RESEARCH ARTICLE

Study on LNG storage modes and the influence on engine performance

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Abstract: With the global oil shortage and the increasingly prominent problem of environmental pollution, reducing the fuel consumption rate of vehicle engine and the harmful gas composition in exhaust has increasingly become an important research topic all over the world. Under the background of accelerating the process of green and low-carbon development, promoting the energy revolution and accelerating the development of natural gas industry at home and abroad, LNG has become one of the fastest growing energy sources in the world. New fuels bring changes in fuel properties, and a series of new problems need to be studied. The emergence of LNG "aging" phenomenon is one of them. NLG stored in the storage tank at low temperature has a large temperature difference from the external environment, which makes the heat penetrate continuously. Heat infiltration and multicomponent NLG are the two root causes of NLG "aging". LNG storage tank is an important facility of LNG plant. The construction process is complex, the manufacturing process is harsh, and the investment cost is huge. The precooling of LNG storage tank is very important for the successful operation of LNG unit before putting into operation. In order to verify the feasibility and practicability of the index system and evaluation model, taking the Fuling LNG plant of Sinopec Chongqing Tonghui Energy Co., Ltd. as an example, it is concluded that the LNG + Liquid Nitrogen Precooling mode is the best scheme.

Keywords: LNG factory, pre-cooling method of storage tank, fuzzy analytic hierarchy process

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1 Introduction

1.1 Research background and significance of LNG storage mode

1.1.1 Natural gas and LNG storage tanks

Natural gas has the characteristics of high quality, clean and efficient. It is also a low-carbon energy. It can be used as an effective supplement to renewable energy, including nuclear energy. It is one of the most reasonable and realistic choices to achieve clean energy supply. Internationally, the signing of the Paris Agreement and the convening of the 2030 agenda for sustainable development have set clear goals and timetables for the world to accelerate the development of clean energy and promote low-carbon development. For China, increasing the proportion of natural gas in energy consumption is an important means to promote the construction of China's clean, safe and efficient modern energy system; It is a realistic choice to effectively prevent and control air pollution and actively deal with environmental problems such as climate change; It is also an important part of implementing clean heating in winter in northern China and promoting the improvement of rural lifestyle. At the same time, accelerating the development of natural gas industry can drive the development of relevant equipment manufacturing industry and expand new economic growth points. Although after nearly two decades of development, China's overall natural gas consumption has jumped to the third place in the world, second only to the United States and Russia, compared with the world's major gas consuming countries and regions, China's natural gas consumption and utilization rate are still at a low level. At present, China's natural gas consumption accounts for only about 6% of China's energy consumption, far below the world average of 23.8%, while that of the United States and Russia is as high as 30% and 50%. With China vigorously promoting the development and utilization of natural gas, accelerating the revolution of energy production and consumption, accelerating the process of new urbanization and vigorously promoting the reform of oil and gas system, China's natural gas demand will usher in rapid growth, and the natural gas industry is ushering in new development opportunities. LNG (liquefied natural gas) is the abbreviation of liquefied natural gas.

Compared with compressed natural gas CNG (compressed natural gas) and product oil, it has the characteristics of cleaner, more efficient and convenient for safe storage and transportation. LNG is used to replace coal and petroleum fuel, which can alleviate the problem of environmental pollution. It is a green energy strongly advocated by the state. Generally speaking, the distance between the place of natural gas production and the place of demand is relatively far [1]. Therefore, natural gas is usually liquefied into LNG after pretreatment, and then the liquefied natural gas is transported to the place of demand by large LNG ship or tank car. LNG storage tank is the necessary equipment for LNG from the place of production to the place of demand. Its main function is to store the LNG products produced by the LNG plant or receive and store the LNG commodities transported by the LNG ship. Since the construction of China's natural gas transmission pipeline started relatively late, compared with other countries, the coverage of natural gas pipeline is low, and the length of China's natural gas transmission pipeline accounts for only 3.7% of the total length of the world's pipeline. Where natural gas pipelines are difficult to cover, LNG is an important supplementary means, which can meet the needs of industry and residents [2-4]. As the main equipment for storing

LNG, LNG storage tank has the advantages of high storage efficiency, easy operation and management, cost saving and large storage scale. It has gradually become the preferred equipment for natural gas liquefaction plant, peak shaving station, terminal and other facilities. The precooling process of LNG storage tank is the most critical link in the LNG production process, and it is also the link with the highest risk. At present, liquid nitrogen or LNG is usually used as precooling raw material for LNG storage tank precooling. There are three kinds of storage tank precooling methods: LNG precooling, Liquid Nitrogen Precooling and liquid nitrogen + LNG mixed precooling. The three kinds of tank precooling methods have their own advantages and disadvantages.

1.1.2 Research status abroad

Natural gas, coal and oil are called the three pillars of the world's primary energy. The development of social economy has greatly stimulated the demand for energy all over the world. At present, oil and coal resources can not meet people's needs. Coupled with the improvement of people's awareness of environmental protection in recent years, natural gas has been widely used for its excellent performance of low pollution, rich reserves and high calorific value per unit mass. At present, the proportion of natural gas in the world's primary energy consumption structure has reached. The global consumption of natural gas will greatly exceed that of coal, oil and nuclear energy in the same period. It can be said that the degree and efficiency of a country's utilization of natural gas directly measure the country's overall energy utilization capacity and level. However, although the world's natural gas resources are rich in reserves, they are unevenly distributed. The proven natural gas reserves in the world are mainly concentrated in western Siberia and the Persian Gulf in the Middle East in Russia. In terms of regional distribution, the Middle East is the region with the richest natural gas resources in the world. In terms of countries, Russia's natural gas reserves account for ranking first in the world. However, a large number of key natural gas consuming countries and regions do not have enough natural gas resources. Therefore, how to economically and safely transport natural gas from gas fields or resource countries to target users has become the most urgent problem. In general, pipeline transportation is a better choice, but for long-distance transoceanic transportation, there are no technical and economic conditions for the construction of deep-sea long-distance transportation pipeline, so it is necessary to find other transportation methods. Liquefied natural gas (hereinafter referred to as LNG is a form of storage, transportation and application of natural gas. Its production process is usually to purify and dehydrate the natural gas extracted from the gas field, remove heavy warp, acid gas, Lai and other impurities, and adopt advanced refrigeration technology to freeze the natural gas into liquid under normal pressure. Its main components are methane and ethane. There is also a small amount of nitrogen, propane and a very small amount of butane. After liquefaction, its volume is only in gas state, which can greatly save the cost of storage and transportation. Therefore, it has obvious advantages in natural gas storage and transportation. Import helps energy consuming countries to achieve diversified energy supply, ensure energy supply security and reduce environmental pollution. Export helps energy exporting countries to realize the effective development of natural gas resources, increase foreign exchange income and promote national economic development. Therefore, trade has become a hot spot in the global energy market. Some major energy consuming countries, such as the United States, Japan and some European developed countries, are building receiving terminals on a large scale, and the introduction of has received great attention. Major international oil companies have also shifted their new profit growth points to business.

The development history of LNG technology can be traced back to the beginning of last century. In 1914, the United States published the LNG patent for the first time in the world and successfully built a small natural gas liquefaction plant. In 1939, hope natural gas company built a natural gas liquefaction plant with a daily processing capacity of 1000 m^3 in West Virginia, and was committed to the research of LNG long-distance transportation technology. In 1940, Ohio natural gas company established a natural gas plant in Cleveland in the northeast of the United States, with a daily processing capacity of 1.13 × 105 m^3. Meanwhile, the company has built three spherical LNG tanks with a diameter of 17.37 m. In 1958, Chicago bridge steel company built the first industrial scale LNG storage tank in Louisiana, with a volume of more than 5550 m^3. Since the middle of last century, the volume of LNG storage tank has been expanding: it was about (1 ~ 3) × 104 m^3 in the 1960s, about (5 ~ 10) × 104 m^3 in 1970s. By the 1980s [5-6], this figure had exceeded 20 × 104 m^3. Japan has the largest number of large LNG storage tanks in the world. According to the statistics in 2008, Japan has a total of 27 large LNG receiving terminals. In addition, Japan is also the country with the largest LNG imports in the world, accounting for about 40% of the total global LNG imports [7].

LNG storage is a key step in LNG production. Therefore, the design and construction of large capacity atmospheric LNG storage tank has attracted much attention. Many large atmospheric LNG storage tanks have been built in LNG exporting countries including Russia and Qatar and LNG importing countries such as South Korea. At present, LNG is used most in Asia, accounting for about 78% of the world's use, while among Asian countries, Japan's use is the largest, accounting for about 62% of the world's total use. At present, only a few countries in the world have the technology and capacity to build large and medium-sized atmospheric LNG tanks.

Foreign codes and standards for LNG tank design mainly include the following: (1) API-650 [8] and API-620 [9] prepared by American Petroleum Institute; (2) Japanese industrial standard JISB-8501 [10]; (3) British standard BS-2654 [11]. Among the above foreign standards, American Petroleum Institute standards API650 and API-620 and European standard BSEN-14620-2006 modified and formulated according to British national standards have been widely recognized all over the world and are also the most used LNG storage tank standards [12].

In the field of design and construction of large low-temperature LNG tanks, developed countries such as the United States, Britain and Japan have formulated their own specifications or standards respectively. For example, API-650 steel welded oil storage tanks in the United States, BS-7777-1 general provisions guide for the design, manufacture, installation and operation of flat bottom, vertical and cylindrical storage tanks for low temperature in the United Kingdom The European Union's BSEN-14620-1 design and construction of field assembled vertical cylindrical flat bottom steel low temperature liquefied gas storage tanks with operating temperatures between 0 °C and - 165 °C - General Provisions, and Japan's JGA-107-02 guide for liquefied natural gas (LNG) underground storage tanks, etc.

Oliveski [13] studied the natural convection coefficient of the temperature field in low-temperature storage tanks with different tank capacities. Through the numerical simulation of tanks with different tank capacities, the dimensionless quantity high Prandtl number which determines the convective heat transfer in the tank is obtained. Boukeffa et al. [14] Established the experimental model and numerical model of small low-temperature liquid nitrogen container respectively, and studied the heat loss law of low-temperature thermostat during precooling. The research shows that the experimental results are consistent with the simulation results. Chen et al. [15] Studied the variation law of internal pressure and temperature of low-temperature storage tank, conducted thermodynamic analysis on the storage tank, calculated the pressure drop of 56.7 m^3 LNG storage tank, and compared the calculated results with the actual measured values. Edmund et al. [16] Took the influence of ambient temperature on low-temperature storage tank as the research object and carried out numerical research; Cho et al. [17] Conducted relevant research on the structural performance of cylindrical structure under thermal convection. Dahmani [18] established the ANSYS finite element model of LNG storage tank under the condition of inner tank leakage, and studied the temperature field distribution, heat flux density and heat gradient of concrete outer tank. The conclusion shows that there is a large temperature gradient along the thickness direction of outer tank Gillarde et al. [19] Conducted transient thermal analysis on the concrete outer tank, obtained the temperature field distribution of the outer tank with time, and focused on the cooling process of the outer tank.

The application of liquefied natural gas (LNG) is more and more widely used, which promotes the rapid development of liquefaction technology. Through the optimization and transformation of traditional dehydrocarbon process, new technologies such as supersonic separation technology and ifpex-1 new technology have been formed. There are also combination technologies of traditional technology and new technology, such as throttling separation method.

Supersonic separation technology is a new technology of condensing and separating water and liquid hydrocarbon from natural gas. Its equipment is mainly composed of hydrocyclone, Laval nozzle, vortex separation blade and diffuser. During the process of gas injection, the temperature decreases and the speed increases. At this time, water and heavy alkanes in natural gas are condensed into liquid to achieve the purpose of separation. The principle of throttling separation is that when the gas is throttled from high pressure to low pressure, the temperature of actual gas changes before and after throttling. Different components are separated in the process of cooling by taking advantage of the different condensing temperatures of hydrocarbon components in hydrocarbon containing feed gas.

1.1.3 Research status in China

Urban gas refers to the fuel gas used for urban industry and residents' life, which belongs to the category of urban infrastructure. From the aspect of gas source structure of urban gas, there are mainly artificial gas, liquefied petroleum gas and natural gas. From the perspective of industrial chain, urban gas includes three links: gas source, transmission and distribution and application. Compared with other urban public utilities, urban gas industry has public welfare and safety, natural monopoly and economies of scale of pipe network, seasonal fluctuation and continuity, regional consumption market, etc.

Many cities and towns are facing increasingly serious environmental pollution problems. Starting from the problems existing in the development of gas industry in small and medium-sized cities, it is clearly pointed out that accelerating the development of gas industry in small and medium-sized cities is of great significance to improve people's life, promote national economic growth, alleviate urban air pollution and promote social coordinated development. LNG gas supply mode has brought new development opportunities to the gas industry in small and medium-sized cities.

1.1.3.1 Development history of urban gas in China

China is a large country with a large population, and the economic development and resource conditions in various regions are extremely unbalanced, which also leads to the early start but late development of China's urban gas industry. In Sichuan in the third century A.D., China used bamboo as a pipeline to transport natural gas for salt industry. As a city gas, it has developed very slowly since 1865 when British businessmen built a horizontal furnace in Shanghai to produce gas for lighting. By 1949, only nine cities in China, such as Shanghai, Dalian, Shenyang, Anshan, Fushun, Changchun, Jinzhou, Harbin and Dandong, had coal to gas. After the founding of new China, the gas industry has made great progress. In the 1950s, the development of gas was mainly the transformation and construction of small coke ovens and the utilization of coke oven residual gas from metallurgical industry. By the early 1960s, Sichuan, northeast and North China began to supply natural gas successively. With the development of petroleum industry, many large and medium-sized cities began to use LPG and heavy oil to gas as gas sources. By the 1970s, the development of LPG and natural gas was slow due to resource and policy constraints. Most of them were gas plants with coal and petroleum products as raw materials. After the reform and opening up, the domestic urban gas industry has made a breakthrough development. Over the past 20 years, it has gone through three major stages: the first stage is the 1980s. With the promotion of the national energy-saving policy and the support of energy-saving funds, a number of urban gas residual gas utilization projects focusing on the utilization of coke oven gas and industrial residual gas have been built in China, and many cities have built gas transmission and distribution networks for this purpose; The second stage was in the early 1990s. Due to China's permission to import LPG and the cancellation of quota restrictions, imported LPG was first used in economically developed and energy deficient areas such as the coastal areas of Guangdong. LPG resources in both domestic and foreign markets have been fully utilized, and the annual import of LPG for cities has exceeded 5 million tons, LPG began to become one of the main gas sources of urban gas; The third stage is from the late 1990s to now. Starting with the "Shaanxi gas to Beijing" project, especially the implementation of the "west to East Gas Transmission" project, China's urban gas industry has entered the natural gas era.

1.1.3.2 General status of LNG

China's urban gas is mainly composed of artificial gas, LPG and natural gas. According to the statistical bulletin of urban construction of the Ministry of construction, the total supply of artificial gas in cities nationwide in 2007 was 322.5 × 108 m^3, total natural gas supply 308.6 × 108 m^3, total LPG supply 1466.8 × 104t. The gas consumption population is 324 million, and the gas penetration rate is 87.5%. In terms of residential gas, LPG accounts for the largest proportion, accounting for 63.4%, followed by natural gas, accounting for 20.2%, and artificial gas accounts for the smallest proportion, accounting for 16.4%.

China's LNG industry has grown from scratch and made great progress in liquefaction process technology, related devices and equipment. China has also developed its own LNG process with reference to foreign patented technology. However, compared with foreign technology, there are still deficiencies in process optimization in China, especially the efficiency is relatively low and the reliability of equipment is not high.

According to the statistics of the economic and Technological Research Institute of CNPC, China's annual LNG output reached 9 million tons in 2010 and is expected to reach 19 million tons of natural gas in 2011. By the end of 2010, in addition to the three LNG terminal projects that have been completed and put into operation in China, there are eight projects that have been approved by the state and are under construction, namely CNOOC Zhejiang Ningbo LNG, CNOOC Zhuhai Jinwan LNG, CNOOC Guangdong Jieyang LNG, PetroChina Jiangsu Rudong LNG, PetroChina Liaoning Dalian LNG, and PetroChina Hebei LNG, Sinopec Shandong Qingdao LNG and Dongguan Jiufeng LNG projects. "The three LNG terminals completed and put into operation have an annual scale of 9.3 million tons in phase I and 28.3 million tons. At present, they have not reached production capacity. The above eight LNG terminals under construction have a scale of 22.5 million tons / year in phase I and 67.5 million tons / year in phase I and phase II. In addition, the projects under preparation include Sinopec Guangxi Tieshan port area LNG project, CNOOC Shenzhen LNG project and CNOOC Shenzhen LNG project CNOOC Hainan LNG project, etc; China's natural gas market has entered a stage of rapid development. The average annual growth rate of China's natural gas demand from 2010 to 2030 is 6.1%, 6.4% and 5.6% respectively. Under the benchmark scenario, the proportion of natural gas in the primary energy structure will reach 9.2% in 2020 and 10% in 2030. The next 10-15 years are a strategic opportunity period for forming a complete natural gas industrial system.

1.1.3.3 Development of urban gas in China

(1) The development momentum of urban gas is strong

After entering the new century, China's urban gas industry has developed rapidly, and the total gas supply is increasing at an average annual rate of 12.9%. In just a few years, the penetration rate of gas consumption has increased by 27.8 percentage points, and the gas consumption population has increased by 84%. China's urban gas industry is in a stage of rapid development.

(2) The coexistence of multiple gas sources is the basic feature of urban gas in China

The basic policy followed by China's urban gas development is "multiple gas sources, multiple uses, adjusting measures to local conditions and rational utilization". The coexistence of artificial gas, LPG and natural gas is the main feature of urban gas in China. With the development of the times and the progress of technology, various types of gas are affected by their own characteristics, technology, price, new substitutes and other factors, and their proportion composition will change. However, China's urban gas will still be mainly composed of these three kinds of gas for a long time in the future, and this situation will not change.

(3) The proportion of natural gas will continue to increase

In May 1996, at the "research meeting on urban gas development and Countermeasures" held in Beijing, the State Planning Commission clearly pointed out the development direction of China's urban gas industry, that is, "vigorously develop natural gas, actively promote liquefied petroleum gas, and gradually transform and restrict coal to gas". Under the guidance of this policy, a series of natural gas projects such as "west to east gas transmission, Sea gas landing and LNG landing" have been implemented, and China's urban gas industry has entered the natural gas era. In just a few years, the supply of natural gas has increased rapidly, with an average annual growth rate of 17.8%, much higher than 13% of artificial gas and 9% of LPG. By 2007, the proportion of natural gas in urban gas has reached 48%. According to the calorific value, natural gas has become the largest source of urban gas. Natural gas is superior to artificial gas and LPG in technology and economy, with the greatest market potential and the strongest price bearing capacity. China's urban gas is mainly natural gas and LPG before 2005, and will develop in the direction of natural gas as the leading gas source around 2010, which is an inevitable development trend. According to the latest domestic statistics, the Fifth China LNG (liquefied natural gas) International Conference in 2010 pointed out that China's natural gas market has entered a period of rapid development marked by the operation of the first line of West to East Gas Transmission in 2004. It is estimated that by 2015, China's natural gas demand will reach 260 billion m^3, doubling from 2008; From 2016 to 2020, the growth rate of natural gas demand will slow down, but it will still maintain an average annual growth rate of about 8%. China's natural gas demand is expected to exceed 400 billion m^3 in 2020. China's medium and long-term energy development plan clearly points out that during the 12th Five Year Plan period, we should vigorously develop natural gas. By 2030, natural gas will account for 10% of primary energy and become one of the green energy pillars and highlights in China's energy development strategy.

(4) The proportion of artificial gas will gradually decrease

From 1999 to 2007, although the average annual growth rate of artificial gas reached 12.9% and the total output more than doubled in six years, its proportion in the composition of urban gas was basically stable and decreased slightly, from 25% to 20%. With the rapid development of national economy, the problem of changing energy structure and improving air quality will attract more and more attention from the government and all sectors of society. Artificial gas cannot compete with natural gas and LPG because of its complex process, poor quality, large investment, high cost and environmental pollution in the production process. With the rapid development of natural gas industry, more and more cities convert the gas source from artificial gas to natural gas, and artificial gas will gradually fade out of people's vision.

(5) LPG will still occupy an important position

China is the country with the fastest growth of LPG consumption in the world. Over the past 10 years, China's average annual consumption of LPG has increased by more than 10%, and a large amount of LPG needs to be imported to meet the increasing requirements of urban and rural residents. In the next few years, with economic development, China with the largest population will still be one of the countries with the fastest LPG growth. LPG will still occupy an important position in China, which is determined by China's economic and resource conditions. With the adjustment of energy structure and economic development. The use of natural gas and LNG as civil fuels will increase greatly. After 2010, the gas demand of major cities in eastern China, including Northeast China and along the west to east gas transmission line will take natural gas as the leading gas source. However, the development and maturity of China's natural gas consumption market is a gradual process, and limited by various resources, it is difficult to replace LPG for urban use in a large scale in the near future. In addition, in the old urban areas and suburbs of the city, the pipeline natural gas is still not fully covered in the short term. At this time, LPG will exist for a long time as an auxiliary gas source of natural gas. Therefore, in the coming period, China's LPG market will still develop to a certain extent, but the growth rate will slow down. With the acceleration of China's urbanization, more and more people will get rid of old energy consumption habits. With the advantages of less investment, quick effect, flexibility and convenience, LPG still has strong vitality in the 21st century with the increasingly obvious trend of diversified energy. China's vast territory, large population and unbalanced economic development among regions determine that it is impossible for China's vast rural areas to make full use of natural gas. According to the overall urban and rural planning of China, the use of bottled LPG can meet the needs of various people to use gas. LPG will occupy an important position in China's urban gas pattern for a long time, but its development focus will gradually shift from cities to rural areas.

1.1.3.4 Characteristics of gas development in small and medium-sized cities in China

For a long time, the urban gas industry in small and medium-sized cities in China has been at a low level. Since the 1980s, with the development of China's petrochemical industry and the introduction of foreign liquefied petroleum gas, LPG began to develop rapidly in small and medium-sized cities. The supply form is mainly bottled supply. Only a few cities supply pipeline LPG by community gasification, and the gas supply model is basically limited to some communities. After entering the 1990s, with the rapid development of natural gas industry, some small and medium-sized cities close to gas fields and long-distance pipelines also began to use pipeline natural gas. In recent years, with the gradual opening of the urban gas market, many private enterprises began to enter the urban gas market, new gas supply modes such as CNG and LNG began to appear, and the urban gas industry in small and medium-sized cities began to show a diversified gas supply situation. Overall, LPG still plays an important role in the gas of small and medium-sized cities, and bottled gas supply is still the main way of gas supply. In the future, the proportion of natural gas in the gas share of small and medium-sized cities will gradually increase, and new gas supply modes such as CNG and LNG will become the choice of more small and medium-sized cities.

1.1.3.5 Natural gasification is the inevitable direction of the development of cities

Compared with LPG, natural gas has the following outstanding advantages:

1. Convenience and comfort. With the use of natural gas, the pipeline will directly lead to the kitchen. After replacing the bottled liquefied petroleum gas, it eliminates many inconveniences such as filling, handling and maintenance of bottled gas. It is extremely convenient to use and improves the quality of life of the people.

2. Clean and environmentally friendly. Natural gas is the cleanest energy among fossil fuels, known as green energy. Its main component is methane, which does not contain other impurities and can be completely burned. The combustion product is a small amount of carbon dioxide and water, which does not produce pollution and has significant environmental protection. LPG has many impurities, high carbon content and incomplete combustion, which will pollute the kitchen environment. In addition, the impurities in LPG will also affect the service life of the stove.

3. Safe. The density of natural gas is lower than that of air, while the density of LPG is higher than that of air. In case of leakage, natural gas is easy to drift with the wind, which is not easy to cause hidden dangers; Liquefied petroleum gas will accumulate in low-lying places and should cause explosion hazard. In addition, the ignition point and lower explosion limit of natural gas are higher than those of liquefied petroleum gas, and natural gas is relatively less prone to explosion.

4. The price is low. Natural gas is a natural resource with rich reserves, low cost and relatively stable price. The price of natural gas is about 30% cheaper than that of LPG. According to international practice, the supply contract of natural gas follows the principle of "take or pay" for 25 years. The supply contract period is generally long, and the contract stipulates the upper and lower limits of the price. During the contract supply period, no matter how the market changes, the purchase and sales price of natural gas fluctuates only between the two. Therefore, residents' use of natural gas can basically be protected from the frequent fluctuations in international oil market prices, and the expenditure on using natural gas is less than that on using liquefied petroleum gas.

5. Suitable for large-scale utilization. LPG is easy to liquefy, so the transmission pressure can not be too high, which limits the supply scale of LPG. In addition, the price of liquefied petroleum gas is high, which can not be borne by large industrial users and heating users. Therefore, liquid fossil oil and gas is generally only supplied in bottles for residents and commercial users as fuel. The price of natural gas is low, it has good adaptability to all kinds of users, and the gas supply scale can be large or small. It can be used as the main energy of the city and can better meet the needs of urban development.

To sum up, natural gas has very significant advantages over liquefied petroleum gas. Natural gas replaces liquefied petroleum gas as the leading gas source of the city, which is in line with the development trend of urban gas and the development direction of urban gas in the future. With the increase of natural gas supply scale and the emergence of various new natural gas supply modes, small and medium-sized cities will also use clean, environmental friendly and safe natural gas.

1.1.3.6 Chinese scholars' research on the low-temperature insulation of LNG storage tanks.

Wang Tongji and others targeted a terminal 16 × 104 m^3 in Qingdao LNG storage tank, the processes of liquid nitrogen and LNG precooling are introduced in detail, the calculation models of medium flow and precooling temperature drop rate required during precooling are given, the above two precooling methods are calculated respectively, and the total amount of medium required for precooling of storage tank and the time required for precooling are obtained when the precooling medium flow remains unchanged, Thus, it provides a certain theoretical basis for the selection of precooling scheme of large LNG storage tank [20]. Xiong Huabin et al. Taking 104 m^3 storage tank as an example, the three-dimensional model of storage tank is established by solid works, and the analysis software ANSYS is imported to simulate the precooling process of storage tank. The temperature field distribution of storage tank at the end of precooling and the change of heat flow rate with time are obtained [21]. Taking the actual large LNG cryogenic storage tank as an example, Xue Feng introduced the main commissioning work after the mechanical completion of the storage tank, and described the relevant technologies of storage tank precooling, including precooling process, cooling method, nozzle selection, cooling system, preconditions, cooling spray calculation, etc. [22]. Aiming at the common problems in the precooling process of traditional LNG storage tanks, Li Junfang and others proposed the technology of liquid nitrogen + LNG precooling, which was successfully applied to the precooling of LNG storage tanks in Guang'an, Sichuan [23]. Deng Wenyuan et al. Taking 104 m^3 large LNG aboveground full capacity storage tank as an example, the total LNG used for precooling and the required precooling time during precooling are calculated, and the dynamic changes of bog production and storage tank pressure during precooling are obtained, which provides a theoretical basis for designing and optimizing the precooling process of LNG storage tank [24]. In the mid-1990s, China began to build large liquefied gas storage tanks, represented by 2 × 104 m^3 in Shenzhen liquefied petroleum gas (LPG) low temperature storage tank and Yangzi Petrochemical 1 × 104 m^3 low temperature ethylene storage tank [25-26]. At the end of last century, China's first LNG storage tank was built in Shanghai with a capacity of 2 × 104 m^3[27].

From 2002 to 2005, Hefei General Machinery Research Institute took the lead to start the "2 × Research on "development of 104 m^3 LNG storage tank" and other topics, focusing on the welding of 9% Ni steel, low-temperature thermal insulation materials and structure, LNG storage safety, nondestructive testing and other aspects [28-29]. Since the beginning of the 20th century, "three barrels of oil" - PetroChina, Sinopec and CNOOC have established large LNG terminals in Guangdong, Liaoning, Fujian, Jiangsu, Shanghai, Zhejiang, Shandong and other coastal provinces respectively, and various small natural gas-liquid plants invested and constructed by companies such as Northern Shaanxi gas field, Zhongyuan Oilfield and Xinjiang Guanghui have also carried out business one after another. Although China has not yet promulgated relevant standards or specifications for the design and construction of large low-temperature LNG tanks, the National Natural Gas Standardization Technical Committee is preparing to study and formulate the standard system of China's LNG industry, and has published the draft for comments. Looking at the existing studies on the precooling of liquefied gas storage tanks at home and abroad, most of them focus on some specific technical parameters of the precooling of liquefied gas storage tanks, and there are few studies on the analysis and evaluation of different precooling methods.

Research purpose and content with the global development of clean energy, accelerating the process of low-carbon development, and China accelerating the construction of a clean, low-carbon, safe and efficient modern energy system, and vigorously promoting the development and utilization of natural gas, the liquefied natural gas (LNG) industry will usher in the spring of leapfrog development. LNG storage tank is an important facility of LNG plant. Precooling of LNG storage tank is the key link for the plant to be put into production and operation. The technical requirements are high. The success of precooling plays a decisive role in whether the plant can be put into production and operation normally. In order to carry out tank precooling safely, economically and efficiently, this paper analyzes the physical characteristics of liquid nitrogen and LNG, the main factors affecting LNG tank precooling, the structure and characteristics of LNG tank, low-temperature insulation technology and precooling process flow, analyzes the advantages and disadvantages of three LNG tank precooling methods, constructs an evaluation index system and establishes an evaluation model, This paper analyzes and evaluates the three tank precooling modes of LNG, liquid nitrogen and liquid nitrogen + LNG mixed precooling commonly used in LNG plants, in order to find the best precooling mode. Finally, combined with Fuling LNG plant 1 × 104 m^3 The precooling of LNG storage tank is analyzed, the precooling mode is selected, and the model is used for evaluation. The evaluation results are consistent with the research results of this paper.

1.2 Background and advantages of LNG as automobile fuel

1.2.1 current situation of natural gas vehicles

In the 21st century, green culture with "green, environmental protection and sustainable development" as the main content is rising all over the world. While paying attention to economic development, people pay more attention to the harmonious development with the environment. In order to control the urban air pollution caused by automobile exhaust and reduce the dependence on scarce oil resources, natural gas vehicles have developed rapidly because of their good emission, economy, fuel universality and safety. Natural gas was first used as automobile fuel in the 1930s, but it has not been widely used due to the limitation of natural gas storage technology. Until the 1970s, with the progress of material science and technology and manufacturing technology, the use of natural gas on vehicles became possible. On the other hand, under the requirements of strict emission regulations and fierce commercial competition, the vehicle engine technology with electronic control technology as the core has become increasingly mature, which has promoted the technical progress of natural gas vehicles. The fuel storage and supply system, special electronic control system, emission control and exhaust gas purification system of various natural gas engines are constantly emerging. The research on the overall structure scheme and control strategy of various engines has continuously improved the power, economy, emission and other performance of natural gas engines and optimized the matching with vehicles, The potential of natural gas as a high-quality fuel has also been brought into full play. The use of natural gas for vehicles has attracted more and more attention from all countries. There were more than 1.2 million natural gas vehicles in the world in 1995. Up to now, the United States has millions of natural gas vehicles, and natural gas vehicles have been applied in nearly 50 countries. In terms of natural gas vehicle technology, the United States and Japan take the lead.

1.2.2 Advantages of LNG as automobile fuel

At present, compressed natural gas(CNG) technology is mainly used in the development of natural gas, which compresses and stores natural gas in high-pressure tanks above 20MPa under normal conditions. There are many difficult problems in practical application, such as short vehicle mileage, poor economy, poor safety and so on, which limit its wide application.

In contrast, liquefied natural gas has more advantages. It replaces compressed storage by liquid storage:

1. high storage energy density and long driving range of LNG. The storage energy density of LNG is 2.2 times that of composite container CNG and 3.9 times that of steel container CNG. It can be seen that the driving range of LNG can be greatly improved and is suitable for long-distance bus fuel.

2. The purification process requirements of LNG are much higher than those of CNG. During the production of LNG, substances that may solidify during cryogenic process, such as water, CO_2, and heavy hydrocarbons above propane, need to be removed in advance. Therefore, the components of LNG are more pure, and its environmental protection performance is better than CNG as vehicle fuel.

3. It can be seen that the safety performance of LNG is also higher than that of CNG.

4. LNG is 30-40% cheaper than gasoline/diesel and has good economic benefits as vehicle fuel. The preferential tax policies of the state make LNG more competitive as automobile fuel.

5. LNG filling is as convenient and fast as refueling, and there is no difference in operation from fuel oil.

6. LNG can be directly vaporized to CNG, and CNG can also be gasified.

7. The cold energy recovered from LNG can be used as automobile air conditioner.

8. LNG is convenient for transportation. The construction of the station is not limited by the natural gas pipeline network. It is easy for network layout and large-scale development. In addition, the use of LNG as automobile engine fuel can also change the current excessive dependence on oil resources, adjust the country's energy structure and ensure energy security.

1.2.3 Research and application status of natural gas engine technology

1.2.3.1 Various types of natural gas engines

The first natural gas engine is obtained through the corresponding transformation of the diesel engine. It adopts the compression ignition working mode and depends on the diesel engine for ignition. It inherits the characteristics of high efficiency of diesel engine and has good power performance. This form of natural gas engine is usually used in high-power transportation vehicles. It can be used as a dual fuel engine by changing the ratio of diesel to natural gas. Another kind of natural gas engine adopts a structure similar to gasoline engine and is ignited by spark plug. It can be roughly divided into three types according to its air supply mode and control technology. The first system includes a component similar to the carburetor to form a mixture, such as the premixed air supply system of sogngv, a Detroit Diesel Engine Company. The advantages of this type are simple structure and low price, which is convenient for the transformation of the existing carburetor gasoline engine. However, due to the lack of closed-loop control, it is difficult to accurately control the air-fuel ratio, so it is difficult to achieve a high emission control level, and can not give full play to the potential of natural gas to improve emission performance. The second system adopts electronically controlled single point injection (s-work) and closed-loop control combined with oxygen sensor to accurately control the air-fuel ratio, so as to make the engine have better economy and emission. However, due to the long distance between the single point injector and the exhaust gas oxygen sensor, the system is slow to change the air-fuel ratio, so it is difficult to realize rapid oscillation control near the set air-fuel ratio by relying on the signal of the oxygen sensor, especially when accelerating and decelerating, it can not respond quickly to the change of air-fuel ratio, so that the mixture is too lean or rich for a long time, The emission performance under these working conditions is poor, which affects the overall emission index. The third is the electronically controlled multipoint injection system. At present, there are products of electronically controlled multipoint inlet injection system. This system can control the air-fuel ratio by cycle and cylinder, has good responsiveness, and can realize accurate knock control, so it can adopt high compression ratio, so the emission, power and economy are greatly improved. For example, the natural gas engine developed by Honda adopts the electronically controlled multi-point gas injection system developed on the basis of the electronically controlled fuel injection system. The natural gas is supplied to the engine inlet valve by the gas injector, and the engine emission value is significantly reduced. The natural gas engine launched by Ford in 1998 also adopts multi-point injection system The new generation of in cylinder injection system is also approaching practicality. For example, the natural gas electronically controlled in cylinder direct injection system developed by Southwest Institute Research(SWIR) adopts a special jet device to realize in cylinder direct injection of natural gas through electronic control, lean combustion, and ultra-low engine emission combined with catalytic technology.

1.2.3.2 Countermeasures to improve the power of natural gas engine

The energy density of natural gas is lower than that of gasoline and diesel, and most natural gas is supplied in gaseous form, which will occupy the effective inflation volume. Therefore, a problem encountered in the development of natural gas engine is the decline of engine power after switching to natural gas. The researchers put forward various solutions. Because natural gas has a high octane number, the loss of power can be made up by increasing the compression ratio. For example, Nissan advan small ultra-low pollution natural gas vehicle developed in Japan uses natural gas single fuel to increase the compression ratio from 9.5 to 12.8 of the prototype gasoline engine, which greatly improves the engine power and torque. At low speed, the torque is the same as the original engine. Exhaust gas turbocharging technology is also widely used as an effective measure to improve engine power.

1.2.3.3 measures to reduce natural gas engine emissions

At present, there are two main emission control strategies for natural gas engines: one is the lean burn technology plus oxidation catalyst scheme adopted by some companies in the United States and Europe to reduce emissions. For example, BS of Cummins engine GG electronic control engine adopts lean combustion and closed-loop air-fuel ratio control. It is the first natural gas engine to meet the low emission vehicle (Lev) standard certification of the National Environmental Protection Agency (EP) a clean fuel fleet (cfvf) in 1999. It is also the first 6L heavy-duty engine certified by EPA and California Air Quality Commission (car) B, Its target is far lower than the 1998 EPA highway heavy truck and bus emission standard (including NOx emission standard). Lean burn technology also makes the thermal efficiency of the engine much higher than that of the modified CNG / gasoline dual fuel engine. The engine adopts lean burn, dual turbocharging and dual intercooler, which improves the emission, economy and power performance. One is the minimum emission strategy. Ruyi Dali Iveco selects the minimum emission strategy, that is, the closed-loop control based on the input sensor, maintains the NOx emission at 19 / (kW · h), and then uses the three-way catalyst for treatment. In 1992, veoc company developed an electronically controlled carburetor type NGV engine, which has been used on 100 vehicles and has operated for a total of 500 x l05 km. In 2000, IFAT Research Center Applied multipoint injection (MIP) to 2.8L and 9.5L engines. This new generation of ivecongv is mainly used for urban buses and public transport vehicles. The application of exhaust gas recirculation (eg) r technology of natural gas engine has also received extensive attention. For example, westivrgiina university has carried out natural gas lean combustion and EGR research. The University of Texas Austin (etxasatuastin) has studied the natural gas system by using ger to reduce the peak temperature, using exhaust oxygen sensor for closed-loop control and using three-way catalytic device. With the continuous improvement of natural gas engine technology, the emission of natural gas engine is continuously reduced. The emission of high-power natural gas engine has met the very low emission standard (ULEV) of California Air Quality Association (car) B. Honda of Japan has launched ievic series NGV. While maintaining the performance of the original vehicle, its co, NOx and the emissions are 60 times lower than the standards formulated by the U.S. federal government in 1997 and 10 times lower than the world's most stringent California ULEV standard. Moreover, on the basis of full electronic digital control, the control of air-fuel ratio and air intake of natural gas engine is more and more accurate, and the control function is more and more abundant and perfect.

1.2.3.4 Research on liquefied natural gas (LNG) engine

The research on LNG engine started relatively late, the United States and Japan are temporarily in a leading position in the application of LNG, and the number of LNG vehicles actually put into use is also gradually increasing. The United States has made remarkable progress in the development of LNG vehicles in recent 10 years. MVE company in the United States has become the largest LNG equipment design and manufacturer in the world. This company has long experience in the design and production of low-temperature equipment and can provide a full set of LNG equipment including vehicle gas cylinders, gas stations, large storage tanks, automatic gas dispensers and various vacuum insulation pipes. More than 90% of vehicle LNG cylinders in the world are products of MVE company, and most LNG filling stations are also manufactured by MVE. Major automobile companies in the United States, such as Caterpillar, Cummins, Detroit Diesel, John Deere, BWM, Ford, Mack, all produce LNG engines, and their emissions at least meet the low emission standard (Lev) of the United States, and cumimns engines can even meet the ultra-low emission standard (ULEV). In addition, there are now more than 30 American automobile manufacturers manufacturing vehicles. Suzuki Motor, and other companies and research institutions in Japan have successfully developed LNG electronically controlled inlet multipoint injection engine for minibuses.

1.2.3.5 Research and application of domestic natural gas engine

In recent years, the contradiction between energy supply and demand in China has become increasingly prominent. Traditional fossil fuels can no longer meet the needs of China's economic development and environmental protection. In 2002 alone, the import of crude oil and refined oil was nearly 100 million tons, and the oil gap in 2010 is expected to be 120 million tons. In the future, China's demand for energy will increase sharply with the rapid economic development, and China's dependence on foreign oil and natural gas resources will continue to increase. How to ensure China's energy security is directly related to the sustainable development of China's economy and society, which is of great strategic significance. Compared with oil resources, China is rich in natural gas resources, especially in the western region. The use of abundant natural gas as vehicle fuel is an important strategic step to improve energy consumption structure, protect the environment and achieve sustainable development. The west to East Gas Transmission Project currently being implemented in China is also to change China's energy structure. Compared with foreign countries, the research of natural gas engine in China started late. Zhongyuan Oilfield, located in Henan Province, has taken a series of measures to promote liquefied natural gas vehicles (LNGV). At the same time, phase I expansion project and phase II project are under way. Before 2005, the daily output of LNG can be increased by 10 times, and 20000-30000 LNG vehicles can be promoted. From 2001 to 2002, Zhongyuan Oilfield built 9 LNG filling demonstration stations in Beijing, Tianjin, Qingdao and other cities, and established corresponding LNGV demonstration teams. Strive to form Zhongyuan LNGV network within 2-5 years to drive the rapid development of domestic LNGV. In 2003, the LNG bus with single fuel developed by Shanghai Jiaotong University has been put into trial operation in Shanghai. The LNG on-board fuel system is composed of LNG vehicle storage tank, carburetor, pressure reducing and regulating valve, mixer, control system and safety system. The LNG vehicle storage tank adopts double-layer metal plus vacuum multi-layer winding insulation technology. The liquid level and pressure of LNG storage tank are measured by liquid level pressure gauge, which is a capacitive liquid level gauge. The LNG in the vehicle storage tank leaves the storage tank driven by its own saturation pressure (about 0.5MPa) and enters the LNG vaporizer through the low-temperature stop valve and overflow valve. The carburetor uses the engine cooling water as the heat source, and the control system adjusts its vaporization amount according to the engine working conditions. The vaporized natural gas enters the engine mixer after passing through the pressure reducing and regulating valve for automobile use.

To sum up, with the continuous progress of LNG engine technology and the increasing production capacity of LNG fuel as the guarantee, in order to meet the increasingly stringent engine emission regulations and the adjustment requirements of energy structure, as well as the advantages of LNG itself, LNG as the fuel of engine will be widely used. However, due to the cryogenic characteristics and component diversity of LNG, there is a problem that can not be ignored in the process of using LNG as engine fuel, which is the "aging" phenomenon of LNG, which will cause engine damage. The so-called "aging" of LNG refers to the phenomenon that the component concentration of LNG fuel stored in the reservoir changes continuously due to the influence of natural gasification (Bo) g. According to the research of NREL (National Clean Energy Laboratory) in the United States, in order to eliminate the impact of LNG "aging" on the engine, the purity of LNG (that is, the content of methane) should reach 99.4%, which is also used as the standard for the production of vehicle LNG in the United States. However, at the present stage, the process level of Chinese LNG production enterprises is difficult to meet this requirement. According to the data, the maximum purity that can be achieved by China's LNG production enterprises is 95.3%, which is bound to pose a potential threat to the safe operation of LNG vehicle engines. The generation of bog is due to the large temperature difference between the external environment and LNG storage tank, and the continuous infiltration of external heat leads to the "aging" of LNG. The amount of bog produced is related to the amount of LNG in the storage tank and the length of storage time. During transportation and storage, excessive heat infiltration shall be avoided as much as possible, and excessive LNG shall be avoided from parking for a long time during use.

1.3 Feasibility of LNG utilization in cities

1.3.1 Common natural gas supply modes

The main forms of natural gas supply are as follows: pipeline, CNG, LNG and solid. Pipeline supply is the most common way. However, the construction of gas transmission pipeline requires a high one-time investment, which is generally suitable for occasions with stable and large gas consumption. For small and medium-sized cities, due to small gas consumption, it is suitable only when the transmission distance is very short (generally less than 50 km). Obviously, due to the uneven distribution of natural gas resources and the limitation of long-distance pipelines in China, most small and medium-sized cities do not have the conditions to receive pipeline natural gas nearby. CNG is stored in high-pressure storage tank after the pressure of natural gas is increased to 20 MPa by compressor, transported to the destination by trailer, and supplied to users after decompression. CNG generally adopts high-pressure gas cylinder group tank cars, which are transported by road. The tank car is composed of 8 gas cylinders. The geometric volume of each cylinder is 2.25 m^3, the total volume of the tank car is 18 m^3, and the gas storage capacity of the tank car is 4550 m^3 / vehicle under the pressure of 20 MPa. The advantages of compressed supply are simple process, low investment, low cost, short construction period and quick effect. It can also directly fill gas for vehicles; Its disadvantage is limited by the number of trailers, transportation conditions, transportation distance, climate and other factors, and the gas supply capacity is small. According to the literature research results, CNG is generally only applicable to the supply of natural gas to small towns with a daily gas supply of less than 20000 m^3 and close to the gas source (generally no more than 200 km). In addition, the production and transportation of CNG are carried out under high pressure, so it is dangerous. Solid state supply refers to the natural gas hydrate that changes the natural gas into solid state under the action of natural gas and water at a certain pressure and temperature. After being transported to the destination, the natural gas is gasified and released for use by users. Natural gas hydrate has the advantages of convenient transportation and high energy density. 1 m^3 natural gas hydrate can release 150 m^3 natural gas. However, its biggest disadvantage is that the technology is not mature, and there is no example of large-scale application, so the solid-state supply of natural gas is not considered in this subject. In contrast, since the volume of LNG is only 1/600 of that in gaseous state, it greatly reduces the volume and can be conveniently stored and transported for a long distance. LNG is generally transported by low-temperature storage tank truck through highway. The low-temperature storage tank is composed of inner and outer shell. Vacuum fiber insulation technology is adopted. The geometric volume is 43m^3. When the volumetric filling rate is 90%, the capacity is 23000 m^3 / vehicle. LNG supply has the characteristics of low investment, quick effect and flexible use mode. The scale can be large or small. It can not only be used as the leading gas source of small and medium-sized cities, but also be used for natural gas peak shaving and accident emergency in large and medium-sized cities. In recent years, this technology has developed rapidly in China, and all kinds of equipment have been localized, which has a very broad development prospect in the future.

It must be pointed out that the selection of gas supply mode depends on many factors. When the gas source can be guaranteed, it mainly depends on the gas purchase price, gas supply scale, equipment investment, operation cost and transportation distance. The specific selection of mode can only be compared according to the specific conditions of each city.

For most small and medium-sized cities, they generally do not have the conditions for pipeline gas supply. In both CNG and LNG schemes, CNG scheme is suitable when the daily gas supply is less than 20000 m^3 and the transportation distance is not more than 200 km, otherwise LNG scheme is suitable. Obviously, the application scope of LNG scheme is wider.

LNG is the natural gas produced by oil and gas fields, which exists in liquid form at - 162 ℃ after a series of treatment processes such as liquid removal, acid removal, drying, fractionation and low-temperature condensation. The volume of liquefied natural gas is only 1/600 of the original, which can be easily stored and transported. LNG has the advantages of high energy density, low price, convenient use, safety and environmental protection. It has a wide range of uses as urban gas: 1. It can be used as the leading gas source for pipeline gas supply in large and medium-sized cities; 2. Peak shaving gas source that can be used for peak load and accident of urban pipe network gas supply; 3. It can be used as the leading gas source for small and medium-sized cities; 4. Fuel that can be used as automobile fueling.

1.3.2 Advantages of LNG

Excellent temperament, safe and reliable. LNG needs to be purified before liquefaction. Its main component is methane, with very low sulfur content, which is more stable and cleaner than natural gas. The gas phase density of LNG is 0.74 kg/ m^3, which is lighter than air. If there is a slight leakage, it can diffuse with air, which is difficult to reach the explosion limit; Its ignition point is 650 ℃, higher than 460 ℃ of LPG, its explosion limit is 5% - 15%, narrower than 1% - 15% of LPG, and it is safer to use.

Small volume, light weight and convenient storage and transportation. The volume of liquefied natural gas is only 1 / 600 of the original, and its density is less than half of that of water. It can be easily stored in storage tanks and transported over long distances.

Clean and environmentally friendly. Natural gas is a clean fuel, almost free of sulfur, dust and other harmful substances, and produces less carbon dioxide than other fossil fuels during combustion, resulting in relatively low greenhouse effect. If the effect coefficient of natural gas is 1, oil is 1.85 and coal is 2.08.

Huge reserves. There are still many jobs to be done in the exploration, exploitation and utilization of natural gas. Experts have confirmed that methane, which accounts for the main component of natural gas, can be produced not only organically, but also inorganic. CH_4 existed in the earth's crust as early as the formation of the earth. Astronomers also found that some planets may be surrounded by methane atmosphere. This theory has greatly expanded the exploration field of natural gas resources. In addition, oceanographers also found that there may be a large amount of methane at the bottom of the ocean due to the pressure of seawater, which is large enough for human use for decades.

1.3.3 Risks and preventive measures of LNG supply mode

1.3.3.1 LNG supply risk

In case of long transportation distance of LNG, if the traffic is interrupted due to continuous extreme weather or natural disasters, the normal supply of LNG will be affected. In the case of large-scale "gas shortage" in China, the normal production of LNG will not be guaranteed, which may cause the gas shutdown of downstream users of LNG.

1.3.3.2 Preventive measures

Appropriately increase the storage days of LNG in the city, reserve LNG well, and ensure the normal gas supply in the city in case of short-term interruption of gas source. Implement LNG emergency and standby gas sources to improve the safety and reliability of LNG supply. Formulate the urban gas emergency plan in case of accident, classify the users according to their importance, ensure the uninterrupted gas supply to residential users and other users in case of gas source interruption, cut off the gas supply to general users, and ensure the smooth passage of the accident state.

1.3.4 Application approach of LNG

The use of LNG can be roughly divided into the following aspects:

1.3.4.1 Gas source of urban gas

The gas consumption scale of marginal users in some small and medium-sized cities and some large and medium-sized cities is small and far away from the gas transmission pipeline network, or the construction of gas transmission pipeline is inconvenient or uneconomical due to geographical constraints. Therefore, it is very necessary to use the flexible advantages of LNG transportation to build LNG satellite stations as the gas supply source or transitional gas supply source for these cities or communities. Even after the pipe network arrives, LNG can be used as standby and peak shaving gas source.

1.3.4.2 Peak shaving and safety reserve

The construction of LNG Reserve Station for urban gas peak shaving has the unique advantages of small land occupation, high safety and economy. It is not only the first choice for daily and hourly peak shaving of urban gas, but also an effective means to ensure safe gas supply in case of accident. It is predicted that more than 100 cities with pipeline gas supply will build LNG peak shaving stations and accident emergency reserve stations within 10 years. In terms of investment cost, the construction of a gas storage scale is 300 × 104 m^3 / D Reserve Station, the cost of domestic equipment is about 20 million yuan. Small LNG station has strong flexibility for peak shaving. It is not only suitable for seasonal peak shaving, but also suitable for daily peak shaving. Moreover, there are not too many restrictions on site selection. It can be built in a suitable position of the gas supply network according to the needs of gas peak shaving and emergency gas supply. Small LNG is especially suitable for various requirements of urban peak shaving. With independent small LNG, the city has the advantages of regulation and reserve, which can change from passive to active, and reduce the pressure and responsibility of natural gas suppliers. The flexibility of small LNG plays a key role in urban daily peak shaving. LNG used for natural gas emergency peak shaving reserve is an important way to alleviate the safety of urban natural gas supply. We should strive to keep the working capacity of the built gas storage at about 10% ~ 15% of the total domestic natural gas consumption in recent years, so as to reach or exceed the international average capacity of 11%.

1.3.4.3 LNG as an alternative fuel for transportation

It is recognized as one of the ideal clean energy alternative fuels. Compared with diesel, it has the following two advantages: 1. Environmental protection. The NO_2 emitted by the engine using LNG is only 25% of that of diesel engine, the hydrocarbon and carbon oxide are only 32% and 12% respectively, and the particulate matter emitted is almost zero. In addition, the lifting power of LNG engine is only 36% of that of diesel engine; According to relevant data, using LNG as engine fuel, the content of harmful substances in tail gas is 98% and 30% lower than that of fuel oil, which is more conducive to environmental protection. Economic advantages. For engines with the same power, based on the current diesel and LNG prices in the market, using LNG as fuel can save about 30% of the fuel cost than using diesel. Therefore, LNG as an alternative fuel is widely used in automobile, ship and other transportation fields, which is of great significance for the country to achieve the strategic goal of energy conservation and emission reduction. Studies at home and abroad have shown that under the situation of increasing shortage of oil resources, natural gas as a transportation fuel instead of gasoline and diesel has broad development prospects. As a vehicle fuel, LNG has a large one-time filling capacity and a long driving range. However, due to the limitation of gas source, the development speed of LNG is not as fast as CNG. Skid mounted L-CNG automobile fueling device is a CNG automobile fueling device integrating LNG storage tank, high-pressure LNG gasification and gas sales metering. Compared with CNG filling station, it has the unique advantages of less land occupation, no noise, safe and reliable operation, low operation cost and obvious economic benefits due to the absence of compressor. With the massive introduction of LNG in China and the rapid improvement of domestic LNG production capacity, the advantages of LNG as an alternative fuel for transportation will be gradually reflected. China has planned to focus on the development of clean energy vehicles during the 12th Five Year Plan period to gradually replace the existing fuel fueled vehicles. The equipment industry company of the Ministry of industry and information technology of the people's Republic of China has defined the stage goal for 2015 in the development plan for energy saving and new energy vehicle industry: "the structure of vehicle fuel has been optimized, the proportion of alternative fuel in vehicle fuel consumption has reached more than 10%, and the promotion scale of natural gas vehicles has reached more than 1.5 million".

1.3.4.4 Fuels for industrial users

LNG has high purity and high calorific value. Its application in ceramics, glass shell, process glass, metal cutting and other fields can effectively improve product quality or production efficiency. From the perspective of market development, the target industrial users of LNG are mainly users with strong price tolerance.

1.3.5 Characteristics of urban gas in cities

The number of cities is large, the location is scattered, and the scale of gas consumption is small. As of 2007, the daily gas consumption of medium-sized cities generally does not exceed 30×104 m^3. The daily gas consumption of small cities generally does not exceed 10×104 m^3. The daily gas consumption of villages and towns is less than 5×104 m^3. Due to the large number and dispersion of small and medium-sized cities and the small gas consumption, if pipeline gas supply is adopted, not only the investment is huge, but also the investment payback period is very long, which directly limits the possibility of using pipeline natural gas in small and medium-sized cities.

Gas users are mainly civil and automobile. Generally, there are no large industrial users in small and medium-sized cities, and there is no possibility of large-scale heating with natural gas. There are usually no taxis and buses in small towns. Therefore, the types of natural gas users in small and medium-sized cities are relatively single, mainly residential and commercial users, supplemented by industrial, automobile and heating users. With the continuous rise of refined oil prices in recent years, buses and taxis are very willing to refit natural gas. Therefore, natural gas vehicles are also a very important user in small and medium-sized cities with taxis and buses.

The economic affordability of users is poor. The general economic foundation of small and medium-sized cities is relatively weak, and the living standard of residents is relatively low. Therefore, the affordability of users is relatively poor, and they are more sensitive to the price of gas. This requires that the gas projects in small and medium-sized cities must have the characteristics of less investment, short construction period, simple and flexible scheme and strong adaptability, so as to reduce the investment and operation cost as much as possible and make the gas sales price adapt to the affordability of users.

1.3.6 Analysis of gas consumption in small and medium-sized cities

The gas consumption of natural gas in small and medium-sized cities is roughly as follows: 1 Natural gas is widely used in residential life, commerce, industrial production, vehicle fuel, etc. For residential users, gas is mainly used for heating domestic water and cooking, industrial users are mainly used to meet the requirements of industrial production, and commercial users are mainly used for cooking, central heating, heating and refrigeration. In small and medium-sized cities, the residential gas consumption is easy to predict and adjust because of the small consumption of single household and small total gas consumption, while the industrial users are different and the gas consumption is large. Often, the gas consumption of a large industrial user may exceed the total residential gas consumption of the whole city, while the commercial users are vulnerable to seasonal influence, and the total gas consumption is related to the characteristics of users. 2. User development is the basis of natural gas sales, but it is very difficult to develop users in most small and medium-sized cities. There are two main reasons: first, charging the initial installation fee is an important factor restricting the development of pipeline gas users. For commercial users, the initial installation fee will be higher. Through comparison, users will consider choosing other clean energy sources, such as liquefied petroleum gas. Secondly, there are few new industrial enterprises in small and medium-sized cities, while the old industrial enterprises have their own coal to gas plants or use coal as fuel. All enterprises have made huge investments in existing equipment, plant and combustion equipment. If they use natural gas, the original equipment will be idle, which is not economical for users. In addition, the recent rising price of natural gas has brought obstacles to the development of industrial enterprise users. 3. For many small and medium-sized cities, they are often located at the end of the pipeline or downstream of the gas supply, and the gas demand of users cannot be reliably guaranteed. When the gas consumption is peak or insufficient, the first to cut off the gas is small cities. For example, in the gas shortage phenomenon in 2009, the first to limit the gas is small cities, which has seriously affected the life and industrial production of residents in small cities.

1.3.7 Advantages of LNG application in small and medium-sized cities

In China, as a beneficial supplement to pipeline natural gas, the development of LNG industry plays an important role in optimizing the national energy structure, promoting sustainable and healthy economic development, realizing energy conservation and emission reduction and protecting the environment. As a high-quality urban gas source and a new form of natural gas utilization, LNG has the following outstanding advantages over other gas sources and gas supply modes: low price, good economy, flexibility, convenience and strong adaptability. In urban gas, the price of CNG is low, followed by LNG and artificial gas, and the price of LPG is the highest. LNG is 36% cheaper than LPG, which is the biggest advantage of LNG application in small and medium-sized cities. The development of LNG in small and medium-sized cities with poor user affordability will be welcomed by users. It must be pointed out that CNG in the table has more price advantages than LNG, mainly due to different transportation distances. Due to different characteristics, the transportation distance of domestic CNG is very short, generally no more than 300km; The transportation distance of LNG is generally more than 1000 km, up to 4000 km. CNG is only suitable for small towns or communities with short distance, but not for most small and medium-sized cities in China. LNG has strong adaptability to gas supply scale and transportation distance. Since LNG is not sensitive to transportation distance, long-distance transportation can be realized. This will greatly expand the scope of natural gas supply; With the progress of technology, in addition to the traditional tank supply mode, there are also LNG bottle group supply and other gas supply modes, which can supply gas to small towns and even communities, which greatly reduces the threshold of using LNG and enables more small towns to use high-quality and clean natural gas. In addition, LNG is also very suitable as the start-up gas source of medium-sized cities. When the gas consumption is small at the initial stage of construction, LNG can be used as the start-up gas source for transition. After the gas consumption increases to a certain extent, a long-distance pipeline can be built to realize pipeline supply, and the built LNG gasification station can be used as the peak shaving and accident emergency gas source of the city. To sum up, LNG has very good adaptability to the majority of small and medium-sized cities, can meet the needs of cities, and has broad development prospects.

2 Analysis on precooling mode of LNG storage tank

2.1 Physical characteristics and hazards of liquid nitrogen and LNG

2.1.1 Physical characteristics and hazards of liquid nitrogen

Liquid nitrogen (abbreviated as LN_2), that is, liquid nitrogen. It is an inert gas, ultra-low temperature, non combustible, colorless, odorless and non corrosive. Most of the atmosphere in our life is nitrogen (weight ratio 75.5%, volume ratio 78.03%). Nitrogen is inert and cannot be burned. Liquid nitrogen will vaporize and absorb a lot of heat when exposed to the air, and frostbite will be caused in contact with human body. Under normal pressure, the temperature of liquid nitrogen is - 196 ℃. After gasification of 1 cubic meter of liquid nitrogen, about 800 cubic meters of pure gaseous nitrogen at about 21 ℃ can be obtained.

Under standard atmospheric pressure, if the temperature reaches - 196 ℃, liquid nitrogen will be formed. By increasing the pressure, liquid nitrogen can also be formed above - 196 ℃. In industrial applications, liquid nitrogen is obtained by air fractionation, which is separated by the different boiling points of each component in the air. The process is to remove impurities from the air, that is, after purification, liquefy it through the process of pressurization and cooling to form liquid nitrogen. Its health hazard is mainly that human skin contact with liquid nitrogen can cause frostbite. If human skin directly contacts liquid nitrogen for more than 2 seconds, it will cause irreversible frostbite, and in extreme cases, it may also cause hypoxia and asphyxia. Liquid nitrogen will not burn, nor is it explosive, and there is no danger of combustion and explosion.

2.1.2 Physical characteristics and hazards of LNG

LNG is the abbreviation of the English name liquefield natural gas. Its boiling point is - 160 ~ - 164 ℃. It is a colorless fluid in liquid state. LNG is mainly composed of methane, and also contains a small amount of nitrogen, ethane, propane and other components commonly found in natural gas. The LNG production process is that after the natural gas is preliminarily filtered to remove water and solid impurities, it is sent to the feed gas compressor for compression and temperature rise, acid gas, sulfide, mercury and other substances are removed by amine washing method, and then heavy hydrocarbon components such as benzene and cyclopentane are removed by cooling under the action of mixed refrigerant, so as to finally obtain natural gas (LNG) in liquid form of - 162 ℃. After the above liquefaction process, the volume of natural gas can be reduced by more than 600 times.

LNG is similar to methane in nature. It is a simple asphyxiating gas. When the concentration reaches a certain degree, it will cause asphyxiation due to hypoxia. It is a flammable gas, which is easy to form explosive mixture when mixed with air. Direct contact of liquid natural gas with human skin will cause serious burns. When LNG is gasified from liquid state to colder gaseous state, its density is higher than that of natural gas at normal temperature and is about 1.5 times heavier than air. Therefore, LNG will not volatilize immediately during gasification, but will diffuse around and absorb heat along its liquid level or ground, so as to form white clouds. The diffusion of natural gas can be observed through the diffusion of fog, but flammable mixtures will still accumulate outside the fog. If the flammable mixture meets with open fire, it will cause flash combustion, which is very dangerous.

The main characteristics of LNG are: temperature: its storage temperature is generally - 162.20 ℃. Density: it depends on the composition of LNG and decreases with the increase of methane content; It is a function of temperature and decreases with the increase of temperature, with a variation gradient of 1.35 Kg / ℃. In this paper, the density of LNG is 422 kg / m^3.

It is very easy to vaporize. After vaporization into ordinary natural gas, the volume will increase to 625 times of the liquid. When LNG is initially exposed to the air, the surrounding water vapor condenses due to its low temperature, which will form a visible white cloud in the air. Flammable and explosive: the combustion heat of LNG is 1.2 x 104 kcal / kg, and the explosion limit in air is about 5% - 15%, which is a dangerous chemical. As LNG is a hazardous chemical, its use, transportation and storage are highly dangerous, mainly as follows: rollover: the components of LNG in LNG storage tank may produce stratification due to different densities. After heat and mass transfer are generated between layers, LNG on the liquid surface will be continuously gasified. In the process of gasification, the lower liquid is in the state of back heating and overheating due to absorbing the heat of the upper liquid. When the density of the upper and lower liquid is almost the same, a large amount of gas will be mixed and appear, resulting in a sudden increase in the pressure in the storage tank, and even the safety valve may jump, resulting in a rollover accident. Low temperature frostbite: the LNG storage temperature is very low (usually - 162 ℃). When the skin is in direct contact with the low-temperature LNG or the surface of the low-temperature object, the moisture on the skin surface will quickly condense and stick to the surface of the low-temperature object, which will lead to the rapid freezing of the skin and subcutaneous tissue, which is very easy to be torn, leaving a wound and causing personal injury. Leakage: due to the extremely low operating temperature of LNG, metal components will shrink significantly due to stress changes, and leakage may occur at any part, especially valves, flanges, welds, pipe fittings, seals and other parts. If no measures are taken to stop the leakage in time, the generated steam cloud will slowly float up and spread with the wind. Once a fire is ignited by an open fire, thermal radiation or explosion overpressure will cause great harm and risk. Hypothermic anesthesia: without any protective measures, if a person is in an environment below 10 ℃ for a long time, his physiological function and intellectual activity will decrease with the decrease of body temperature, which will lead to hypothermic anesthesia. If the body temperature drops further, it will lead to heart failure and even death. Asphyxia: Breathing LNG low-temperature steam for a short time will lead to difficulty in breathing. If breathing LNG low-temperature steam for a long time, the consequences will be very serious. The low-temperature steam generated by LNG is non-toxic, but the oxygen content in the steam is very low, which is easy to lead to hypoxia and suffocation. If the human body cannot leave quickly after inhaling pure LNG vapor, it will soon lose consciousness and die of suffocation in just a few minutes. Combustion and cold explosion: LNG is very easy to burn in case of static electricity or Mars. If water is encountered in the process of LNG leakage, due to the extremely fast heat transfer rate between water and LNG, LNG will boil violently, spray water mist and produce huge noise, resulting in LNG vapor explosion.

2.1.3 Research on BOG

2.1.3.1 research significance

At the receiving terminal, a large amount of will inevitably be generated. If it is not handled properly, it will lead to overpressure of the storage tank and danger. If it is discharged and burned, it will cause waste of resources and environmental pollution. Therefore, processing has become one of the key issues that must be considered in the design and operation of the receiving station. According to the previous literature research, the Recondenser liquefaction process is widely used in the terminal to recover. Dapeng terminal, the first terminal in China, has accumulated rich experience in the construction and operation of domestic terminals since it was put into operation in. However, there are still some problems in the actual operation of some terminal treatment processes, such as high energy consumption, unstable control of Recondenser liquid level, long-term high, difficult operation when the load fluctuates too much, etc. Therefore, the terminal treatment process has the potential of optimizing operation, energy conservation and emission reduction. In recent years, the competition in the global trade market is becoming increasingly fierce and the price is rising. It also puts forward the requirements of low energy consumption, stable and reliable process for the treatment process.

2.1.3.2 BOG treatment process

At the terminal, Due to the invasion of low-temperature storage tank (about by the heat of the external environment, the conversion of some mechanical energy into heat energy during the operation of submerged liquid record in the tank, it will vaporize and produce evaporated gas, i.e. gas. In order to maintain the constant operating pressure of the storage tank (the gas must be continuously discharged out of the tank. In addition, when the ship is unloading, the liquid level in the tank at the receiving terminal increases, resulting in volume replacement, and the gas is also required to be discharged to ensure the stability of the tank pressure. Therefore, for the recovery, treatment and utilization of the, the tank gas should be returned to the ship in the following order in combination with the specific working conditions of the receiving terminal, so as to fill the vacuum generated by the tank unloading; and then condense Process, re condensing and sending out; Direct compression process, that is, directly pressurize the compressor to the pipe network pressure and then send it to the pipe network for export; Send torch or discharge into the atmosphere. The first method mentioned above is simple and efficient, but it can only balance part of the gas when unloading on board, and can not be used when unloading without board. The fourth way is an emergency safety measure, which is obviously unreasonable in economy and environmental protection. The second recondensation process and the third direct compression process send the gas to the compressor for pressurization and finally to the export pipeline, but the intermediate process is different. Therefore, according to different treatment methods, the terminal process can be divided into direct compression process and recondensation process.

BOG direct compression process. The compressor directly pressurizes all generated in the receiving station to the pressure of the export pipeline network and enters the export pipeline network in the form of high-pressure natural gas for users. The process has the advantages of simple operation and low investment cost; The outlet pressure of the compressor is equal to the pipe network pressure, which directly determines the process energy consumption. The higher the pipeline pressure, the higher the process energy consumption. So, Direct compression process is suitable for export pipeline network with low pressure, gas source type receiving stations with short gas transmission distance. There are many receiving stations in Japan. Generally, the radiation area of gas transmission pipe network is small and the pressure of pipe network is low, so most receiving stations in Japan adopt BOG direct compression process. For example, receiving stations of Osaka gas and Tokyo Gas company in Japan use this process to treat BOG. In addition, in small-scale stations with small processing capacity and unstable export capacity Direct compression process is also suitable for peak shaving terminal.

BOG recondensation process. The energy consumption of direct compression process is mainly determined by the pressure of export pipeline network, When the pressure of the export pipeline network of the terminal is large. The excessive energy consumption of the compressor leads to the excessive energy consumption of the whole direct compression process. Generally, the direct compression process is not used, but the recondensation process is widely used. The main principle of BOG recondensation process is to use the cooling capacity of high pressure itself for condensation, that is, after pressurization, it has a certain degree of supercooling and direct or indirect contact heat exchange. BOG recondensation process mainly has two forms: indirect heat exchange Re condensation process and direct heat exchange re condensation process.

2.1.3.3 Research status at China and abroad

Research status of reducing treatment capacity. No matter what treatment method we adopt, the more we need to treat, the higher the energy consumption of BOG treatment and the more unfavorable it is to the operation of the treatment system. Therefore, reducing the production is the way to reduce the treatment cost from the root. At present, there are many studies on adjusting the pressure of storage tank and improving thermal insulation materials to reduce the production.

The researchers simulated and dynamically analyzed the gas phase space of the tank, analyzed the heat leakage forms of the tank top, wall and bottom, studied various factors affecting the pressure in the tank, and found out the law of pressure change in the tank. The effects of tank pressure and heat leakage on the production are analyzed. Suggestions on the operation of evaporation control and discharge rate control are put forward. The amount generated by the terminal under different working conditions is very different, especially during ship unloading operation, the amount is dozens or even hundreds of times higher than usual. Therefore, the influence relationship between storage pressure during ship unloading and normal export is analyzed in detail, and some useful operation suggestions are given, At the same time, the skills of tank pressure and compressor capacity control are put forward. In view of the problems of high cost and complex process in tank filling. Proposed to replace the gas produced by the tank, and carried out experimental research on the tank. The results show that the technology is not only theoretically and technically feasible, but also has good economic value, It is worth popularizing and applying. At present, storage tanks mainly include atmospheric storage and high-pressure storage. By analyzing the existing problems of the two storage methods, the combination of high-pressure storage tank and atmospheric storage tank has less equipment and simple process, which can reduce investment and storage cost. It is a new type of BOG storage method.

2.1.3.4 The content of BOG and LNG

LNG is stored in a low-temperature container with thermal insulation structure, which has a large temperature difference with the atmospheric environment, so there is heat exchange. The infiltration of ambient heat makes the components in LNG evaporate, and the evaporated gas accumulates at the top of the container. For the convenience of discussion and according to the actual situation, we assume that LNG is mainly composed of two components - methane and ethane. When the pressure reaches the set pressure of the safety valve, the safety valve jumps off and the gas is discharged from the container. This phenomenon is called natural gasification (BOG), and the percentage of heavy fraction in the residual liquid of the container becomes larger. In this way, the percentage of heavy fraction will become larger and larger in the process of use, which is the "weatherign" of LNG fuel. If the daily evaporation rate is 0.1%, the annual BOG value of LNG storage tank with a volume of 1000. For vehicles, the influence of "aging" is also different due to different filling methods of gas cylinders. When the steam recovery filling method is adopted, the influence of "aging" will not accumulate, which is complex; First, when the vapor collapse filling method is adopted, the influence of "aging" will accumulate, but this filling method has simple equipment. BOG is evaporated from the components in LNG, but the content of its components is very different from that of LNG.

2.2 Structure, characteristics and thermal insulation technology of LNG storage tank

2.2.1 LNG storage tank form, structure and material selection

LNG storage tank can be divided into aboveground storage tank and underground storage tank according to its setting mode. According to the structural form of storage tank, it can be divided into membrane tank, single containment tank, double containment tank and full containment tank. According to the capacity of storage tanks, they are classified as follows: small

LNG storage tanks (5 ~ 50 m^3): mainly used in ordinary LNG truck filling stations or residential gas vaporization stations. Medium sized LNG storage tank (50 ~ 100 m^3): commonly used in industrial gas vaporization station, satellite liquefaction unit and other occasions. Large LNG storage tank (100 ~ 40000 m^3): with a capacity of 100 ~ 10000 m^3, it is commonly used in small LNG production units or LNG processing plants; With a capacity of 10000 ~ 40000 m^3, it is mainly used for peak shaving or large load liquefaction units. Extra large LNG storage tank (40000 ~ 200000 m^3): mainly used for LNG terminal.

Generally, LNG plant storage tank is composed of inner tank, outer tank, cold insulation system between inner and outer tanks and process instrument system. At present, LNG low-temperature storage tanks commonly used at home and abroad can be divided into atmospheric tank storage, sub parent tank under pressure storage and vacuum tank under pressure storage according to their structure. The specific storage method can be selected according to the actual storage capacity.

(1) Atmospheric tank. As the name suggests, atmospheric tank is equivalent to atmospheric pressure, and its structure is mostly bimetallic tank. Under special conditions, the outer tank is poured with prestressed concrete at 20000 m ³ Bimetallic tanks are mostly selected for the following LNG tanks. The manufacturing cycle of atmospheric tank is long, which usually takes about 10 months to 1 year, and its inner and outer tanks are welded and installed on site. LNG low-temperature and atmospheric pressure storage tanks often adopt the form of flat bottom double wall cylinder, with an operating pressure of about 15 ~ 18 kpa and an operating temperature of about - 162 ~ - 164 °C. The tank body is divided into inner and outer layers, and the middle is a cold insulation layer, which needs to be filled with thermal insulation materials. The main function of the inner tank is to store LNG in contact with ultra-low temperature, while the outer tank is mainly used for cold insulation and protection. The inner tank and the outer tank are separated and designed independently. The main purpose is to reduce the external heat transfer into the tank. The tank roof is generally an arch roof. The tank roof of the inner tank needs to bear its own weight such as cold insulation materials and the pressure generated by internal gas, which has strict requirements on the strength and stability of the tank roof. Pearlescent sand is mostly used as the cold insulation material in the middle cold insulation layer. Nitrogen with high dry purity is filled to ensure the micro positive pressure of the middle interlayer, isolate the thermal insulation material from the atmosphere, isolate the influence of external environmental changes and prevent wet air from entering the middle cold insulation layer, which increases the service life of the cold insulation material. The installation and construction of thermal insulation structure requires high environmental requirements, and moisture-proof measures shall be taken when necessary. Low temperature and normal pressure storage tanks are mostly used in LNG plants or large terminal LNG receiving stations. Because the terminal stations are mainly used to store LNG, the LNG storage tank volume is designed to be large, and the single tank volume is 5 ~ 20 × 104 m³ Therefore, the vacuum tank and child mother tank can not be realized at all. A liquefaction recovery device for BOG flash steam shall also be set at the receiving terminal station, which can re liquefy BOG into LNG and return it to the storage tank for storage, so as to reduce flash loss. In the LNG plant, the main unit is the liquefaction unit. The BOG generated during storage can be returned to the liquefaction unit for liquefaction again and stored in the storage tank. Therefore, the BOG flash natural gas produced by low-temperature and normal pressure storage tank has little impact on the terminal and plant except increasing power consumption.

(2) The tanks are also pressure vessels. The inner tank adopts multiple low-temperature resistant stainless steel pressure tanks, which are covered with a large carbon steel tank as protection, and the inner and outer tanks are insulated by filling thermal insulation materials. In order to prevent wet air from entering the interlayer, dry nitrogen can be introduced into the interlayer for protection. The inner tank of the child mother tank is manufactured by the factory at one time, formed and tested for pressure filling, and can be directly transported to the site for installation. The outer tank is generally welded and installed on site. At present, the maximum capacity of a single sub tank in China can only be 250 m³. The storage capacity is 1000 m³ To 5000 m³ For the storage and distribution station, the sub master tank can be selected for storage according to the situation. The gasification process flow of the sub master tank is basically the same as that of the vacuum tank described above. Because the interlayer needs to be filled with nitrogen, a set of liquid nitrogen device must be added to the unit.

(3) Vacuum tank. The vacuum tank is a pressure vessel with double-layer metal tank body. The inner tank is usually made of low-temperature resistant stainless steel, the outer tank can be made of carbon steel, and the middle interlayer shall be filled with thermal insulation material and vacuumized. Vacuum tanks are transported to the site for installation after factory manufacturing and pressure test. Usually, multiple vacuum tanks are used for centralized storage. At present, the maximum volume of a single vacuum tank used in China can be 150 m³. The total LNG storage capacity is 1000 m³ following. Process flow of vacuum tank: pressure is supplied to the tank through the supercharger, and the materials automatically flow into the gasifier under the action of pressure. It has simple process, no power equipment and low energy consumption. Therefore, vacuum tanks are widely used in some small LNG gasification stations at home and abroad.

According to the functional characteristics of LNG storage tank, its outer tank, inner tank wall and cold insulation layer have very strict requirements on the selection of manufacturing materials:

1) Inner tank wall. The inner tank wall of LNG storage tank is the main component of low-temperature storage and needs to be welded by steel with good low-temperature resistance and good mechanical properties.

2) Cold insulation layer. The cold insulation layer can be divided into three areas: tank top, tank bottom and tank wall. (1) Suspended rock wool is used as the cold insulation layer on the tank top. 4 ~ 5 layers of glass fiber can be set, each layer is 80mm thick, the density of glass fiber wool is 16 kg/m^3 and the thermal conductivity is 0.04 w / (m · K). (2) the cold storage process at the bottom of the tank is more complicated. The polyurethane foam can be sprayed under the steel plate, and the waterproofing structure is also designed, including the cushion above 65mm, the high strength concrete above 60mm, the 2 to 3 mm thick waterproof felt, the 100mm thick foam glass 2 layers, and the 70mm thick concrete soil. (3) the cold storage

of the tank wall mainly sprayed polyurethane foam inside the lining plate of the outer tank, requiring the thermal conductivity of polyurethane foam to be less than 0.03 W/ (m · K), with a density of 40 to 65 kg/m^3 and a thickness of more than 150 mm.

3) Outer tank. The outer tank is usually made of concrete or carbon steel. The outer tank wall and top of the concrete structure are poured with prestressed reinforced concrete and low temperature resistant steel lining plate. The concrete strength shall be over 25 MPa. Reinforced concrete must have sufficient tensile strength to ensure that the internal pressure caused by accidental gas leakage will not be damaged.

2.2.2 Characteristics of LNG storage tank

LNG storage tanks in LNG plants generally adopt large double wall single containment atmospheric low-temperature storage containers. Its main features are: low temperature resistance and cold insulation performance. The boiling point of liquefied natural gas at atmospheric pressure is - 162 ℃. LNG is stored in low temperature and normal pressure storage mode. The temperature of natural gas is controlled at about - 162 ℃, and the operating pressure in the tank is maintained at 5 ~ 15 kpa micro positive pressure. LNG is relatively stable, high and safe. Therefore, LNG storage tank must have excellent low temperature resistance and cold insulation performance.

High safety requirements. According to the requirements of API, BS and other specifications, LNG storage tank must adopt double-layer wall structure and tank cofferdam must be added. Because the LNG storage tank stores ultra-low temperature liquid natural gas, the leakage of the storage tank will cause a large amount of volatilization of LNG, and the gasification amount is more than 300 times that of the liquid form. It absorbs water and heat in the atmosphere to form a low-temperature natural gas mist. When the natural gas concentration reaches the explosion limit in the range of 5% ~ 15%, it can explode in case of open fire. The explosion produces high pressure, high temperature and combustion in an instant, and the destructive power and risk are incalculable. In the design, the concept of blocking is applied to add a layer of cofferdam, so that when the tank leaks, the cofferdam can completely surround the leaked LNG without spreading to all sides and completely block it to ensure storage safety.

Special materials. The inner tank wall is made of s30408 stainless steel or aluminum alloy, and the outer tank wall is made of prestressed reinforced concrete or carbon steel, which is required to be resistant to low temperature and meet the strength standard.

The thermal insulation measures are strict. Since the external ambient temperature cannot be controlled, the maximum temperature difference between the inside and outside of the tank can reach more than 200 ℃ under extreme conditions. To ensure that the temperature in the tank is maintained at - 162 ℃, the middle layer between the inner tank and the outer tank must be filled with high-performance cold insulation materials to ensure that the tank has very good cold insulation performance. The cold insulation material used at the bottom of the tank must also have sufficient pressure bearing performance.

Good seismic performance. Due to the risk of LNG tank leakage, LNG tank must have good seismic performance. In the design, the seismic requirements of general buildings are to crack but not fall under the design seismic strength load, while LNG storage tanks are required to crack and not fall under the design seismic strength load. Therefore, the seismic fracture zone cannot be selected as the construction site before construction, and the seismic test must be conducted on the storage tank to analyze the structural performance of the storage tank under dynamic conditions and ensure the safety of the storage tank under the design seismic intensity.

Strict construction requirements. The welding quality of storage tank is very high, and there are strict requirements for temperature and humidity during construction. X-ray flaw detection, vacuum airtightness test and magnetic particle test must be carried out for all welds. The construction environment also has strict requirements. It is best not to choose rainy days during welding, and the humidity shall be controlled within 75%. The selection and construction of cold insulation materials are more strict. They must follow the specified procedures and meet the design construction conditions, such as temperature control, temperature control and moisture-proof measures. When pouring concrete at the tank bottom, the hydration temperature must be controlled to prevent cracking due to rapid temperature change.

2.2.3 Low temperature thermal insulation technology of LNG storage tank

The main purpose of thermal insulation of LNG storage tank is to control and reduce the cold loss or evaporation rate of storage tank and achieve the effect of cold insulation. The so-called thermal insulation does not mean to achieve 100% thermal isolation, but to minimize or reduce heat conduction, convection and radiation to minimize heat transfer. In other words, it is necessary to restrain the heat flow from high temperature to low temperature.

Common thermal insulation methods include: stacking thermal insulation, vacuum powder thermal insulation, high vacuum thermal insulation, high vacuum screen thermal insulation, high vacuum multi-layer thermal insulation, etc. Stacking thermal insulation: select thermal insulation materials with small thermal conductivity and fill them to the position requiring thermal insulation through dense filling and pressure, so as to isolate heat flow. Stacking insulation can be divided into two ways: Foam adiabatic, fiber or powder insulation. Foam insulation materials (such as foam glass, foam polyurethane, foam polystyrene, rubber) are heterogeneous materials, and their thermal conductivity is mainly determined by material density and foaming gas, while it is also affected by the average temperature of the insulation layer. The main disadvantage of powder or fiber thermal insulation materials (such as glass fiber, pearlescent sand, asbestos, mineral wool, etc.) is that water vapor and air can penetrate into the cold surface through the thermal insulation layer.

Generally, a steam barrier layer, moisture-proof layer, shall be set. The insulation of LNG storage tank mainly includes tank bottom insulation, tank wall insulation, tank top insulation, etc. The construction of tank bottom insulation is complex, with high requirements and many processes. Mainly include: bottom concrete leveling, ring beam ring, tank center, high strength foam glass at the bottom of the interlayer, elastic asphalt waterproofing membrane laying and so on. The insulation construction of tank wall is also very complex, with strict requirements and many processes. It mainly includes: installing the elastic felt on the outer wall of the inner tank, the elastic felt on the ceiling, the installation of heat shield foam glass and pearlescent sand glass cloth retaining wall, the annular space filling expanded perlite and so on. The most important performance of elastic felt is that it can maintain sufficient and stable resilience without obvious attenuation in the whole service life of storage tank. In order to prevent the filled perlite from invading the inner tank, a tight sealing isolation device is usually installed between the inner tank wall and the tank ceiling. At the same time, it is necessary to ensure gas convection on both sides of the inner tank wall to maintain pressure balance. The expanded perlite is filled on site. After the perlite is expanded on site, the expanded perlite is filled into the annular space between the inner and outer tanks with high-temperature and dry compressed gas. The main purpose of cold insulation on the top of the inner tank is to keep the low temperature of the evaporation space of the inner tank from losing. The construction process includes cold insulation of ceiling series nozzles and laying glass wool on aluminum ceiling. Control the steam entering the space above the ceiling to prevent freezing on the tank top, causing the tank top to be cold and brittle due to low temperature and increasing the tank top load due to icing. The ceiling board is generally laid with glass wool felt or covered with expanded perlite, and the design allows the gas above and below the ceiling to circulate with each other. The main performance indexes of glass wool felt shall be controlled at: density 12 kg/m^3, allowable deviation of single value of density 20 ~ 10% (W), thermal conductivity ≤ 0.035w / (m·K) (at 10 ℃).

2.3 Pre cooling process flow of LNG storage tank

2.3.1 Preparation before precooling of LNG storage tank

According to the process requirements, the LNG storage tank must undergo air tightness test, drying operation, nitrogen replacement and precooling operation before being put into use. The above operations are used to inspect and test the sealing performance and low-temperature performance of the storage tank and its low-temperature equipment and pipelines, so as to prepare for LNG storage. The main purpose of drying operation is to remove moisture that may adversely affect the process, pipeline and equipment. The main purpose of nitrogen replacement is to prevent LNG volatile gas from forming explosive gas after mixing with air. Before precooling, the storage tank system shall be thoroughly dried until the dew point test is qualified. Generally, the dew point value below 20 ℃ under standard atmospheric pressure is regarded as qualified. If the dew point is unqualified, the freezing of the valve may be caused after the cooling capacity enters. After the drying is qualified, in order to reduce the oxygen content in the storage tank to a safe level and further dry the storage tank, PSA nitrogen or high-purity nitrogen (purity over 99.9%, dew point below - 60 ℃) can be used for replacement. The replacement technology requires that the oxygen concentration per unit volume is less than 4%.

2.3.2 Precooling process flow and precooling mode of LNG storage tank

Precooling of LNG storage tank is through spraying at the top of precooling pipeline and columnar injection. Generally, liquid nitrogen or LNG is used to provide precooling cooling energy. The primary precooling of equipment and pipelines, which is carried out by using the cooling capacity gas phase first. Its purpose is to inspect and test the low-temperature performance of low-temperature equipment and pipelines to prevent the equipment and pipelines from being damaged by thermal stress due to excessive temperature difference. Including: 1. Check whether the quality of low-temperature materials is qualified; 2. Inspect welding quality; 3. Check the change of pipe support and pipe cold shrinkage; 4. Check the tightness of low temperature valve; 5. Check whether the storage tank is in working condition. In the second step, the liquid phase is directly used for deep precooling until the precooling reaches - 162 ℃ and a certain liquid level is established. The precooling is qualified and meets the liquid inlet conditions. The specific process flow is: cooling capacity tank car → unloading gasifier → gas phase pipeline → liquid inlet pipeline → storage tank → BOG vent pipeline → flare.

Precautions during precooling: the precooling rate of storage tank shall be controlled according to the specifications to avoid thermal stress in the inner tank. During precooling, pay attention to monitoring the temperature of the annular space of the storage tank and the leakage monitoring point of the storage tank bottom plate. In case of leakage, cut off the precooling valve immediately and continue precooling after treatment. During precooling, the pressure of the storage tank shall be controlled at 5 ~ 15K PA to prevent overpressure; During precooling, vent the overpressure to the cold flare, pay attention to the pipe deformation of the cold flare, whether there is leakage at the welding joint, and whether the supporting pipe support is displaced and firm. According to the previous analysis and the analysis of successful cases of tank precooling at home and abroad, at present, cryogenic gas or cryogenic liquid is generally used to provide precooling energy for LNG tank precooling, and the commonly used materials are liquid nitrogen (- 196 ℃) or liquid natural gas (- 162 ℃). Therefore, the current precooling modes of LNG storage tank can be divided into Liquid Nitrogen Precooling mode, LNG precooling mode and liquid nitrogen + LNG mixed precooling mode.

2.4 Analysis on precooling mode of LNG storage tank

2.4.1 Analysis of LNG precooling mode of LNG storage tank

LNG precooling mode is adopted for LNG storage tank, that is, LNG is transported out by tank truck as the cold material for precooling of storage tank, which is input into LNG storage tank for precooling operation until the storage tank temperature drops to - 162 ℃ and the liquid level is established, and the precooling work is completed.

The main process flow is as follows: Step 1: the LNG storage tank is qualified through drying and replacement to meet the pre cooling conditions of the storage tank; Step 2: connect LNG tanker and gasifier. Firstly, gas phase is used for primary precooling of pipeline, and the precooling rate is controlled at the temperature drop of 2-3℃/h; Step 3: when the temperature of the storage tank drops to - 40℃, close the liquid inlet valve of the gasifier, turn on the bypass valve, and directly use LNG liquid phase for deep precooling, and the precooling rate is still controlled at 2-3℃/h; Step 4: when the storage tank temperature is cooled to - 70℃, the flanges of the whole line shall be cold tightened for the first time; When the storage tank temperature is cooled to - 162℃, the flanges of the whole line shall be cold tightened for the second time. The precooling rate is still controlled at the temperature drop of 2-3℃/h. Step 5: continue to introduce LNG and establish a liquid level of no less than 300mm in the tank, and the precooling process flow of LNG storage tank is completed.Advantages and disadvantages of LNG precooling mode of LNG storage tank:

Advantages: after the precooling of LNG storage tank is qualified, the liquid level can be directly established. If the LNG plant cannot produce products in time, the BOG cycle can ensure that the storage tank is in standby state at any time.

Disadvantages: 1. LNG is a dangerous chemical, which is prone to combustion and even explosion accidents due to improper equipment or operation during precooling; 2. The purchase price of LNG products is high. During precooling, LNG is gasified and discharged to the flare for combustion, resulting in a waste of resources. 3. If the LNG plant cannot produce products in time, it must use outbound LNG to maintain precooling results; That is, using BOG cycle to maintain precooling storage tank also has high cost for low load operation and energy consumption of equipment.

2.4.2 Analysis of Liquid Nitrogen Precooling mode of LNG storage tank

Liquid Nitrogen Precooling mode of LNG storage tank, that is, liquid nitrogen is used as precooling cold materials into the storage tank to precooling the LNG storage tank until the storage tank temperature drops to the target temperature of - 162℃. However, if liquid nitrogen is used to precooling the LNG storage tank, in order to meet the use requirements of LNG liquid inlet, the nitrogen remaining in the storage tank during precooling must also be replaced until the nitrogen content in the tank reaches the standard. The main process flow is as follows: Step 1: the LNG storage tank is qualified through drying and replacement to meet the pre cooling conditions of the storage tank; Step 2: connect the liquid nitrogen tank car and gasifier. Firstly, the gas phase is used for primary precooling of the pipeline, and the precooling rate is controlled at the temperature drop of 2-3℃/h; Step 3: when the temperature of the storage tank drops to - 40℃, close the liquid inlet valve of the gasifier, turn on the bypass valve and directly use the liquid phase for continuous precooling, and the precooling rate is still controlled at the temperature drop of 2-3℃/h; Step 4: when the storage tank temperature is cooled to - 70℃, the flanges of the whole line shall be cold tightened for the first time; When the storage tank temperature is cooled to - 162℃, the flanges of the whole line shall be cold tightened for the second time. The precooling rate is still controlled at the temperature drop of 2-3℃/h. Step 5: when the second cold tightening is performed, the temperature of the storage tank has cooled to - 162℃, the LNG product of the device is turned on to enter the storage tank, and the nitrogen retained during precooling in the storage tank is replaced until the nitrogen content in the tank is lower than (28%), and the replacement is qualified; Step 6: continue to introduce LNG and establish a liquid level of no less than 300mm in the tank, and the precooling process flow of LNG storage tank is completed. Advantages and disadvantages of Liquid Nitrogen Precooling LNG storage tank:

Advantages: 1. Nitrogen is an inert gas, leakage will not produce deflagration, and operation safety is high; 2. Liquid nitrogen is obtained by air fractionation. It is liquefied under pressure and cooling. The process is simple. All LNG plants have PSA nitrogen generating units, which are supplied in general industrial parks. The purchase price and logistics cost are relatively cheap, and the cooling cost is low.

Disadvantages: 1. Liquid nitrogen is usually about - 192℃. Generally speaking, the design temperature of LNG storage tank is - 163 ~ - 180℃. In the later stage of tank precooling, the temperature is not easy to control, which is easy to cause tank supercooling; 2. After the precooling of the storage tank is qualified, the nitrogen used when the tank is full of precooling cannot be discharged. It must be replaced with LNG until the nitrogen content of LNG products in the tank meets the requirements. This process takes a lot of time and causes a waste of LNG resources (the replacement gas is usually discharged to the flare), increasing time and economic cost.

2.4.3 Analysis of liquid nitrogen + LNG mixed precooling mode of LNG storage tank

Liquid nitrogen mixed precooling mode of LNG storage tank, that is, at the initial stage of storage tank precooling, liquid nitrogen is used as cold material to input into the storage tank for precooling. When the storage tank temperature reaches the predetermined value, switch the cold material to LNG input into the storage tank to continue Precooling until the LNG storage tank temperature reaches - 162℃ and the nitrogen content in the tank meets the requirements, and establish the LNG liquid level. The main process flow is as follows: Step 1: the LNG storage tank is qualified through drying and replacement to meet the pre cooling conditions of the storage tank; Step 2: connect the liquid nitrogen tank car and gasifier. Firstly, the gas phase is used for primary precooling of the pipeline, and the precooling rate is controlled at the temperature drop of 2-3℃ / h; Step 3: when the temperature of the storage tank drops to - 40℃, close the liquid inlet valve of the gasifier, turn on the bypass valve and directly use the liquid phase for continuous precooling, and the precooling rate is still controlled at the temperature drop of 2-3℃/h; Step 4: when the storage tank temperature is cooled to - 70℃, the flanges of the whole line shall be cold tightened for the first time; Step 5: when the temperature of the storage tank cools to - 120℃, close the liquid inlet valve of the liquid nitrogen tanker, connect the LNG tanker, and continue precooling with the LNG liquid phase. The precooling rate is still controlled at the temperature drop of 2-3℃/h; Step 6: when the storage tank temperature is cooled to - 162℃, the flanges of the whole line shall be cold tightened for the second time. Step 7: detect that the nitrogen content in the tank is lower than (28%), continue to introduce LNG and establish a liquid level not lower than 300 mm in the tank, and the precooling process flow of LNG tank is completed.Advantages and disadvantages of liquid nitrogen + LNG precooling LNG storage tank:

Advantages: because liquid nitrogen is relatively cheap and inert gas, Liquid Nitrogen Precooling in the previous stage not only effectively avoids the risk of combustion or explosion caused by leakage, but also reduces the material cost of precooling; In the later stage, after the first cold tightening, the leakage risk is greatly reduced and the safety is higher. In addition, the use of LNG not only continues the pre cooling of the storage tank, but also replaces the nitrogen in the storage tank. When the pre cooling of the storage tank reaches - 162℃, the nitrogen replacement is basically qualified (28%), the liquid level can be directly established and wait for the entry of LNG products of the unit.

Disadvantages: 1 In the precooling preparation stage, liquid nitrogen and LNG need to be purchased at the same time. Due to the uncertain factors in precooling, the demand time of precooling medium and the demand quantity of two kinds of cooling capacity are difficult to control. 2. The technical ability and experience of the technical team are highly required, and the precooling rate control and material switching temperature point of the two materials shall be basically consistent with the calculated value.

2.5 LNG liquefaction process

2.5.1 Current situation of liquefaction area

At present, the refrigeration modes of LNG stations include throttling refrigeration, expansion refrigeration, hybrid refrigeration, cascade refrigeration, hybrid refrigeration with precooling, double hybrid refrigeration and unit hybrid refrigeration. With the in-depth research on natural gas, the refrigeration modes continue to appear. The more commonly used refrigeration modes are as follows:

Hybrid refrigeration. Hybrid refrigeration process is the most widely used technical route in large LNG plants in the world. It has the advantages of short process flow, high liquefaction efficiency and energy saving. The disadvantage is that it is easy to fluctuate and difficult to control, especially it is difficult to start and stop. The mixed refrigeration process uses the mixture of nitrogen, methane, ethylene, propane, butane and pentane as the refrigeration medium. After cooling, the first and second stage pressurized refrigerant enters the plate fin heat exchanger. Through primary cooling and primary separation, the liquid phase enters the cold box for cooling and throttling expansion to provide cooling capacity; The gas phase enters the third stage compressor for further pressurization. After water cooling, the pressurized refrigerant enters the plate fin heat exchanger for further cooling. After secondary separation, the gas phase and liquid phase are separated. After the gas and liquid phase refrigerant return to the cold box for further cooling, they are throttled and expanded respectively to provide cooling capacity. The heat exchange process is concentrated in a large heat exchanger (cold box).

Multi component mixed refrigerant is used for mixed refrigeration. Different temperature levels are obtained by using the characteristics of different boiling points and partial condensation of different components, and the feed gas is cooled and liquefied in sequence. Only one set of compressor unit is required for hybrid refrigeration, and the process flow is greatly simplified. However, the refrigerant still needs to be divided into different temperature levels or pressure levels, resulting in high energy consumption and high key control point technology, especially in the high proportion requirements of refrigerant.

Cascade refrigeration. Typical cascade refrigeration cycle this process selects multiple groups of refrigerants with evaporation temperature gradient, such as propane, ethane (or ethylene) and methane, and exchanges heat with natural gas through multiple refrigeration systems to gradually reduce the temperature of natural gas to liquefaction. This method is usually called step refrigeration process or cascade refrigeration process. However, due to the relatively complex process and many equipment units, it is difficult to manage and maintain. The refrigerants are flammable and explosive gases, which have high requirements for the process. Once leaked, it will have serious consequences. Therefore, the requirements for the management, inspection and maintenance of the station are very high. In order to improve the operating rate of some large LNG production units using cascade refrigeration, each refrigerant system is equipped with double turbines. Although this can make it possible for the unit to maintain production even if a turbine fails, the operation is more complex and the unit cost is greatly increased.

Hybrid refrigeration with Precooling. The mixed refrigerant refrigeration process based on propane precooling is most used in this process. The cooling capacity required for liquefaction is provided in two sections. Propane is used as refrigerant in the high-temperature section to precooling the feed gas and mixed refrigerant according to several different temperature levels, and mixed refrigerant of different pressure levels is used to liquefy the feed gas in sequence in the low-temperature section. This process combines the advantages of cascade refrigeration and general hybrid refrigeration. The process flow is relatively simple, the efficiency is higher and the operation cost is lower.

2.5.2 Research on Chinese chemical equipment and domestic liquefaction process

According to the research on the liquefaction process of Tai'an liquefaction station that has been put into operation, the LNG stations constructed do not adopt the above liquefaction process, but adopt a single nitrogen circulation system. The advantages of adopting the nitrogen circulation system are as follows: (1) the refrigerant is nitrogen, the requirements for the process are lower than those for flammable and explosive gases, and there will be no explosion risk in case of leakage; (2) convenient start-up, shutdown and maintenance, suitable for small LNG stations. (3) nitrogen is cheap and easy to buy; (4) the equipment has short manufacturing cycle and low cost, which is suitable for the construction of small LNG stations; (5) the replacement of nitrogen and air in the pipeline is convenient and reliable, and the detection of nitrogen dew point is convenient. (6) only a small part of the nitrogen used for refrigeration needs to be purchased during startup, and the rest is produced by PSA equipment. (7) reciprocating compressor is adopted, which has high efficiency, easy control and large output adjustment range. (8) the adjustment range of natural gas treatment capacity is relatively large, which can be adjusted between 35% - 100%. (9) the standby expander can be switched online without shutdown. (4) the operation stability is relatively strong and the system operation will not be affected by nitrogen flow and pressure fluctuation. (10) in the process of refrigeration expansion, there will be no liquid at the outlet of the expander, which improves the safety and reliability of the device. (11) the operation stability is relatively strong and will not affect the system operation due to nitrogen flow and pressure fluctuation.

There are disadvantages: (1) large nitrogen circulation volume. For domestic equipment, the nitrogen compressor has poor sealing performance and has a certain leakage rate. The nitrogen volume is often supplemented. (2) the requirements for nitrogen compressor are high and the nitrogen circulation volume is large. In addition, the domestic nitrogen compressor has insufficient experience in natural gas liquefaction station, the valve seat of compressor inlet valve is often damaged (the material requirements of valve seat are high), which affects the normal operation. The valve seat shall be made of good materials to ensure stable operation. (3) the reciprocating piston compressor has large vibration and long time, which affects the connection of pipeline and connecting accessory equipment, resulting in damage to accessory equipment. (4) the reciprocating piston compressor has less processing capacity and more equipment, which increases the operation and maintenance of moving equipment. (5) the natural gas treatment capacity should not be too large.

According to the operation of Tai'an liquefaction station for a period of time and continuous experience in operation, the process is improved. At present, the station is in stable production. In terms of the construction of domestic small LNG stations, the station adopts nitrogen circulation system and domestic equipment, and the whole station adopts independent intellectual property process, which is very successful. The construction cycle is short. Compared with the same station, it shortens the time of one year to one and a half years, and the investment is less, with a year-on-year decrease of nearly 100 million yuan. It fills many gaps in domestic LNG station construction investment, construction time, domestic equipment and domestic technology with independent intellectual property rights, plays an important role in promoting the construction of domestic LNG stations, drives the effective development and utilization of domestic supporting equipment of domestic LNG stations, and more importantly, trains a number of scientific and technological personnel in the field of LNG. The liquefaction process is divided into: natural gas precooling system, natural gas liquefaction system and nitrogen circulation system.

2.5.3 Precooling of natural gas

The composition of natural gas is complex. Through the purification process, the impurities such as H_2O, acid gas (including CO_2, H_2S, cos and organic sulfide), mercury and heavy hydrocarbon in the feed natural gas are removed. After purification, the pressure of natural gas is maintained at 3.0MPa and enters the precooling system to precooling the temperature of natural gas to 0 ± 2 ℃.

Advantages: BHDL series semi closed screw natural gas precooling unit is selected for this precooling process: (1) The main engine adopts semi closed screw compressor; The control adopts a novel PLC programmable controller. (2) The evaporator and condenser of the heat exchange part are all customized and processed by the newly developed high-efficiency heat exchanger, with high heat exchange efficiency. (3) The unit has the advantages of small volume, light weight, stable operation, low noise and high degree of automation. (4) The control of the unit has the ability of error correction and error prevention procedures to prevent non-standard operation, and has the characteristics of high operation reliability.

Disadvantages: the load regulation range of the precooler is relatively large, with only three regulation areas of 0-50% - 75% - 100%. When the natural gas processing capacity fluctuates greatly, the precooler is often made to shut down automatically. If the heat load of natural gas is lower than 50% of the cooling capacity of the precooling mechanism, it will affect the normal, continuous and stable operation of the precooler, resulting in too low load of the precooler, automatic shutdown protection, and manual on-site start-up and recovery, so as to cause small-scale fluctuation of natural gas in the liquefaction area.

Advantages of r407 refrigerant precooling process flow: R407C refrigerant is a mixed refrigerant composed of HFC substances, does not contain any substances that destroy the ozone layer, and the ODP value of r407 refrigerant is zero. R407C has strong chemical stability, non toxicity, no flammability and is very safe. Refrigerant is cheap. The precooling process can reduce the heat exchange temperature difference between cold and hot fluids, improve the heat exchange efficiency of the system and reduce energy consumption. Disadvantages (1) insufficient precooling depth.

2.5.4 Natural gas liquefaction system

After precooling, the natural gas has a pressure of 3.0 MPa and a temperature of 0℃. It enters the cold box and flows reversely with N_2 refrigerant in the plate fin heat exchanger for cooling. It is cooled to - 48℃ and the pressure is reduced to 2.98mpa. The natural gas enters the heavy hydrocarbon separator. The C^{3+} hydrocarbons in the natural gas are separated as liquid (LPG) and sent out of the cold box into the LPG storage tank. The natural gas enters the main heat exchanger. Nitrogen is composed of two nitrogen gas streams with different temperatures. One is from the middle of the main cooling tank at a temperature of about - 52℃, and the other is from the expansion end of the high temperature turbine expander at a temperature of about - 95℃. Adjust the flow of two streams of nitrogen with different temperatures according to the heat exchange effect of the heat exchanger and the natural gas treatment capacity, and adjust the nitrogen inlet temperature of the plate fin heat exchanger to the design value of - 52℃ and the outlet temperature to - 9℃. In the heat exchanger, the natural gas is cooled and the temperature drops to about - 48℃.

Key points of natural gas in the auxiliary cooling box: (1) Inlet and outlet pressure difference between natural gas and nitrogen channel: if the inlet and outlet pressure difference of natural gas channel increases, the purification effect of feed gas is poor: the content of carbon dioxide and water exceeds the standard or there are solid impurities, it is necessary to adjust the parameters of purification system or replace the filter. (2) Temperature control of natural gas out of the auxiliary cooling box: it shall be adjusted according to the composition of feed gas to ensure the separation effect of heavy hydrocarbons, that is, the content of heavy hydrocarbons shall be less than 70ppm. If the separation of heavy hydrocarbons is not complete, the low-temperature flow channel of natural gas in the main cooling box will be frozen and blocked. (3) The liquid level of heavy hydrocarbon separator shall be kept at a certain height. Protective measures such as high level alarm and low level alarm shall be added from DCS control. When the liquid level is lower than a certain value, it is easy to cause pressure channeling. High pressure natural gas enters the medium pressure heavy hydrocarbon system, resulting in overpressure hazard of vessels and pipelines. If the liquid level is too high, heavy hydrocarbons will be brought into the main cooling tank, resulting in ice blockage and pressure holding of the main cooling tank, resulting in bursting of the cooling tank.

The natural gas enters the main cooling tank for further heat exchange with nitrogen to complete the liquefaction transformation of natural gas. The main cooling box adopts four aluminum plate fin split series heat exchangers: (1) Multiple heat exchanger plate bundles can be welded together in parallel and series to form a composite plate bundle. In this case, the height of the heat exchanger can exceed the size limited by the brazing furnace of the manufacturer. (2) The designed length of each plate fin heat exchanger is much longer than the standard 5.8-6.0 m, so as to enhance its heat exchange capacity, reduce the heat exchange temperature difference and improve the heat exchange efficiency,

The temperature is further cooled to - 130℃. After pressure reduction and throttling by the throttle valve , the temperature is about - 142℃ and the pressure is 0.45 MPa. It enters the gas LNG flash tank (s502) for flash vapor liquid separation. LNG flows out from the bottom of the separation tank and enters the LNG storage tank. The bog flashed from the flash tank (s502) controls its flash pressure through the pressure control valve and returns to the main cooling tank in turn to provide cooling capacity, It is reheated to normal temperature of 32℃ to the purification unit for regeneration gas. Bog generated: (1) Some clean gas is used as dryer regeneration, heating and cold blowing, and then enters the urban pipe network after being pressurized by bog and booster. (2) Some of them are reheated and sent to the heat transfer oil circuit as fuel.

2.5.5 Nitrogen circulation system

The cooling capacity required for LNG is provided by the nitrogen circulation system. The refrigeration system is mainly composed of three nitrogen compressors, two groups of coolers, two parallel double temperature zone turbine expansion units and main cooling box.

The turbine expansion unit uses the high-speed nitrogen gas flow generated during high-pressure nitrogen expansion to impact the working impeller of the turbine expander, so that the impeller rotates at high speed driven by the high-speed nitrogen gas flow. The high-speed rotating impeller generates certain power, and drives the booster end impeller through the central shaft to pressurize the nitrogen in the booster section and work on it. Due to the external work done by the nitrogen flow that generates power, the temperature and pressure of the expanded gas drop, resulting in low-temperature cooling capacity and power to the pressurization end.

The nitrogen in circulating operation flows out of the EX1 plate of the main cooling tank and enters the low-pressure nitrogen balance tank. After stabilizing the pressure, it is compressed to 1.8 MPa by the nitrogen compressor (three for use and one for standby for four nitrogen reciprocating compressors) and cooled to normal temperature by the water cooler. The compressed nitrogen is summarized and distributed to the high and low pressure The compressor compression end of the expander in the low-temperature section is further pressurized to 2.3Mpa, and then collected and cooled by the water cooler to normal temperature. It enters the EX1 plate of the main cooling tank for heat exchange. One of them is cooled to - 36℃ and then enters the expansion end of the expansion compressor in the high-temperature area for expansion cooling, depressurization to: - 93℃ and 0.64mpa, and then enters the EX2 and EX1 plates of the main cooling tank, which are natural gas flow channels The nitrogen channel provides cooling capacity, which is rewarming to normal temperature and continues to return to circulating refrigeration. After leaving EX1, another stream of nitrogen enters EX2 plate for further cooling and cooling to - 93 ℃, then enters the expansion end of low-temperature expansion compressor for expansion and pressure reduction to 0.64mpa, refrigeration and cooling to - 136 ℃, and then enters the main cooling tank EX3, EX2, EX1 and auxiliary cooling tank to provide cooling capacity for natural gas channel and nitrogen channel respectively. It is reheated to normal temperature and continues to return to circulating refrigeration.

Problems needing attention in nitrogen circulation system: (1) Before starting the nitrogen compressor, turn the motor to ensure normal operation. (2) The nitrogen pressure of the nitrogen circulation system shall not be lower than 0.55mpa, and ensure that the nitrogen dew point is lower than - 63℃. (3) The water flow of cooler shall not be less than 90 m^3/m. (4) avoid starting the nitrogen compressor under pressure and vent the nitrogen in the cylinder block. (5) When the nitrogen pressure exceeds 0.64mpa, slowly open the inlet valve of the turbine expander and slowly increase the speed. When the speed tends to be stable, quickly open the nitrogen inlet valve to prevent the overspeed of the turbine expander. (6) Ensure that the oil pressure and oil temperature of the turbine expander are normal. (7) Observe the nitrogen pressure change of the primary pressure instrument on site, notify the central control room of the on-site change, and better control the supplement amount of nitrogen.

With the rapid development of China's economy and the continuous adjustment of energy structure, natural gas has become the main energy in China and even the world. Liquefied natural gas is an important form of natural gas resource application. China will quickly become a LNG importer and occupy the market at an extremely fast speed. It has become one of the important topics in the field of natural gas application and development to speed up the process technology research of natural gas liquefaction units suitable for China's characteristics and increase the strength and investment in relevant application technology research. Therefore, the development of LNG is the current trend of world development, and the sustainable development of China's economy and society must take the sustainable development and utilization of LNG as the premise, and carry out the rational development and utilization of LNG according to the requirements of sustainable development, which has broad market prospects.

3 Purpose of LNG tank precooling and analysis of main factors affecting tank Precooling

3.1 Purpose of precooling LNG storage tank

After the construction of the low-temperature pipeline and LNG storage tank of the LNG plant is completed and the strict test is qualified, the full precooling operation must be carried out before the formal operation, that is, before entering the low-temperature liquid, that is, the storage tank must be gradually cooled to the service temperature, so as to prevent the tank damage caused by too fast temperature drop and the loss caused by too large temperature difference. Stainless steel has excellent low-temperature performance, but the linear expansion coefficient is large. Under the condition of LNG temperature, the shrinkage rate of stainless steel is about 3 ‰. For 304L pipeline, when the working temperature is - 162℃, the shrinkage of 100m pipeline is about 300mm. The contraction and compensation of LNG pipeline is also a key issue in the precooling process. Due to the different ambient temperature during construction, the stress caused by cold shrinkage between two fixed points during precooling may exceed the yield point of the material and cause tensile crack of the material. In particular, the requirements for tanks and pipelines in LNG tanks are more stringent. Problems such as uneven stress or rapid shrinkage due to too fast cooling are likely to cause serious risks such as tank deformation, stress cracking, LNG leakage, combustion and explosion. Designers will take effective compensation measures during pipeline design. Usually, mobile pipe support and elbow compensation are adopted on LNG equipment and pipeline to achieve the purpose. Although the designers consider the compensation of cold shrinkage in the design, if the temperature change rate is too large, the materials or connecting parts will be deformed or damaged due to too fast temperature change and too large thermal stress. Therefore, pre cooling operation must be carried out before low-temperature pipelines, low-temperature equipment and storage tanks enter low-temperature liquid to reduce the temperature linearly, so as to ensure the safety of operation.

The main purpose of precooling operation of LNG storage tank is to inspect and test the low-temperature performance of low-temperature equipment and pipelines, mainly including:
1) Inspect the quality of materials at low temperature.
2) Inspect the welding quality of storage tank and pipeline.
3) Inspect the change of pipe support and pipe cold shrinkage.
4) Inspect the sealing performance of low temperature valve.
5) Make the temperature of the storage tank close to or reach the working state, so as to facilitate the use.
6) The bolt connection parts are cold tightened step by step to achieve the optimal working state.

3.2 Analysis of main factors affecting precooling of LNG storage tank

Precooling of LNG storage tank refers to the operation of introducing low-temperature materials through precooling pipeline and combining top spray precooling and columnar injection precooling. Generally, low-temperature gas or liquid is used to provide precooling cold energy, such as liquid nitrogen (- 196℃) or liquid natural gas (- 162℃). Due to the huge volume of large LNG storage tanks, they are usually fabricated and installed on site. Their steel is required to be resistant to low temperature, complex manufacturing process, strict welding quality requirements, huge investment cost and long construction period. The investment cost of 104 m^3 single containment double-layer steel wall LNG storage tank exceeds 100 million yuan, and the construction period is more than 10 months. Therefore, it is very important for the pre cooling of LNG storage tanks before the LNG plant is put into operation, which is the key step for the normal operation of the plant. By analyzing the previous discussions and consulting relevant data, combined with my own experience in the pre cooling process of LNG storage tank, this paper summarizes the main factors affecting the success of pre cooling of LNG storage tank in the following six aspects.

3.2.1 Safety risk factors

Safe production is the basic principle that all enterprises must strictly abide by. Although LNG storage tank and its auxiliary pipelines, instrument valves, etc. have undergone a series of experiments and inspections before putting into operation, the working condition of cooling the storage tank and pipeline from normal temperature to - 162℃ through cold materials is a comprehensive inspection of design parameters, equipment materials and welding quality. If the operation is improper or the material has its own defects, it is very likely that the temperature difference of the pipeline or tank wall is too large due to too strong precooling energy and too fast precooling rate during the precooling process, resulting in deformation, crack or damage of the pipeline or tank body due to stress, and the leakage of precooling materials will bring the risk of low temperature frostbite and environmental pollution, If materials leak and air form explosive gas mixture, there is also the risk of combustion and explosion. This will not only cause the economic loss of damaged and scrapped storage tanks, but also cause safety accidents of personal injury or death. At the same time, it will delay the production of the plant, and its safety risk and economic loss are immeasurable. Therefore, the safety risk factor is the most important factor affecting the precooling of storage tank.

3.2.2 Economic cost factors any enterprise attaches great importance to economic cost

Low temperature gas or liquid shall be selected as the precooling material of storage tank to provide cooling capacity. Liquid nitrogen (- 196℃) and LNG (- 162℃) both have the above two characteristics and are suitable precooling materials. However, due to the influence of raw materials, production process and the supply-demand relationship of the factory location on the required materials, the value of the above materials varies greatly. According to the current market situation, the price of liquid nitrogen is about 1000 yuan / ton and the price of LNG is about 4000 yuan / ton, but the price fluctuates with the market supply-demand relationship. How to select suitable precooling materials according to the needs of the factory is not only the key consideration before precooling, but also the main aspect of the economic cost control of the whole precooling operation.

3.2.3 Technical capacity factor in the preparation of tank precooling

The preparation of technical capacity is also very important. For example, lack of technical capacity, insufficient operation experience, incomplete allocation or insufficient number of professionals and operators will affect the precooling operation, even failure of precooling or operation accidents. Generally, at least three talent teams are configured, mainly including: leading group, professional technical team and skill operation team. Professional technical team includes process, electrical, instrument, equipment and other professional engineers; The skill operation team is the main executive layer of the main precooling work, which must be qualified through professional training, and be able to skillfully operate facilities and equipment and emergency disposal ability.

3.2.4 Condition preparation factors

As the name suggests, condition preparation means that all conditions must be met. First, the equipment hardware conditions must meet the preparation requirements for precooling, that is, the equipment, pipelines, valves and instruments are installed in place and debugged normally, the preliminary preparations for precooling such as purging, air tightness and drying have been completed, and the detection meets the precooling requirements. Secondly, operating tools must be available to operate corresponding wrenches, testing instruments, protective articles, etc; Third, the operation plan must be complete and approved by relevant experts, the operation procedures shall be issued to the operators and mastered, and the emergency plan shall be formulated and rehearsed.

3.2.5 Natural environment factors

Natural environment is also an important factor affecting the success of tank precooling. It mainly includes seasonal temperature variation. The higher the temperature, the greater the impact on precooling; Weather change factors, such as the influence of natural disasters such as strong wind, lightning, rainstorm and flood; Surrounding environmental factors, including convenient transportation, social stability, etc. Others may also involve the impact of policies, the quality of precooling materials and public security environment.

3.2.6 Time control factor

In the ideal state, if only single work of tank precooling is considered, as long as the precooling rate control is stable, no matter which precooling method is adopted, the precooling demand time has little difference. However, as the LNG plant is an overall system, the purpose of storage tank precooling is to make the storage tank reach the required temperature and establish a stable LNG liquid level in the storage tank, make the storage tank and its auxiliary facilities reach the service state, and ensure that the products produced by the LNG plant can enter the storage tank for storage and sales smoothly. In this process, it is not only necessary to consider that the temperature reaches the standard and meets the LNG liquid inlet conditions, but also to consider cooperating with the commissioning progress of the production unit of the LNG plant. If the commissioning of the production unit of the LNG plant is completed and LNG products are produced, and the precooling of the storage tank still does not meet the liquid inlet requirements, the production unit will be forced to shut down, a large amount of feed gas will be vented, the refrigerant will be lost, and the human and material resources input for shutdown and startup will be greatly lost. If the storage tank is precooled in advance to reach the liquid inlet conditions and wait for the device commissioning, BOG evaporation will be caused, and the precooling materials will be lost until the LNG products of the production unit enter, which is bound to increase the material consumption and precooling input. Therefore, the pre cooling time of storage tank and the commissioning time of device must be accurately calculated and highly consistent.

4 Construction of comprehensive evaluation index system for precooling mode of LNG storage tank

4.1 Construction principle of comprehensive evaluation index

When evaluating anything, the selection of evaluation index system is the most basic and important part. It is not only related to the authenticity of evaluation results, but also has a certain impact on practical guidance [30]. In the selection of comprehensive evaluation indicators, this paper adopts the way of questionnaire survey, reads a large number of relevant literature and draws lessons from previous studies.

At the same time, when constructing the comprehensive evaluation index system, we should also pay attention to the following principles: (1) Scientific principle. Scientific principle means that the evaluation must be guided by the scientific concept of evaluation. In the process of evaluation, keep in mind the evaluation objectives, and the selection of indicators should also strictly abide by scientific norms, eliminate the interference of unreasonable and unscientific influencing factors, and prevent unscientific evaluation results from affecting the realization of evaluation objectives [31]. When selecting indicators, this paper first combs and analyzes the evaluation index system established by predecessors in relevant research, and strictly follows the scientific principle of indicator selection in combination with the characteristics of the analysis object. (2) Practicability principle practicability principle refers to that the selected evaluation indicators must contribute to the realization of evaluation objectives. Whether positive or negative indicators, they must be realistic, conform to the actual situation of the evaluation object, and cannot exceed the standard of the specified actual range. (3) Comprehensiveness principle comprehensiveness principle means that the characteristics of the evaluation object must be considered in an all-round way. Whether it is positive or negative, it should be included in the index system. The indicators complement each other and form an organic whole. At the same time, in the process of selecting evaluation indicators, we should also pay attention to listening to the suggestions of various parties and work together to avoid one sidedness in selecting evaluation indicators. (4) Operability principle operability principle refers to the elimination of indicators with unclear meaning when selecting evaluation indicators. At the same time, the selected indicators should have specific values. If the evaluation indicators cannot be quantified, they should also meet the measurability and evaluability, and can be evaluated by high and low levels and sizes [32]. In addition, the value of the evaluation index should be true and effective, and the data should be easy to obtain and calculate, so as to facilitate the implementation of later analysis. (5) Independence principle independence principle means that the selected evaluation indicators are independent of each other, and the indicators should avoid mutual inclusion or overlap. In other words, among the evaluation indexes at the same level of the evaluation index system, there can be no index that can be derived directly or indirectly from a certain item. (6) Representativeness principle representativeness principle means that the selected evaluation indicators must be able to reflect the characteristics or nature of the evaluation object. If there is no direct relationship between the evaluation indicators and the evaluation object, the evaluation process will be meaningless.

4.2 Selection of comprehensive evaluation indicators

4.2.1 Questionnaire design, distribution and recovery

In order to establish a scientific and reasonable comprehensive evaluation index system, this paper designs a questionnaire. For the main factors affecting the precooling of LNG storage tanks, the respondents listed 3-5 specific impact indicators of each factor. The survey objects mainly include: relevant design experts of LNG discipline of the Design Institute, engineers and professional technicians of LNG technical service team, relevant leaders of LNG plant, professional engineers and skilled operators, etc. As the survey is highly professional, it is mainly aimed at relevant experts, engineers and technicians in the field of design, production and technical services in the LNG industry. It mainly includes: relevant LNG design experts of the Design Institute, engineers and professional technicians of LNG technical service team, relevant leaders of LNG plant, professional engineers and skilled operators, etc.

4.2.2 Selection of evaluation indicators

Index is the unit and method to measure the goal. It embodies the characteristics of material stipulation and quantity stipulation. The selection of indicators will directly affect the effectiveness and scientificity of decision-making results. Based on the results of the questionnaire on the main factors affecting the precooling of liquefied natural gas (LNG) storage tanks, combined with previous research results and relevant successful cases, and comprehensively considering the different precooling process flow, materials and characteristics of LNG storage tanks, According to the factors affecting the precooling of LNG storage tank, the comprehensive evaluation indexes are summarized into the following six categories: (1) Safety risk index: it is the evaluation index that must be considered first in any work. Considering the whole process of storage tank precooling, different materials (usually liquid nitrogen or LNG) shall be selected to provide cooling energy for storage tank precooling, and corresponding safety measures shall be taken according to their physical characteristics, To ensure the safety and reliability of the precooling process. The safety risk factors selected in this paper are: flammable and explosive risk, leakage risk, frostbite risk, poisoning and suffocation risk. (2) Economic cost index: it is an evaluation index of great concern to the construction unit. If different precooling materials are selected, the corresponding economic cost shall be borne. The economic cost indicators selected in this paper are: purchase price, usage and transportation price. (3) Technical capability index: it is an important index for the smooth progress of precooling. The technical ability indexes selected in this paper are: core leadership ability, professional technical ability and skill operation ability. (4) Condition preparation index: whether the condition preparation is sufficient or not is also an important index for the smooth progress of precooling. The condition preparation indexes selected in this paper are: equipment hardware, operation tools and implementation scheme. (5) Natural environment index: the change of natural environment also has a great impact on the promotion of precooling. The natural environment indexes selected in this paper are: Quarterly temperature change, weather change and surrounding environment. (6) Time control index: due to different precooling materials, their precooling processes and operations meeting service conditions are different, and their demand time is also very different. The time control indicators selected in this paper are: whether to replace, precooling rate, rewarming or supercooling treatment.

5 Evaluation model of precooling mode of LNG storage tank

The comprehensive evaluation method is also called multi index comprehensive evaluation method, which refers to the method of using more systematic and standardized methods to evaluate multiple indexes and units at the same time. Comprehensive evaluation is to establish an evaluation index system for the research object, analyze the collected data by using certain methods or models, and make a quantitative overall judgment on the evaluated things. The comprehensive evaluation method is generally a combination of subjective and objective. The selection of the method needs to be based on the actual index data. The most important thing is the selection of the index and the setting of the index weight. Its characteristics are: the evaluation process is not completed one index after another, but the evaluation of multiple indexes is completed at the same time through some special methods; In the process of comprehensive evaluation, weighting should be carried out according to the importance of indicators to make the evaluation results more scientific; The evaluation result is the unit ranking according to the comprehensive score, and the conclusion is obtained accordingly. The function of comprehensive evaluation in practical application is as follows: comprehensive evaluation can systematically describe the research object; Be able to comprehensively measure the overall state of the research object; Be able to carry out hierarchical analysis on the complex performance of the research object; Be able to cluster the research objects; It can effectively reflect the combination of quantitative analysis and qualitative analysis. There are many commonly used comprehensive evaluation methods.

(1) grey correlation analysis (GRA) in the objective world, the relationship between factors is often grey, that is, it is difficult to distinguish which factors are close and which factors are not close. In this case, it is difficult to find the main characteristics and main contradictions of things. Correlation degree is an index used to characterize the correlation degree between two things, and grey correlation analysis (GRA) mainly measures the correlation degree between factors by comparing the degree of similarity or difference in development trend between factors. This method is one of the main methods to evaluate

the adaptability of things. It can analyze the changes of the development trend of the studied things in the case of incomplete information [33], which solves the problem of difficult statistical quantification of evaluation indicators to a certain extent. In addition, this method relies less on people's subjective judgment. However, this method can only be adopted on the basis of sample data, and the sample data must have the characteristics of time series. The evaluation results can only evaluate the advantages and disadvantages of the evaluation object, but can not fully reflect the absolute level of the evaluation object.

(2) Data envelopment analysis data envelopment analysis (DEA) is mainly used to study the multi input and multi output production function, and can conduct more effective comprehensive evaluation for the same type of departments with multi index input and multi index output [34]. In 1978, the DEA method was first proposed by the famous operational research experts a. Charnes and W. W. Cooper. They proposed the method based on the concept of "relative efficiency evaluation" and based on linear programming and convex analysis. They named the model C2R in their name. In 1985, the two doctors, together with B. Golany, L. Seiford, J. On the basis of evaluating and ranking the relative effectiveness of decision-making units of the same type, DEA model can also use "window" technology to find out the relatively weak aspects and causes of decision-making units, which can not only improve production efficiency, but also provide important information for decision-makers, Facilitate its management and decision-making. This method has simple structure and convenient application. In addition, it eliminates the influence of many subjective factors and can effectively deal with the evaluation of multi input and multi output indicators. It is widely used in the comprehensive evaluation of production function technology, industrial efficiency and scale effectiveness. However, DEA also has a fatal disadvantage. When calculating the weights, each decision-making unit chooses to start from the most selfish point of view, which makes these weights change with the change of DMU, resulting in the lack of comparability between the characteristics of different decision-making units, and then the evaluation results may be inconsistent with the objective reality.

(3) Principal component analysis principal component analysis, also known as principal component analysis, was first introduced by Karl parson and applied to non random vectors. The core of this method is to use the idea of dimension reduction to transform multiple indexes into a few comprehensive indexes that can reflect the original index information. This method can avoid the overlap of information between indicators, and can generate weights through mathematical operation based on the information provided by indicators. To a certain extent, it can effectively avoid the deviation caused by human factors. Generally speaking, it is more objective and reasonable, and is suitable for comprehensive evaluation with more samples. However, this method relies too much on objective data and has certain limitations.

(4) Analytic hierarchy process analytic hierarchy process (AHP) was first proposed by American operations research scientist sati in the early 1970s and introduced into China in 1982. This method can transform semi quantitative and semi qualitative problems into quantitative calculation problems. Its core principle is to decompose complex problems into various constituent factors, and then decompose these factors into target level, criterion level, scheme level, etc., and then compare the importance of relevant factors in the system through a series of comprehensive treatment, Finally, the system is reduced to the determination of the relative importance weight of the lowest level (decision-making objects, schemes and measures) relative to the highest level (overall goal). The advantage of this method is that it can simplify the complex evaluation factors into a clear hierarchical structure. At the same time, it can also quantify the evaluation factors that are difficult to quantify by other methods by pairwise comparison, and can effectively determine the relative importance of each factor in multi factor evaluation to a certain extent. However, analytic hierarchy process also has its own shortcomings, such as poor objectivity of weight; In addition, when the judgment matrix is inconsistent, the elements of the judgment matrix must be adjusted to make it consistent. This process often needs repeated adjustment and inspection.

According to the advantages and disadvantages of different comprehensive evaluation methods and the characteristics of comprehensive evaluation index data of LNG tank precooling, this paper uses fuzzy analytic hierarchy process to evaluate the precooling mode of LNG tank. Compared with the traditional method of determining weight, fuzzy analytic hierarchy process can improve the objectivity of weight. Fuzzy analytic hierarchy process (FAHP) is an improvement made by scholars on the basis of AHP, and how to determine the weight of the scheme is discussed. Literature [35] studied the method of determining the weight by using fuzzy analytic hierarchy process.

6 Evaluation of precooling mode of LNG storage tank in LNG plant

In order to verify the feasibility and practicability of the above evaluation model, this paper evaluates and measures the actual case of precooling mode in Fuling liquefied natural gas (LNG) plant of Chongqing Sinopec Tonghui Energy Co., Ltd. The evaluation shows that the selection of precooling mode of Fuling liquefied natural gas (LNG) plant is consistent with the conclusion of this paper.

6.1 Plant background and project overview

Fuling liquefied natural gas (LNG) plant project of Chongqing Sinopec Tonghui Energy Co., Ltd. is located in Baitao chemical industry park, Fuling District, Chongqing, covering an area of 263 mu. It is the first LNG plant project of Sinopec. LEP low energy consumption process technology with independent intellectual property rights of Sinopec is adopted. The project is designed to process 1 million m^3 of raw natural gas per day, The annual consumption of raw natural gas is 333 million m^3, the annual cost of LNG is 221300 tons, and a 10000 m^3 LNG storage tank is equipped. In this project, the LNG produced by the liquefaction unit adopts the low-temperature and normal pressure storage process, and the LNG storage tank is a bimetallic wall single containment structure. It is mainly composed of inner tank, outer tank, cold insulation system between inner and outer tanks, process instruments and other accessories. The inner tank is composed of s30408 stainless steel inner tank bottom plate, s30408 stainless steel inner tank wall plate and aluminum alloy ceiling; The outer tank is composed of Q345R carbon steel plate and Q345R carbon steel tank top; The cold insulation system is composed of ceiling cold insulation layer, tank wall cold insulation layer, tank bottom cold insulation layer, etc. The top cold insulation layer is made of glass wool felt, and the aluminum ceiling is suspended under the top of the outer tank to cover the inner tank and support the cold insulation materials of the ceiling; The cold insulation of tank wall is expanded perlite and elastic felt; The bottom cooling material is foam glass brick. A flexible sealing system is arranged between the top of the inner tank wall and the ceiling. In addition, in order to prevent accidental overflow of low-temperature LNG, inlet and outlet connections, instrument connections, process connections and safety relief systems shall be accessed from the top of the storage tank as far as possible.

6.2 The pre cooling mode of LNG storage tank

The plant is Fuling LNG plant, which is located in Baitao chemical park, a municipal chemical park with relatively complete supporting facilities and convenient transportation, and does not involve demolition and other unstable social factors. The pre cooling time is set in February after the Spring Festival, with low temperature and avoiding extreme weather. The precooling materials liquid nitrogen and LNG are from Chongqing Changshou and Sichuan Deyang respectively. The project is independently designed and built by SINOPEC. Important equipment such as submersible pump and low-temperature valve are imported equipment, which is at the domestic advanced level in design concept, equipment selection and manufacturing process. Sinopec Engineering Construction Co., Ltd. is responsible for the design, procurement and construction of the project, Sinopec No.5 construction company is responsible for the installation of LNG storage tanks, and Sinopec SVW Quality Inspection Branch is responsible for quality supervision. After the intermediate delivery of the project, the production preparation department of Sinopec engineering department took the lead in organizing the confirmation of conditions before trial production, agreed to the trial production, and handled the relevant procedures such as safety supervision, environmental protection, fire control and special inspection. The technical service for tank precooling is provided by Sinopec Zhongyuan Oilfield and the operation service is provided by Sinopec Jianghan oilfield production and service center. The whole leadership, technical ability and operation team configuration are strong. Finally, after repeated research and demonstration by experts, the mixed precooling mode of liquid nitrogen and LNG is determined.

6.3 Fuzzy comprehensive evaluation process of precooling mode of LNG storage tank

The questionnaire on the evaluation of main factors affecting the precooling of liquefied natural gas (LNG) storage tanks was prepared through questionnaire survey. Aiming at the selection of precooling mode of LNG storage tanks in Fuling LNG plant, the influencing factors such as safety risk, economic cost, technical capacity, condition preparation and timely control of natural environment were investigated The scores of LNG and liquid nitrogen + LNG mixed precooling shall be evaluated and scored by experts. The survey objects mainly include: relevant design experts of LNG discipline of the Design Institute, engineers and professional technicians of LNG technical service team, relevant leaders of LNG plant, professional engineers and skilled operators, etc.

6.4 Conclusion

According to the evaluation criteria of fuzzy synthesis and the maximum membership principle, the best scheme is the one with the largest vector value in the comprehensive evaluation vector B. Compared with the precooling mode of the comment set, it can be concluded that under the condition of tank precooling of Fuling LNG plant at that time, the liquid nitrogen + LNG precooling mode is the best scheme, followed by the Liquid Nitrogen Precooling mode, and finally the LNG precooling mode. The evaluation result is consistent with the precooling method actually adopted by Fuling liquefied natural gas (LNG) plant of Chongqing Sinopec Tonghui Energy Co., Ltd.

7 Conclusion and prospect

7.1 Conclusion

LNG storage tank is an important facility of LNG plant. Pre cooling of LNG storage tank is a very important work link for the success of plant operation. This paper starts with the purpose of introducing the precooling of LNG storage tank, and analyzes the six main problems and factors affecting the precooling of LNG storage tank. Based on these six factors, the structure, characteristics and low-temperature thermal insulation technology of LNG storage tank are further introduced, and three common methods of precooling of LNG storage tank are analyzed in detail. For the three precooling methods, the evaluation indexes are extracted and the evaluation model is established around the six main factors affecting the precooling of storage tank. Combined with the three tank precooling processes of liquid nitrogen, LNG and liquid nitrogen + LNG mixed precooling commonly used in LNG plants, the evaluation model is used for analysis and evaluation, and it is proposed that the liquid nitrogen + LNG mixed precooling method is the best scheme for LNG tank precooling in LNG plants. This paper also combines Fuling LNG plant the precooling of 1 × 104 m^3 LNG storage tank is evaluated and analyzed by using the evaluation model to further verify that the liquid nitrogen + LNG mixed precooling process is the preferred scheme with safety, economy and efficiency suitable for LNG plants at present. Among the tank precooling methods in LNG plant, liquid nitrogen + LNG precooling method is a better LNG tank precooling method, which can meet the requirements of enterprises for controlling the safety risk and economic benefit of tank precooling. Compared with the other two tank precooling methods, the liquid nitrogen + LNG precooling method in the tank precooling method of LNG plant can effectively avoid their shortcomings, reduce safety risks and improve economic benefits. It is the preferred scheme with safety, economy and efficiency suitable for LNG plant.

7.2 Deficiency of the paper

The evaluation index system constructed in this paper collects the expert opinions of LNG industry, including design, construction, operation and other teams; The fuzzy analytic hierarchy process is used to establish the evaluation model to improve the objectivity of the weight; In the case study using the model, the expert opinions are collected again, and the reliability and validity are analyzed. The research results have certain reference and reference value in the application of related professional fields. However, due to the limitation of time and other factors, there is still a lot of work to be further supplemented and improved. There are mainly the following deficiencies:

This paper puts forward the evaluation indexes and establishes the evaluation model from the six main factors affecting the precooling of storage tanks, but there may be other factors that have not been summarized and refined in practice, resulting in a certain one sidedness of the evaluation. In this paper, the fuzzy analytic hierarchy process is selected, and the scoring data of some experts are summarized for analysis and evaluation. The selection of methods and data collection still need to be further studied. This paper only analyzes the main factors of tank precooling, but in the whole process of the project, including the design, procurement and construction quality in the early stage, the standard of air tightness, drying and replacement in the medium term, as well as the precooling process control and human factors, will also affect the evaluation of tank precooling.

7.3 Application suggestions

The research on the "aging" phenomenon of LNG is a new topic, and there are few references. This paper makes an exploratory study on the mechanism of LNG "aging" and the influence of LNG "aging" on engine performance. After efforts, the following aspects have been completed: 1 Familiar with the fuel system of LNG single fuel vehicle, read the discussion on LNG "aging", deeply understand the mechanism of NLG "aging" and the significance of studying NLG "aging"; 2. The causes of LNG "aging" and the factors affecting LNG "aging" are analyzed, and the following conclusions are drawn: 1) the reason of LNG "aging" is the difference of heat exchange between storage tank and environment and evaporation capacity of LNG components; 2) Heat exchange between LNG storage tank and environment is related to temperature difference and LNG volume; 3) Due to the existence of natural gasification bog phenomenon and different evaporation capacity of LNG components, the concentration of LNG components will change and the concentration of heavy fractions will increase; 4) The daily evaporation rate of LNG is related to the amount of LNG in the storage tank. 3. The mathematical model of "aging" process of LNG in storage and use is established. Through the simulation of "aging" process, the following conclusions are obtained: 1) when the storage is stopped, the same initial volume and different initial purity are naturally vaporized to the same volume. The lower the purity (methane content), the faster the increase rate of heavy fraction concentration; The same initial purity, different initial volume, natural vaporization to the same volume, the more the concentration of heavy fraction with large initial volume increases. At the same storage time, the increase rate of heavy fraction concentration in low purity LNG is greater than that in high purity LNG. 2) When used continuously, the initial volume and residual volume are the same, the use speed is slow, and the concentration of heavy fraction increases greatly; The residual volume and service speed are the same, the initial volume is small, the increase of heavy fraction concentration is large, the initial volume and service speed are the same, the residual volume is large, and the increase of heavy fraction concentration is large. With the same storage time and different use methods, the increase rate of heavy fraction concentration is different. If it is stored without immediate filling after use, the increase rate of heavy fraction concentration is large.

The research results of this paper have reference significance in the selection of storage tank precooling mode in the same type of LNG plant. Through comprehensive analysis of various conditions of the plant, reasonable selection of precooling mode can effectively improve safety, economy and timeliness, and bring better economic benefits. The precooling of other low-temperature storage tanks of the same type also has specific reference value, but the evaluation parameters and weights will change accordingly. For other smaller LNG skid mounted stations and LNG tank cars, due to their small scale, they can be selectively used for reference.

7.4 Outlook

Due to the limited test conditions, the "aging" process of LNG is only simulated, while the actual test is carried out on a dual fuel engine. The fuel is CNG plus high-purity ethane to simulate the "aging" result of LNG, but LNG also contains a small amount of propane. After the "aging" of LNG, the existence of propane will further affect the performance of the engine. In addition, the influence of "aging" process on dual fuel engine and single fuel engine will be different. Therefore, in the next step, the LNG storage tank used in the real vehicle shall be used to test the "aging" process of the stored LNG, so as to verify the simulation results of the "aging" process; The "aged" LNG fuel is tested on the LNG single fuel engine, and the fuel sampling is analyzed to evaluate the impact of LNG "aging" on the performance of LNG single fuel engine, so as to more accurately determine various parameters of LNG single fuel engine and specific requirements for LNG purity, so as to ensure the safe operation of the engine. Due to the "aging" problem of LNG, it can not be ignored in the design of LNG single fuel engine. Compression ratio, ignition timing and other key parameters can ensure the safe operation of the engine within a certain fluctuation range of LNG components. In order to better promote LNGV, LNG production should also have a unified national standard to ensure that the purity of LNG as engine fuel is suitable for the safe operation of LNG single fuel engine.

With the acceleration of global green and low-carbon development, natural gas, as one of the important energy sources to replace gasoline and diesel, LNG industry will achieve greater development in the process of energy replacement. LNG plant will become the main fulcrum of LNG popularization and application in China, especially in Southwest China. Through the analysis of precooling process before putting into use of large LNG storage tanks in LNG plant, this paper constructs a comprehensive evaluation index system. This research result has good reference significance in the construction of similar LNG plants and the selection of precooling methods of storage tanks. However, the research of this paper is still one-sided, especially based on the selection of evaluation methods and evaluation factors, which need more professional and in-depth research in order to make a more comprehensive and scientific evaluation.

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