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Selection and Application Research of LNG Vaporizer

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ABSTRACT

In the context of global energy transition and sustainable development, liquefied natural gas (LNG) is becoming more and more prominent due to its clean and efficient advantages. As a key equipment in the LNG industry chain, gasifiers have a significant impact on their performance and efficiency, and different types of gasifiers have their own characteristics. This study aims to deeply explore the selection and application of LNG gasifiers, and establish scientific selection methods and application strategies through a comprehensive analysis of different types of gasifiers. From a theoretical point of view, it can fill the gaps in the comprehensive evaluation and systematic comparison of existing studies. In practice, it can ensure stable energy supply, reduce costs, and promote industrial technological progress. There has been progress in this field at home and abroad, but there are still problems such as imperfect multi-objective optimization and the need to strengthen reliability and safety. The innovation of this study lies in the multi-dimensional comprehensive analysis, the combination of qualitative and quantitative, and the focus on new technologies and application scenarios, providing strong support for LNG projects.

KEYWORDS

LNG; Vaporizer; Model Selection; Receiving Station.

1. INTRODUCTION

Under the background that global energy transformation and sustainable development have become the core issues, the development and utilization of clean energy has become increasingly critical. Liquefied natural gas (LNG) has significantly improved its position in the energy structure with its advantages of clean, efficient, high energy density and convenient storage and transportation. [1] In 2024, the global LNG trade volume increased by 2.4% year on year. China led the world with 78.64 million tons of imports, and its application prospect is broad.

As the key equipment of LNG industry chain, vaporizer is responsible for vaporizing liquid LNG into gaseous natural gas. Its performance and efficiency directly affect the stability of supply and energy efficiency. Different types of vaporizers, such as open rack vaporizer (ORV), submerged combustion vaporizer (SCV) and intermediate fluid vaporizer (IFV), Ambient Air Vaporizer(AAV), have their own characteristics and different application scenarios. [2-5]

At present, although there are achievements in the research on the selection and application of LNG vaporizer, there are still some shortcomings, such as single evaluation factors and unsystematic comparative research, which lead to blindness and subjectivity in the actual selection. And improper selection may lead to problems such as low efficiency, increased cost, safety accidents, etc.

Therefore, this study aims to comprehensively analyze the working principle, performance characteristics and applicable conditions of different gasifiers, and establish scientific selection methods and application strategies. This can not only fill the theoretical gap, provide technical support for project planning, design and operation, ensure stable and reliable energy supply, reduce energy

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consumption and operating costs, but also promote technological progress and sustainable development of LNG industry, which is of great significance in the context of green and low-carbon development.

2. TYPE AND WORKING PRINCIPLE OF LNG VAPORIZER

2.1. Open Rack Vaporizer (ORV)

2.1.1. Structrue and Materials

Open rack vaporizer (ORV) is mainly composed of tube bundle plate, seawater distribution system, LNG distribution and collection system, etc. [6] Tube bundle plate is the core component of ORV, which is composed of many heat exchange tubes. These heat exchange tubes are usually made of aluminum alloy material, with star section inside and fins outside. Aluminum alloy material has good thermal conductivity, which can effectively transfer heat and improve heat exchange efficiency. It is light in weight and convenient for equipment installation and maintenance. The inner star section and the outer fin structure greatly increase the heat transfer area, change the flow field distribution, enhance the disturbance in the flow process, and further strengthen the heat transfer effect.

The seawater distribution system is located at the top of the vaporizer, and its main function is to evenly distribute seawater to the outer surface of the tube bundle plate. It usually includes Seawater Manifold, butterfly valve, seawater header and other components. Through reasonable design and layout, it can ensure that seawater can overflow from the edge of the seawater tank and flow down evenly along the surface of the heat exchange pipe, providing a stable heat source for LNG gasification.

The LNG distribution and collection system is responsible for transporting LNG to the heat exchange pipe and collecting the gasified natural gas. LNG is distributed to each tube bundle plate through LNG nozzle and LNG manifold, flows from bottom to top in the heat exchange tube, and exchanges heat with seawater outside the tube for gasification. The gasified natural gas is delivered to the ng discharge pipe through the ng manifold and ng nozzle and output to the subsequent pipeline system.

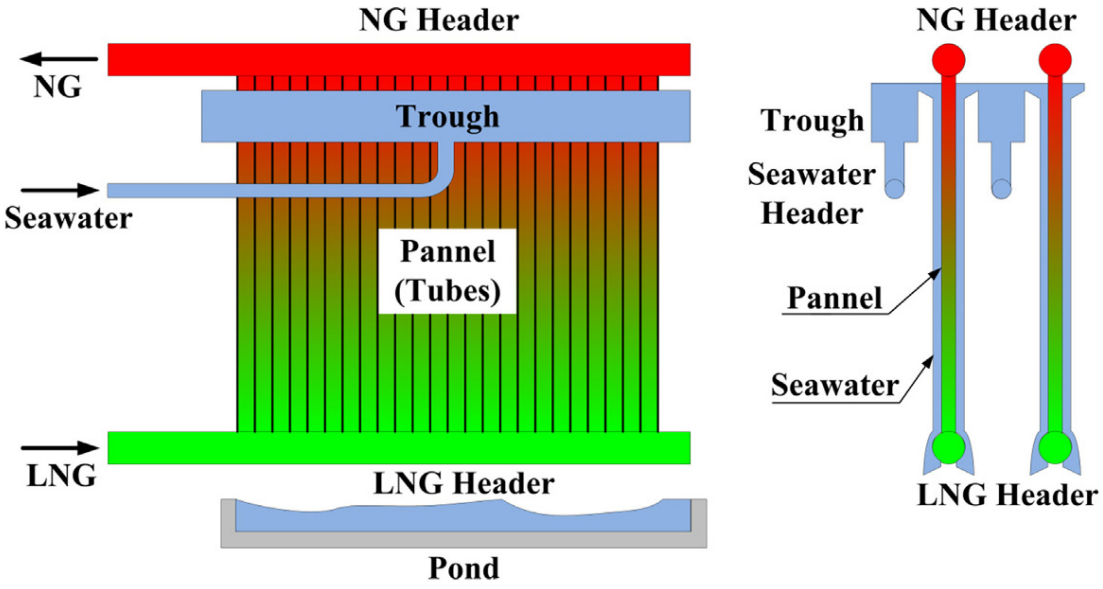


Fig 1. Structure of ORV

2.1.2. Workflow

The ORV uses seawater as the heat source, and its working process is as follows: the low-pressure pump will deliver LNG to the high-pressure pump for boosting and then send it to the ORV, which

will be evenly distributed into the heat exchange tubes of each tube bundle plate through the LNG nozzle and manifold, and the LNG will flow from bottom to top in the tubes; At the same time, after the sea water is transported through the pipeline, it is distributed through the sea water manifold, butterfly valve and header, overflows from the edge of the sea water tank and flows downward along the surface of the heat exchange pipe, and fully exchanges heat with the LNG in the pipe to vaporize the LNG. When the temperature of the vaporized ng rises to more than 2℃, it is transported to the discharge pipe through the ng manifold and nozzle and output to the natural gas pipe network; During operation, the seawater flow is accurately controlled by the flow regulating valve on the seawater pipeline, and each seawater pump corresponds to a vaporizer to achieve independent control. Generally, the seawater temperature drop is required to be no more than 5℃ to reduce the impact on the marine ecological environment.

2.1.3. Performance Characteristics

ORV has excellent economy. Because it uses inexhaustible seawater as heat source, it does not need to consume additional fossil energy. It has low operation cost, simple structure, high reliability and small maintenance workload. Large scale application of large-scale LNG terminal can significantly reduce energy consumption and operation costs and improve economic benefits; Its load regulation has certain flexibility. Although the scope is limited, it can meet the gasification requirements under different working conditions by adjusting the seawater flow and LNG input; It has obvious advantages in maintenance, simple structural design, easy disassembly and assembly of components, and the heat exchange tube is made of corrosion-resistant aluminum alloy, which can reduce corrosion damage and prolong service life. Regular inspection and maintenance of seawater and LNG distribution and collection system can ensure stable operation; However, its application is limited by the need for a large amount of seawater. It is suitable for areas close to the sea and rich in seawater resources, such as large LNG terminals, but not for areas far away from the sea or lack of seawater.

2.2. Submerged Combustion Vaporizer (SCV)

2.2.1. Structure and Combustion System

The submerged combustion vaporizer (SCV) mainly consists of a water tank, heat exchange tube bundle, burner, combustion chamber, flue gas distributor and other components. [7]The water tank is the main structure of the SCV, filled with a large amount of water inside, providing a heat transfer medium for the vaporization of LNG. The heat exchange tube bundle is immersed in the water of the water tank. LNG flows within the tube bundle and vaporizes through heat exchange with the hot water in the water tank via the tube wall.

The burner is one of the key components of the SCV. Its function is to mix fuel (usually natural gas) with air and ignite it to generate high-temperature flue gas. Burners usually adopt special designs to ensure that fuel and air can be fully mixed to achieve efficient combustion. Common burner structures include the double spiral air duct structure, etc. This structure enables the primary and secondary combustion-supporting air to enter the combustion chamber in different ways, forming a stable combustion flame. The primary combustion-supporting air accounts for approximately 30% of the total air volume. It enters from the primary air inlet at the bottom of the burner and forms the main flame in the reverse vortex cylinder, ensuring stable and complete combustion. The secondary combustion-supporting air accounts for approximately 70% of the total air volume. It descenders clockwise along the vortex air duct from the upper volute of the burner. Under the effect of centrifugal force, the airflow forms a counter-rotating flow in the middle cone of the burner, effectively regulating the center position of the combustion flame and controlling the flame length, thus preventing overheating at the top of the burner.

The combustion chamber is the space where fuel burns. Its structural design needs to meet the requirements of the combustion process and ensure the stability and safety of combustion. The

combustion chamber is usually made of high-temperature and corrosion-resistant materials to withstand the erosion and corrosion of high-temperature flue gas.

The flue gas distributor is located below the combustion chamber. Its function is to evenly distribute the high-temperature flue gas generated by combustion into the water tank, allowing the flue gas to fully contact the water in the water tank and transfer heat to the water, thereby increasing the water temperature and providing heat for the gasification of LNG.

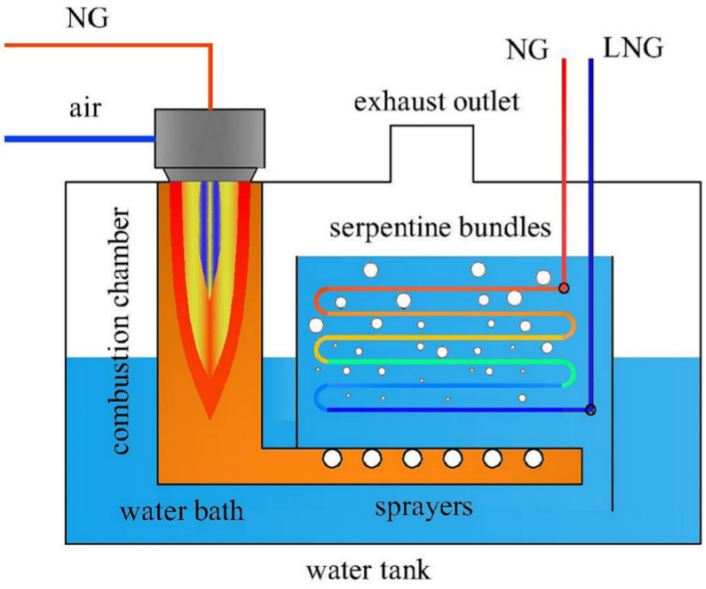


Fig 2. SCV working process

2.2.2. Workflow

The working process of SCV is based on the principle that water is heated by combustion and then LNG is vaporized. The blower sends air and fuel (natural gas) into the burner in proportion for mixing and ignition. The high-temperature flue gas generated is discharged into the water tank through the flue gas distributor to exchange heat with water. After cooling, it is discharged through the chimney. Meanwhile, the hot water in the water tank transfers heat to the heat exchange tube bundle immersed in it through conduction and convection. The LNG entering the tube bundle absorbs heat and vaporizes, and is heated to the external transportation temperature before being discharged into the transportation pipeline. Meanwhile, when the pH value of the water in the water tank is less than 6, the automatic alkali addition system will be activated and 25%NaOH solution will be added to stabilize the water quality and pH value and prevent equipment corrosion.

2.2.3. Performance Characteristics

SCV features a rapid start-up characteristic and can reach the working state within a short period of time. It is suitable for emergency backup and peak shaving scenarios and can be quickly put into use to ensure supply when there is a sudden increase in natural gas demand, other vaporizers fail, or during the peak gas consumption period in winter. Its load response is excellent. By adjusting the fuel and air supply of the burner, it can be quickly regulated within the load range of 10% to 100%, achieving precise control of the LNG vaporization volume to adapt to different gas consumption loads. In terms of safety, the burner is equipped with devices such as ignition guns, high-pressure igniters and flame scanners to monitor the combustion status. When an abnormality occurs, the control system will cut off the fuel supply. Moreover, the water in the water tank can isolate the high-temperature flue gas from LNG, reducing the risk of fire and explosion. However, SCVS consume fuel for combustion, resulting in relatively high operating costs. Moreover, combustion generates pollutants such as particulate matter, nitrogen oxides, and carbon monoxide. The treatment and control of these

pollutants further increase costs and management difficulties. Therefore, they are more suitable for applications where high start-up speed and load response are required, and where operating costs and environmental pollution are relatively less sensitive. LNG receiving terminals in northern regions where the average winter temperature is below 5℃.

2.3. Intermediate Fluid Vaporizer (IFV)

2.3.1. Structure and Intermediate Medium

The intermediate medium vaporizer (IFV) is typically composed of three tube bundle heat exchangers, namely the intermediate medium vaporizer E1, the LNG vaporizer E2 and the natural gas (NG) heater E3, among which E1 and E2 share one shell. In IFV, the intermediate medium plays a crucial role in heat transfer, and propane is a common intermediate medium. [8]

The function of the intermediate medium vaporizer E1 is to transfer the heat from heat sources such as seawater to the intermediate medium, causing it to evaporate into gas. Seawater passes through the E1 tube side, while the shell side serves as the intermediate medium. Seawater enters from the E1 tube side and transfers heat to the intermediate medium in the shell side, causing it to be heated and evaporate. The LNG vaporizer E2 uses the heat of the intermediate medium steam to vaporize LNG. LNG enters from the E2 side and is heated and vaporized by propane vapor in the shell side. The natural gas heater E3 is used to further heat the gasified natural gas to bring it to the appropriate external transportation temperature. Seawater enters from E3, overheats the NG in the E3 shell side and then leaves the vaporizer.

Propane, as an intermediate medium, has the characteristic of a low boiling point, which enables it to evaporate into gas at a relatively low temperature, thereby effectively transferring heat. Propane is heated and evaporated by seawater in the E1 tube side at the lower part of the E1/E2 shell side, then rises outside the E2 tube side and is condensed by LNG inside the tube. Relying on gravity, the condensate freely falls back to the lower part and is evaporated again. Thus, a closed cycle is formed in the E1/E2 shell side, continuously transferring the heat of the seawater to the LNG.

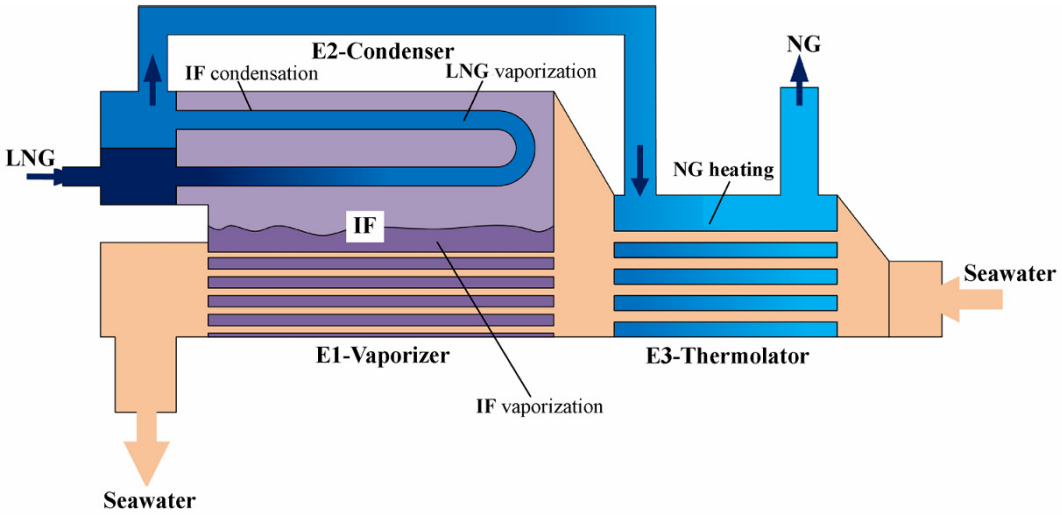


Fig 3. Typical structure and operating process of IFV

2.3.2. Workflow

The working process of IFV is based on the principle of intermediate medium heat exchange: seawater, as the heat source, first enters the shell side of the E3 heat exchanger, where it exchanges heat with the natural gas from E2 to further superheat and then enters the E1 tube side. In the E1 tube side, it transfers heat to the propane in the shell side, causing the propane to absorb heat and evaporate

into steam. Propane vapor rises to the E2 shell side and exchanges heat with the LNG in the tube side, promoting the LNG to absorb heat and vaporize. The gasified natural gas enters the E3 shell side and exchanges heat with the seawater in the tube side again. After being heated to the external transportation temperature, it leaves the IFV and enters the transportation network. Meanwhile, propane continuously evaporates and condenses in the E1/E2 shell side, efficiently transferring the heat of the seawater to the LNG and avoiding the freezing problem caused by direct heat exchange between seawater and ultra-low temperature LNG.

2.3.3. Performance Characteristics

IFV has a strong adaptability to different heat sources. Besides seawater, it can also utilize hot water, air, etc. It can ensure the normal vaporization of LNG in areas without seawater resources and has wide applicability. It transfers heat through an intermediate medium, avoiding direct contact between seawater and ultra-low temperature LNG, effectively solving the icing and frosting problems of other vaporizers, and enhancing the stability and reliability of equipment operation. Compared with air-cooled vaporizers, IFV uses intermediate media such as propane for forced convective heat transfer, which has better heat exchange performance and a higher vaporization rate. Moreover, compared with submerged combustion vaporizers, it is more energy-efficient as the heat sources are mostly natural ones. However, the cost of IFV consumables is relatively high. The manufacturing of IFV requires materials that can withstand low temperatures, high pressures, corrosion, and wear. For instance, titanium or titanium-lined composite materials are commonly used for heat exchange tubes in contact with seawater, while 304 stainless steel or composite steel plates are used for those in contact with LNG. The processing and welding techniques have high requirements, so it is more suitable for occasions where the stability and reliability of the equipment are highly demanded and cost is relatively less sensitive. Such as floating storage and regasification units at sea and onshore LNG vaporization terminals with high requirements for seawater quality.

2.4. Ambient Air Vaporizer（AAV）

2.4.1. Structure and Heat Exchange Principle

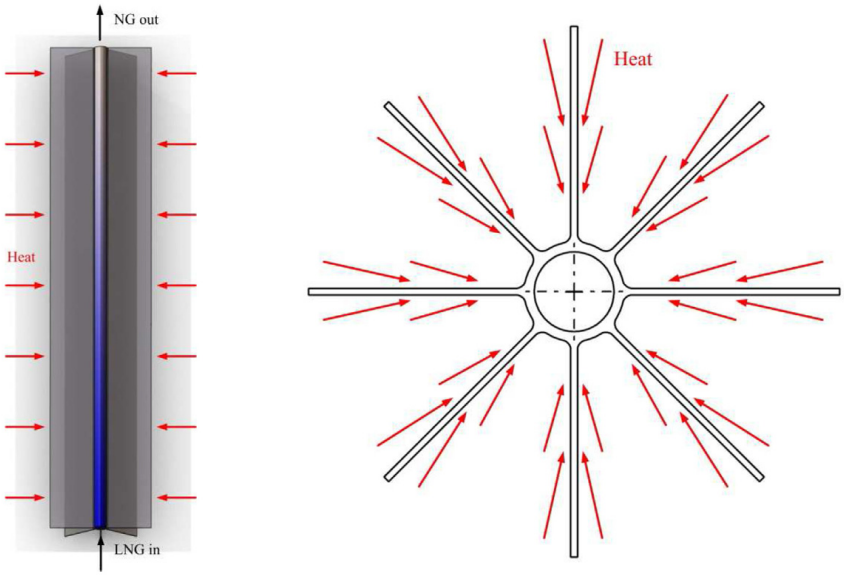


Fig 4. Schematic diagram of AAV.

The ambient air vaporizer (AAV) is mainly composed of heat exchange tube bundles, frame structures and other components. [9] The heat exchange tube bundle is the core component of AAV, usually made of aluminum alloy material, and has excellent thermal conductivity. The tube bundle adopts a

special design, such as star-shaped heat exchange tubes inside, to increase the heat exchange area and improve the heat exchange efficiency. The exterior is usually treated with anti-oxidation to extend the service life of the equipment.

The heat exchange principle of AAV is to utilize the natural convection of air for heat exchange. When ambient air flows over the surface of the heat exchange tube bundle, due to the temperature difference between the air and the LNG inside the tube bundle, heat is transferred from the air to the LNG, causing the LNG to absorb heat and gradually vaporize. The driving force of natural air convection comes from the density change caused by the temperature difference of the air. Hot air rises and cold air falls, forming a natural air flow that continuously provides heat for heat exchange.

The frame structure is used to support and fix the heat exchange tube bundle, ensuring the overall stability of the equipment. The frame is usually made of steel structure, which has sufficient strength and rigidity to withstand the weight of the heat exchange tube bundle and various forces that may be generated during operation.

2.4.2. Workflow

LNG is transported from the storage tank through pipelines to the inlet of the heat exchange tube bundle of the AAV, and flows upward from bottom to top within the tube bundle. Under the effect of natural convection, ambient air flows through the outside of the heat exchange tube bundle. During this process, the air exchanges heat with the LNG in the tube bundle. The heat from the air is transferred to the LNG, causing it to gradually vaporize into natural gas as it heats up. As heat exchange proceeds, LNG continuously vaporizes into natural gas. The natural gas continues to flow upward within the tube bundle and is eventually discharged from the outlet of the heat exchange tube bundle, entering the subsequent natural gas transmission pipeline. Throughout the entire working process, no additional power equipment is required to drive the flow of air or LNG. The vaporization of LNG is entirely achieved through natural physical processes.

2.4.3. Performance Characteristics

AAV has significant energy-saving advantages. It utilizes natural convection of air for heat exchange, without consuming additional energy, and its operating cost is almost zero, which conforms to the concept of energy conservation and environmental protection. Moreover, it has a simple structure and is easy to install and maintain. The use of aluminum profiles for "bridge" connection can eliminate thermal expansion and contraction stress. The combined structure is firm and has a long service life. It is suitable for occasions with low energy consumption requirements and small gas usage scale. For instance, small-scale LNG vaporization stations, self-owned vaporization devices of industrial enterprises and civil gas supply systems can leverage their energy-saving and low-cost advantages to provide economical and convenient natural gas supply. However, the gasification efficiency of AAV is greatly affected by the ambient temperature. In low-temperature environments, the temperature difference between air and LNG decreases, leading to a reduction in heat exchange efficiency and insufficient gasification volume, which affects the stability of gas supply. In cold regions, the surface of the heat exchange tubes is prone to frosting, further reducing the heat exchange effect. In extremely low-temperature conditions, auxiliary heating devices may be required, thereby increasing equipment costs and the complexity of operation and management.

3. INFLUENCING FACTORS OF LNG VAPORIZER SELECTION

3.1. Analysis of Gasification Demand

The accurate determination of gasification volume is the basis for the selection of LNG vaporizers, directly related to the choice of vaporizer specifications and quantities, and further affecting the operational efficiency and cost of the entire LNG project. In practice, factors such as gas consumption scale and demand fluctuations need to be comprehensively considered The gas consumption scale of

industrial users is large and relatively stable. When determining their gasification volume, historical data, production plans and development plans can be combined, and seasonal factors should be taken into account to select an appropriate design gasification volume. For example, a large chemical enterprise has an average daily gas consumption of about 500,000 cubic meters, with a monthly fluctuation of ±10%. The gas consumption in winter and summer varies due to production adjustments and heating demands. Urban gas supply is influenced by population, residents' habits, seasons, etc., and the demand fluctuates significantly. To determine the gasification volume, seasonal fluctuations should be taken into account, and methods such as time series analysis should be adopted for prediction. At the same time, a margin should be reserved in combination with urban development planning and population growth.

3.2. Consideration of Environmental Factors

Climatic conditions are important environmental factors affecting the performance of LNG vaporizers. When selecting a model, full consideration should be given to: In cold regions, the low temperature in winter (such as the average winter temperature in Northeast China below -20℃, with extreme temperatures reaching -40℃) can cause the air-cooled vaporizer to experience a decrease in heat exchange efficiency and insufficient vaporization volume due to the reduced temperature difference between air and LNG. It may also lead to frost formation that hinders heat transfer. To address this issue, measures such as increasing the heat exchange area, installing auxiliary heating devices (such as electric heating or hot water heating), and selecting cold-resistant materials are necessary. When the summer temperature in high-temperature areas exceeds 40℃, air-cooled vaporizers have difficulty dissipating heat, and the temperature rise of the equipment affects its performance and service life. Therefore, water-cooled or high-efficiency heat dissipation vaporizers should be given priority, and the materials and structure should be optimized to enhance high-temperature resistance. In areas with high humidity (such as coastal and parts of the south), high moisture in the air can easily cause condensation inside equipment, corrode components and shorten their lifespan. It is necessary to enhance sealing, install drainage devices and select corrosion-resistant materials.

3.3. Safety and Reliability

As a key piece of equipment in the LNG industry chain, the safety design of LNG vaporizers is of vital importance, directly related to personnel and environmental safety as well as the stable operation of the project. In terms of explosion-proof design, explosion-proof electrical equipment is selected. The equipment adopts a sealed structure to prevent natural gas leakage. Grounding is done well to discharge static electricity. Large gasification stations are also equipped with combustible gas alarm systems. When the concentration exceeds the threshold, an alarm will be triggered and measures such as cutting off the gas source and starting ventilation will be taken. In the leak-proof design, high-quality sealing materials and technologies are used for pipes and joints to ensure sealing. The selection of materials takes into account both corrosion resistance and low-temperature resistance to prevent leakage. At the same time, leakage detection devices are set up. Once leakage is detected, the emergency shut-off device is activated and dealt with. In addition, emergency shut-off devices are provided to cut off the supply of LNG in case of emergency. Good ventilation facilities are set up to reduce the concentration of natural gas. Safety warning signs are placed in the operation area to ensure the safety of operators.

4. CONCLUSION

This study conducted an in-depth analysis of the selection and application of LNG vaporizers and achieved a series of important results. In terms of the types and working principles of LNG vaporizers, the structure, working process and performance characteristics of open rack vaporizers (ORV),

submerged combustion vaporizers (SCV), intermediate fluid vaporizers (IFV) and ambient air vaporizers (AAV) are comprehensively and systematically expounded.

(1) ORV uses seawater as the heat source and has the advantages of economic efficiency and strong reliability. It is suitable for large-scale LNG receiving terminals close to the sea and with abundant seawater resources. SCV can start up quickly and has excellent load response capability, making it suitable for emergency backup and peak shaving scenarios. IFV has strong adaptability to heat sources and effectively solves the problem of ice and frost formation. It is suitable for scenarios with high requirements for equipment stability, such as floating storage regasification units at sea. AAV features energy conservation and a simple structure, making it suitable for small-scale LNG vaporization stations and other applications with relatively small gas consumption scales.

(2) In the research on the influencing factors of LNG vaporizer selection, it is clearly pointed out that vaporization demand, environmental factors, as well as safety and reliability, are the key considerations. Accurately determining the gasification volume is the basis for selection. Climatic conditions have a significant impact on the performance and applicability of vaporizers. Safety design and measures are the prerequisites for ensuring the stable operation of the gasifier.

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