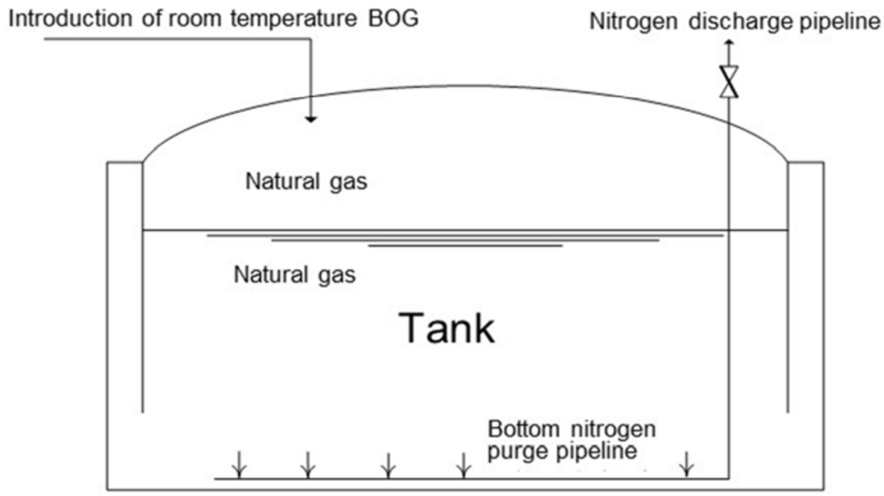

Figure 2. *Nitrogen replacement process at room temperature BOG.*

3.1.2. Implementation of Nitrogen Replacement by Natural Gas at Room Temperature

Table 2. *Methane content detection at nitrogen outlet.*

Flow m³/h	Time	Test situation
5000	6 hours later	Detection of storage tank dome area 95%
5000	34 hours later	The outlet detected methane.
5000	38 hours later	The outlet detected methane. 50%
5000	40 hours later	The outlet detected methane. 85%

By adjusting the load of low temperature BOG compressor in receiving station, the outlet natural gas (BOG) will enter the tank from the top of the tank through the empty pipeline at receiving station. The pressure of the tank will be controlled to 20 kpa. The amount of gas entering the tank will be adjusted to about 5 000 m/h. The nitrogen will be extracted from the nitrogen purging pipeline at the bottom of the tank. The whole replacement process will last 40%. When the methane content at the nitrogen outlet is 85%, the replacement stops. The methane detection at the nitrogen outlet is shown in Table 2.

3.2. Dynamic Simulation and Analysis of Tank Cooling

3.2.1. Commissioning Process of LNG Tank in Traditional Commissioning

LNG spraying method is used to cool the tank directly. LNG spraying method is used to cool the surrounding gas as shown in Figure. 3 below. Then the cooling gas absorbs heat and cooling the inner wall of the tank (mainly the inner tank steel plate, suspended ceiling steel plate, tank bottom, tank top and annular space insulation material) until the tank is cooled, most of the cooling process is completed. The cooling capacity is not enough to absorb heat directly to discharge to the torch.

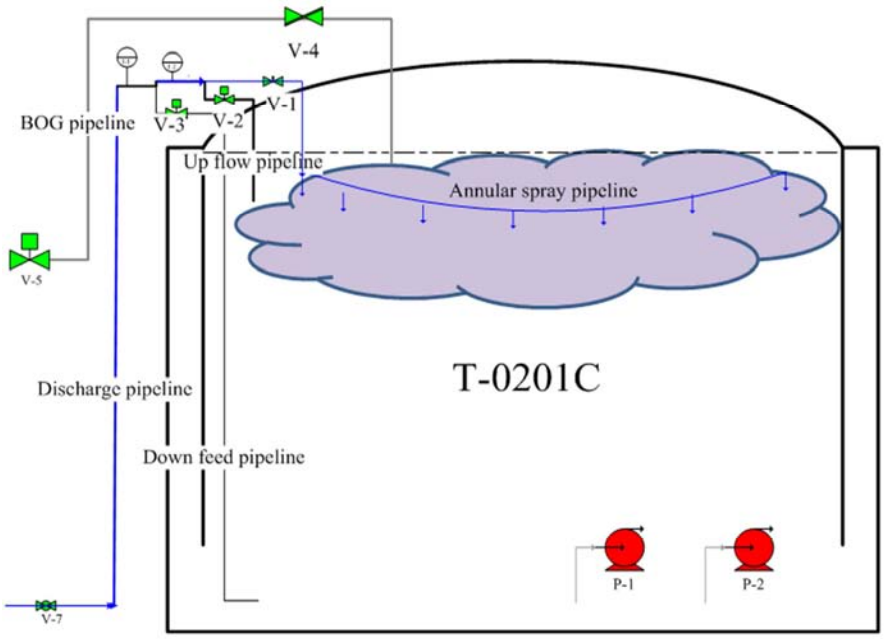

Figure 3. *Conventional spray cooling storage tank.*

Through the Simulink simulation tool, MATLAB programming is used to build the tank cooling dynamic simulation platform [6-13], as shown in Figure 4.,LNG consumption and time at different stages of simulated tank cooling,Combined with the cooling examples and calculation methods of LNG tanks in Fujian, Zhejiang and Zhuhai [14-17], the preliminary results are as follows: Table 3.

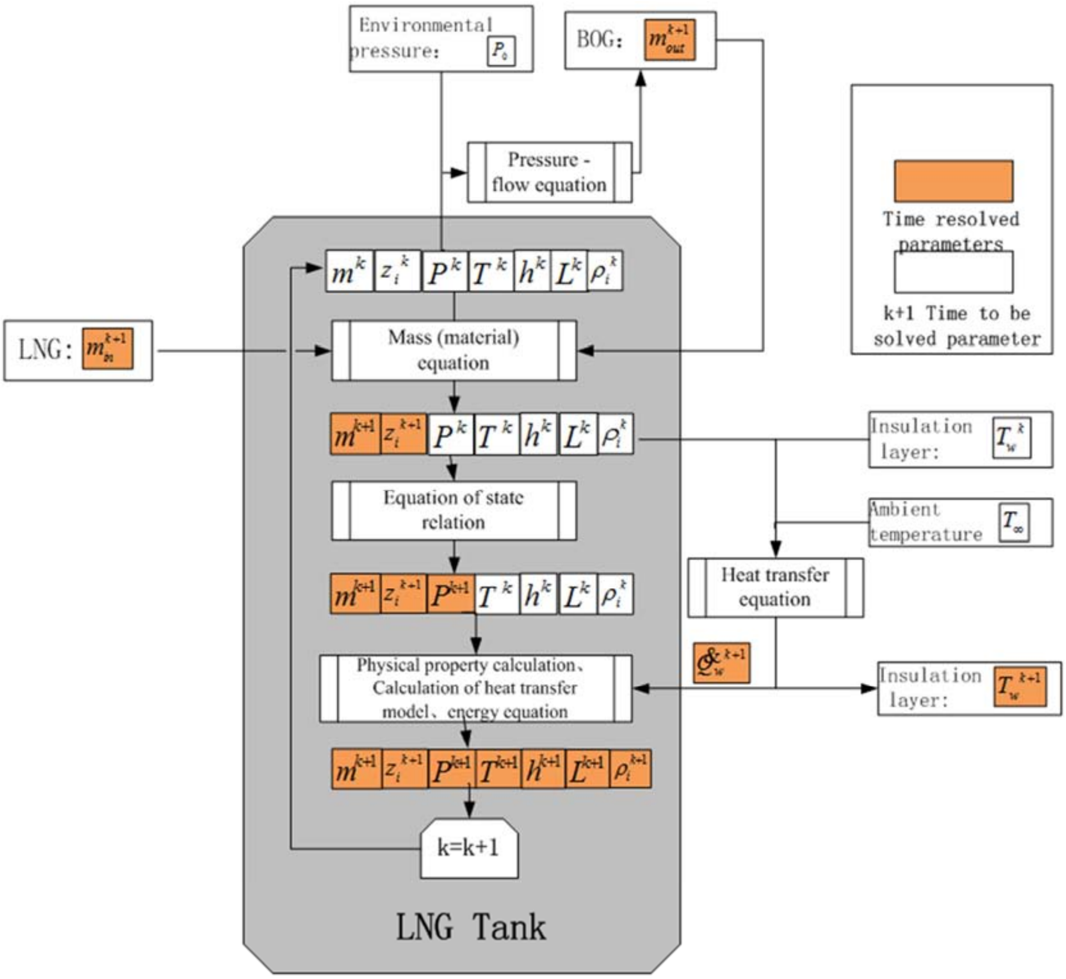

Figure 4. *Tank cooling simulation platform.*

According to the simulation results, the LNG consumption and duration of conventional tank cooling are obtained.

Table 3. *Routine simulation of LNG consumption and duration of tank cooling.*

Average temperature of tank bottom°C	**LNG consumption m³/h**	**Consuming time h**	**Self evaporation BOG×10⁴m³/h**	**BOG total×10⁴m³/h**
15～0	1～10	4	0.4	0.5～1
0～-25	10～20	7	0.4	1～1.65
-25～-45	20～25	7	0.4	1.65～1.9
-45～-65	25～30	7	0.4	1.9～2.3
-65～-85	30～35	7	0.4	2.3～2.6
-85～-105	35～40	7	0.4	2.6～2.9
-105～-125	40～55	8	0.4	2.9～3.8
-125～-145	55～60	8	0.4	3.8～4.2
-145～-155	60～75	4	0.4	4.2～5.2

3.2.2. Cooling Process of "BOG+LNG" Storage Tank

Effectively reduce the risk of cooling operation, reduce the BOG hourly production during the tank cooling process. According to the low temperature BOG density characteristic table 1, make full use of the low temperature BOG cooling capacity produced by the self-evaporation of the tank used in the receiving station to carry out the tank cooling as shown in Figure 5. The low temperature BOG is sent into the cooling tank through the process pipeline and adjusted. The amount of BOG entering the tank ($3000m^3/h$-$12000m^3/h$) and the temperature (spraying LNG into the unloading main pipe to control the BOG temperature between - 120°C to - 155°C) maintain the cooling rate of the tank. After cooling to the target temperature, the LNG is filled with small flow until the tank is cooled.

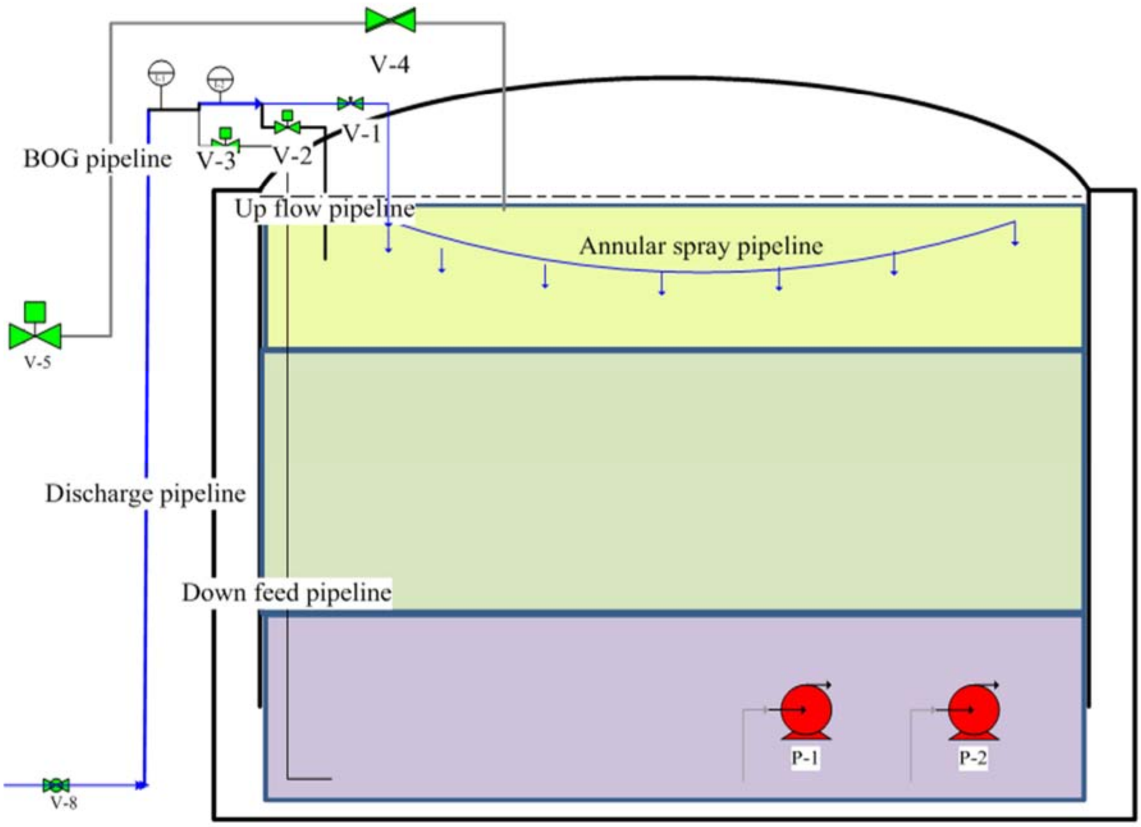

Figure 5. *Schematic diagram of cooling of "BOG+LNG" tank.*

According to the 3.2.1 model, the platform was built by changing the cooling capacity and heat absorption mode, and the temperature change of BOG + LNG tank was simulated by the 3.2.1 model. The LNG consumption was calculated and the preliminary results were as follows: Table 4.

Table 4. *LNG consumption simulation for cooling process of "BOG+LNG" storage tank.*

Average temperature of tank bottom°C	LNG consumption m^3/h	Consuming time h	Self evaporation BOG×$10^4m^3/h$	BOG total×$10^4m^3/h$
15～-50	0	46	0.4	0.4
-50～-100	0～13	35	0.4	0.5～0.9
-100～-130	13～20	23	0.4	0.9～1.2
-130～-150	20～25	18	0.4	1.2～1.7

3.2.3. Comparison of Cooling Processes for Two Kinds of Tanks

(1) Two ways can be used to cool the tank.
(2) The spraying method is used to cool the tank for about 59 hours, and the BOG + LNG method is used to cool the tank for about 122 hours.
(3) Spraying cooling method has high LNG consumption per unit time, fast cooling rate, low LNG consumption per unit time and slow cooling rate.
(4) Using the "BOG+LNG" method to cool the storage tank, the cooling rate at the late cooling stage needs to increase the amount of LNG spray.

4. LNG Storage Tank Zero Discharge Commissioning Trial Practice

4.1. Cooling Process of "BOG+LNG" Tank

The low temperature BOG (minimum temperature up to -140°C/h) of the natural evaporation of tank A/B (shown in Figure 6, 1, 2) is used to enter the tank through the bottom feeding line of tank C (shown in Figure 6, 5), and the BOG is discharged from the tank through the top pipeline of the tank (shown in Figure 7, 4) and transported through the BOG compressor. During the cooling process, the self-evaporating BOG is controlled by spraying LNG on the main discharge pipe to ensure that the cooling rate of the tank is - 1°C/h ~ - 4°C/h and a small amount of LNG is introduced into the tank for cryogenic cooling until the tank is cooled. Fig. 7 shows the cooling trend of Zhuhai LNG tank C. Note: the blue in Figure 6 indicates that the tank has been put into storage, and the yellow indicates the pre cooling tank

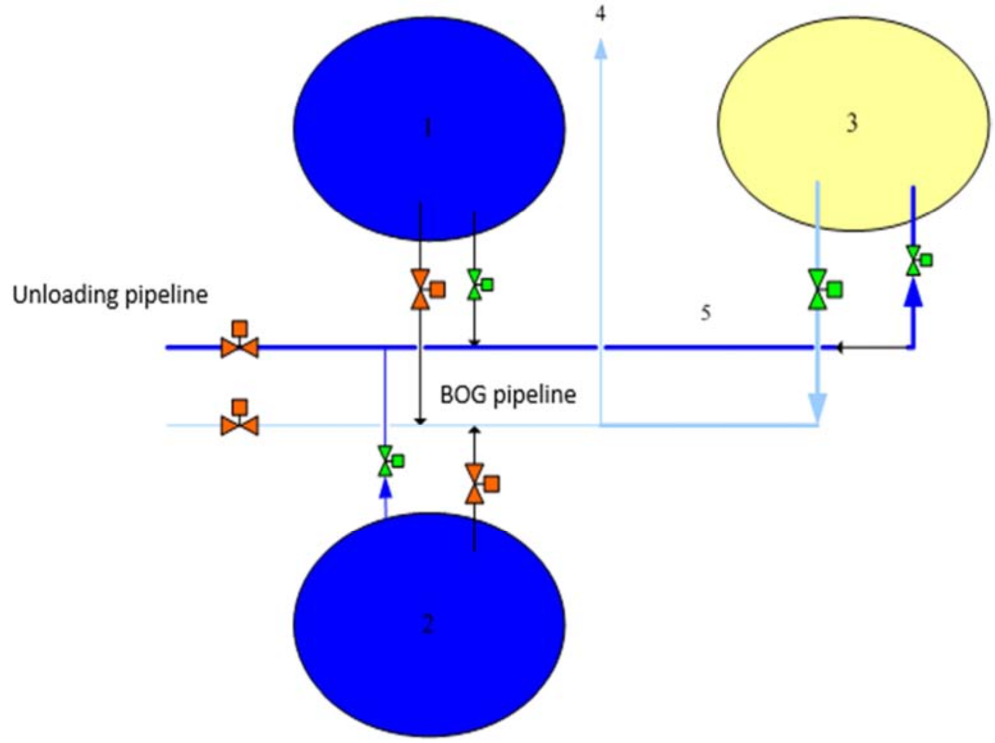

Figure 6. *Using the self evaporating gas cooling process of a storage tank.*

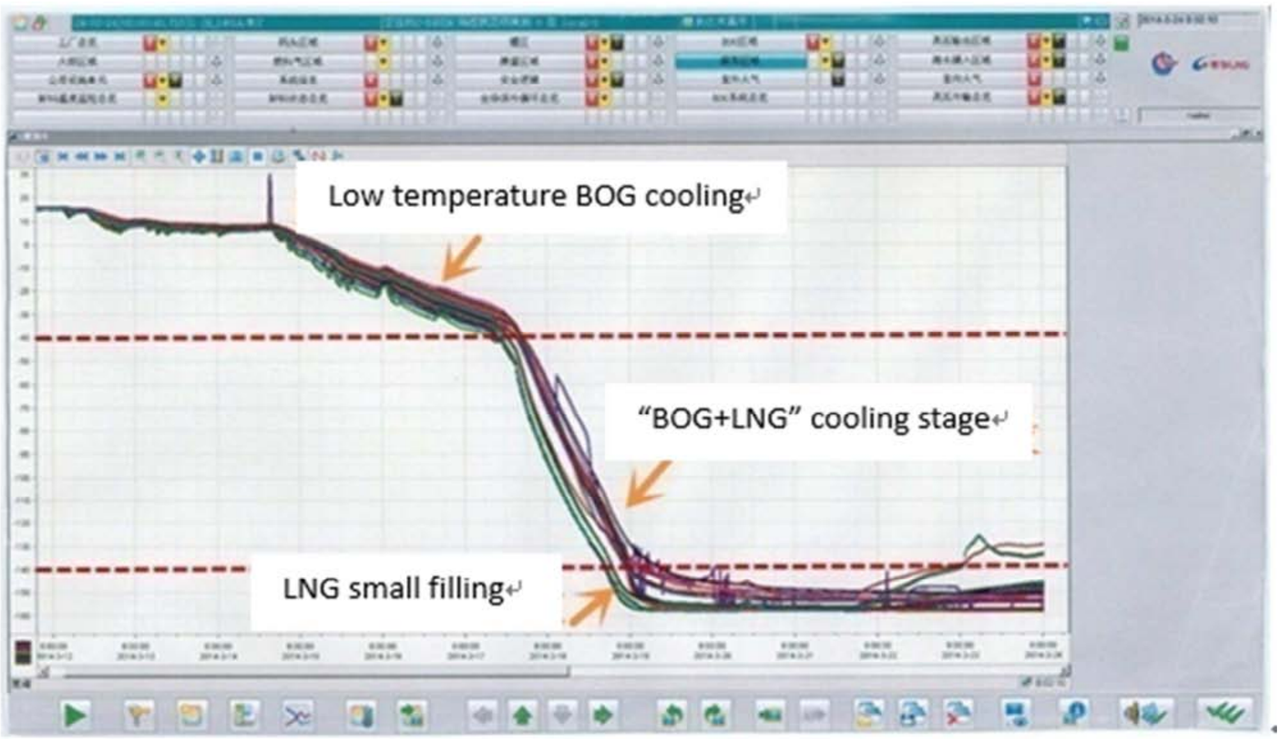

Figure 7. *Cooling trend chart of LNG tank in Zhuhai.*

According to the actual consumption and duration of LNG in the cooling process of tank C, table 5 is shown in the following table.

Table 5. LNG consumption of tank cooling.

Average temperature of tank bottom°C	LNG consumption m³/h	Consuming time h	Self evaporation BOG×104m³/h	BOG total×104m³/h
10～-42	0	59	0.4	0.4
-42～-100	2～14	22	0.4	0.5～1.2
-100～-140	14～20	18	0.4	1.2～1.6
-140～-155	20～25	10	0.4	1.6～1.9

Comparing with the practice of Zhuhai LNG tank, spray cooling method is adopted in A/B of Zhuhai LNG tank. BOG produced in cooling process is released by torch, and the consumption of LNG is large. Nitrogen displacement is carried out before C cooling of the tank. BOG + LNG method is adopted to cool the tank. The consumption of LNG is less and the time is longer. The following table 6 shows the cooling LNG consumption and time of three tanks.

Table 6. Shows the LNG consumption of cooling tanks in different ways.

Tank	Cooling process	Cooling time h	LNG consumption m³
A	Top spray	61	
B	Top spray	63	2355
C	Bottom intake	107	810

4.2. LNG Tank Commissioning BOG Zero Emission

In general, the LNG receiving station uses the re-condensation method to treat BOG. According to the characteristics and working conditions of high-pressure pump, the re-condenser can only treat BOG according to a certain gas-liquid ratio. According to the BOG quantity produced in Table 2 and table 5, according to the design requirement of the re-condenser of the receiving station, the BOG re-condensation treatment corresponds to a certain amount of outflow [18-21]. According to the design requirement of Zhuhai LNG, the corresponding flow rate of BOG treatment is shown in Table 7 below. From the table, when the amount of re-condensation BOG exceeds 3 $*10^4$ m^3/h, the instantaneous gas outflow rate reaches 51 $*10^4$ m^3 / h, the amount of LNG participating in condensation will reach 408 m^3/ h. This kind of working condition requires high production of the receiving station in reality, and can hardly be dealt with. During the C cooling period of Zhuhai LNG tank, the nitrogen content of BOG is extremely low, the maximum BOG is $1.9*10^4$/h, and the maximum gas outflow is 32 $*10^4$ m^3/h. All BOG is recovered directly by re-condensation during the cooling period to achieve zero BOG emission.

Table 7. BOG re condensing capacity.

BOG $10^4m^3/h$	LNG flow m ³/h	HP flow m³/h	NG Transportation×$10^4m^3/h$
1	136	256	17
2	272	512	34
3	408	768	51
4	544	1024	68
5	680	1280	85

5. Conclusion

(1) Before cooling, the LNG tank can replace the nitrogen in the tank by bottom nitrogen exhaust, and the replacement effect is very ideal.
(2) Compared with the top spraying LNG method, the bottom air intake method has higher cooling efficiency, more full utilization of cold energy and less consumption of cold energy.
(3) Adopting "BOG + LNG" cooling method can reduce the amount of BOG produced in the process of tank cooling, match the BOG processing capacity of receiving station, and realize the zero emission of BOG in tank cooling.
(4) The "BOG + LNG" cooling method has less LNG consumption in the process of tank cooling, which can effectively achieve energy saving and emission reduction, reduce loss.
(5) Nitrogen replacement method at tank bottom and BOG+LNG cooling method can be used as reference for LNG tank commissioning in the future.

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