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Optimization Study of BOG Treatment Technology in LNG Receiving Station

Yaqian Wang

Xi'an Shiyou University, Shaanxi 710000, China

Abstract: The use of regasified liquefied natural gas (LNG) and biogas (BOG) as fuel for LNG-fueled ships often results in wasted cooling energy. To address this problem, BOG recovery and treatment is required. This paper focuses on BOG recovery and purification processes, outlines current recovery technologies and discusses further developments.

Keywords: LNG Receiving Terminal; BOG; Optimization.

1. Introduction

In order to cope with the global greenhouse effect and environmental pollution, the use of clean energy to replace traditional energy has become a major trend. Natural gas plays an important role in improving the atmospheric environment, optimizing the primary energy consumption structure and easing the tight oil supply, and is one of the clean energy sources with a promising future. Natural gas has been widely used as a clean, sustainable, high-calorie and low-cost energy source, and is expected to become a major global energy source by 2035. Since the volume capacity of liquefied natural gas (LNG) is 1/600th of natural gas, its small size and high density make LNG widely used for long-distance transoceanic transportation. However, LNG faces challenges in its supply chain process. during loading, unloading, transportation and storage, part of the liquid vaporizes to produce BOG. BOG is the non-negligible evaporation of liquefied natural gas from storage tanks and cargoes. the formation of BOG not only creates obstacles throughout the LNG supply chain, but it also has an impact on the environment. As BOG continues to increase, the pressure in the storage tanks will gradually increase. In order to prevent explosions caused by excessive pressure in the storage tanks, the generated BOG must be properly handled.

2. Process Flow of LNG Receiving System

An LNG terminal, also known as a liquefied natural gas (LNG) terminal, serves primarily as a hub connecting the marine transportation of LNG to the end-user. It typically consists of LNG storage facilities and gasification units built in coastal areas. The core function of these terminals is to offload LNG from ships, temporarily store it, re-gasify it and deliver it to a variety of users, including commercial uses, power stations and city gas networks. Receiving terminals play a vital role in the LNG supply chain by enabling a smooth transition from the production side to the consumption side. A standard LNG terminal operation involves the key steps of unloading, storage, pressurization, evaporated gas treatment (BOG), regasification and distribution of the gas.

When an LNG carrier is docked at a terminal, the ship's LNG delivery system is connected to the onshore delivery system via an offloading unit at the terminal. Using the ship's pumping facilities (e.g. submerged pumps), the LNG is transferred from the ship's tanks to the receiving terminal's storage tanks. In order to prevent negative pressure building up in the tanks as a result of the LNG being unloaded, a portion of the gas is pumped back into the ship's tanks. Despite effective insulation, some heat can penetrate through the equipment and piping, and evaporation can occur as a result of heat input from dynamic equipment, volumetric displacement during material transfer, and pressure differences. As a result, a considerable amount of evaporated gas is generated during the transportation and storage of LNG [1]. These generated evaporated gases (often referred to as BOG) need to be sent to the treatment system to maintain the pressure balance in the storage tanks, except in the case where some of them are returned to the ship's tanks during the unloading process. The LNG in the tanks is pressurized by the built-in transfer pumps and is sent to the gasifier after reaching the appropriate pressure according to the different usage requirements. Inside the gasifier, the LNG is converted to a gaseous state and then distributed to individual users through metering equipment or transported to the pipeline network.

3. BOG Generation in LNG Receiving Systems

Liquefied natural gas (LNG) is the product of the cooling of natural gas to a liquid form. In LNG receiving facilities, when the system is subjected to external heat penetration, when the liquid level in the storage tanks decreases, or when the tank pressure decreases, a certain amount of liquefied natural gas is rapidly evaporated, forming what is known as evaporated gas (BOG).

3.1. Heat Leakage into the LNG System

Storage of liquefied natural gas (LNG) requires temperatures below -162 degrees Celsius at standard atmospheric pressure. As a result, components involved in cryogenic storage, power equipment, transmission lines and valves must be efficiently insulated. However, even when insulation is implemented in these facilities, heat penetration into the system is inevitable.

Cryogenic pumps used in storage tanks consume electricity to provide the required power during operation. In the process, the pumps also generate additional heat that is transferred to the LNG system. As the LNG absorbs this heat, its temperature rises. Once the temperature of the LNG exceeds its boiling point at a specific pressure, some of the liquid evaporates and changes to a gaseous state.

3.2. Decrease in LNG Tank Level

In the operation of an LNG receiving terminal, whether it is unloaded from a ship's cargo hold to an onshore facility, loaded from an onshore tank to a transport vehicle or delivered to an external pipeline network via gasification, the liquid level within the storage space decreases as the liquid is removed. This drop in liquid level results in the formation of additional evaporated gas (BOG) within the storage space.

3.3. Reduction of LNG System Pressure

The temperature at which LNG begins to evaporate, known as the bubble point, will be governed by tank pressure and liquid composition. In the event of a sudden decrease in atmospheric pressure due to extreme weather such as a typhoon, the air pressure in the storage tank will also decrease relatively, causing the bubble point temperature of LNG to drop. In this case, if the temperature of the LNG exceeds the adjusted bubble point, some of the LNG will undergo a phase change and be converted to flash gas.

4. BOG Treatment Process

Large quantities of evaporated gas (BOG) are inevitably generated in the tanks, operating equipment and pipelines of liquefied natural gas (LNG) receiving terminals due to a variety of factors such as heat loss, energy introduced by equipment operation, volumetric displacement during loading and unloading and flash evaporation due to pressure differences. If not managed properly, this can lead to the risk of overpressurization of the storage tanks, while direct venting and combustion of BOG can lead to loss of resources. Therefore, the safety, reliability, and economic efficiency of the gasification gas management system are crucial considerations in the operation of LNG receiving stations [2]. Currently, there are two common methods of handling BOG: one is to reconvert BOG to LNG through a re-liquefaction unit and store it back in cryogenic vessels; the other is to use BOG as fuel for gas turbines to generate power, although this method may require additional handling of excess BOG when LNG vessels are unloaded or when the amount of BOG generated is large. In order to efficiently utilize BOG, several different treatment technologies are commonly employed.

4.1. BOG Direct Compression Process

So-called direct BOG compression processing is the direct pressurization of evaporated gas (BOG) to the required pressure level in the pipeline network, which is then transported to the natural gas pipeline network for reuse. This method allows for rapid treatment and reuse of BOG, is easy to operate, requires little mechanical equipment, and has a low initial investment. However, this method imposes a high operating pressure on the BOG compressor and also requires that the entire pipeline network can withstand the corresponding pressure; if the pressure is too high, it may result in an inability to reuse the compressed BOG for secondary use. Therefore, the associated energy consumption needs to be carefully evaluated when employing this process. Suitable occasions for this process are those LNG receiving stations where the pressure of the external pipeline network is low, typically in the range of 2 to 3 megapascals (MPa) [3].

4.2. BOG Recondensation Process

The BOG re-condensation process is a common re-liquefaction technology used to treat evaporated gas (BOG) and is widely used in LNG receiving terminals that use natural gas as a gas source. This process is usually divided into two main methods. The first method is to pressurize the off-take LNG by using a pump (usually a submersible pump) to convert it to a supercooled liquid state and use this supercooled LNG to condense the compressed BOG, indirectly exchanging heat through a heat exchanger to condense the BOG. The second method is the re-liquefaction of BOG through the use of a re-condenser. Compared to the direct compression method, the BOG compressor requires less outlet pressure in this process, thus reducing the energy consumption of the system. However, this recondensation process requires sufficient outgoing LNG to provide the necessary cooling capacity to condense the BOG, which means that the effectiveness of the process can be constrained by changes in LNG output. Also, if the BOG load fluctuates, this can create challenges for the operation of the recondensation process.

4.3. Direct Compression + Recondensation Process

The Direct Compression + Re-Condensation process is an integrated approach that encompasses the advantages of both the Direct Compression process and the Re-Liquefaction process. In this process, a portion of the evaporated gas (BOG) generated at the LNG receiving terminal is sent to a re-liquefaction unit for treatment, while the other portion is fed directly into a high-pressure BOG compressor for eventual delivery into the pipeline network. The core equipment of the process consists of a BOG compressor, LNG pumps for high pressure delivery and a re-condenser.

The advantages of applying a combination of direct compression and recondensation processes over single treatment include ease of operation, energy efficiency, environmental friendliness and flexibility. It can also utilize liquefied natural gas as a coolant to achieve a completely emission-free BOG. However, a disadvantage of this combined process is the need for high pressure BOG compressors and conditioning equipment, which can increase upfront investment costs. This process effectively integrates the respective advantages of direct compression and recondensation, allowing all BOG to be recovered during normal transportation, while in the high-pressure compression section, BOG regeneration can be realized even during non-transportation hours or pre-cooling stages, reducing energy losses. In this way, it not only avoids the energy loss that may result from direct compression, but also solves the problem that in some cases the recondensation process is not able to recover energy [4].

4.4. Nitrogen Expansion Refrigeration Liquefaction Process

The expanded and cooled nitrogen can be liquefied into LNG through a heat exchange process and delivered back to the storage tanks or, after pressurization and gasification, delivered to an external pipeline. The initially low-pressure nitrogen is compressed and initially cooled in a cooling device, after which it is expanded through an expansion device to form low-temperature, low-pressure nitrogen.

The RBP (Refrigeration by Pressure) system using nitrogen as the refrigerant has several advantages over other liquefaction technologies: the refrigerant itself is safe and non-flammable; the system is designed to be simple and highly integrated, making it easy to operate; and since the whole process is mainly done in the gaseous state, it is less affected by the movement of the ship. The main disadvantage of the nitrogen expander liquefaction process is the high energy consumption, how to reduce the energy consumption has become an important issue. An innovative propane-nitrogen two-phase expansion mechanism has been proposed for cold cycles to improve energy efficiency. For the energy-using process based on the expander, the nitrogen expansion process for ships is recommended based on the energy-using analysis of different energy-using processes. The N2-CO2 expansion process for ships was also proposed and the process parameters were optimized to reduce energy efficiency.

4.5. Mixed Refrigerant Refrigeration Liquefaction Process

The mixed refrigerant system consists of two main parts: one part is the BOG recovery circuit, where the cold BOG is compressed in a compressor and subsequently condensed in a condensing refrigeration unit, and finally converted back to the LNG form through a throttling device; the other part is the mixed refrigerant circuit, where the mixed refrigerant is first compressed in a dedicated refrigerant compressor, followed by a condenser and a condensing refrigeration unit to be cooled, after which it is further depressurized through a throttling valve to achieve the cooling effect on the BOG [5].

The mixed refrigerant technology is recognized for its maturity, simplicity, few equipment limitations and ease of use. The refrigerant blend of this technology can be partially or fully replenished by extracting and reproducing it from the feedstock gas, however it has significant disadvantages: due to the complexity of the refrigerant blend, its measurement requirements are more stringent, the process may incur some loss of refrigerant and its regeneration process consumes a lot of time and energy. In addition, refrigerant blending systems require a continuous supply of BOG gas, so this process is more suitable for large LNG production and receiving terminals.

4.6. Liquid Nitrogen (or Propane) Refrigeration Liquefaction Process

In a liquefaction process that takes advantage of the low-temperature properties of liquid nitrogen (or propane), BOG relies heavily on the cooling energy provided by the liquid nitrogen to become liquid. First, the BOG in the storage tank is separated and stabilized by an inlet separator and then pressurized by a BOG compressor. The pressurized BOG enters the condenser and exchanges heat with the refrigerant. The BOG, which has absorbed the cooling energy, is transformed into LNG and collected in the LNG buffer tank. When the liquid level in the buffer tank reaches a certain height, the LNG is centrally transferred back to the main storage tank through the return pipeline. Meanwhile, the gas produced from the LNG buffer tank is returned to the inlet separator, ready for the next round of liquefaction process.

The liquefaction process using liquid nitrogen (or propane) as a refrigerant simplifies the design of the liquefaction system, thus enhancing the overall system reliability. As liquid nitrogen has excellent low-temperature performance, small volume, low price, good safety and linkage with on-board purging device in actual use, it shows excellent performance in BOG pre-cooling and liquefaction process. However, it is necessary to control the refrigerant flow rate and speed according to the amount of BOG to avoid incomplete condensation of BOG due to insufficient cooling supply.

5. Conclusion

Current research focuses on the improvement of the BOG recondensation recovery process. In LNG receiving terminals, direct compression and delivery is usually used to treat BOG. these studies have improved the traditional treatment method to some extent, reducing the generation of BOG and its volatility, but this has also made the recycling and treatment system more complex, limiting its application scope in engineering practice. In addition, most of the past studies have focused on the simulation and optimization of a single process, while there are relatively few comprehensive simulation and optimization of the whole process flow. At the same time, after inputting BOG into the urban gas network, there are not many analytical studies for the change of urban gas supply. In order to solve these problems, future research should pay more attention to the systematization and integration of the BOG processing system, and consider the operational efficiency and stability of the whole LNG receiving station; when performing process optimization, not only the economic cost, but also multiple objectives such as the environmental impact, energy consumption, and system safety should be taken into account; and by using advanced control theories and intelligent algorithms, such as fuzzy control, neural networks, and genetic algorithms, the Develop intelligent control strategies to achieve automatic adjustment and optimization of the BOG treatment system; conduct in-depth research on the flow and distribution characteristics of BOG after it is inputted into the urban gas pipeline network, taking into account the changes in the city's gas supply to ensure the reliability and economy of gas supply. We look forward to realizing more efficient, environmentally friendly and sustainable BOG treatment technology in the future to support the healthy development of the LNG industry.

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