Discussion on refrigeration method of natral gas liquefaction plant

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The refrigeration methods used in several mature natural gas liquefaction plants at home and abroad (cascade refrigeration cycle, mixed refrigerant cycle, expansion refrigeration cycle, etc.) and the latest research progress in this field are reviewed, and they are analyzed and compared. On this basis, a new refrigeration method of LNG-absorption refrigeration cycle is introduced. This method uses the change of solution concentration to obtain the cooling capacity, that is, the refrigerant evaporates under a certain pressure to absorb heat, and then the absorbent is used to absorb the refrigerant vapor. This circulation system is not only suitable for offshore natural gas liquefaction devices, but also suitable for areas rich in solar energy and geothermal energy, which can not only reduce the product cost, but also realize waste utilization. Finally, aiming at the generation of steam in the transportation and storage of LNG, several auxiliary refrigeration methods in transportation and storage devices are introduced: G-M refrigerator and Stirling refrigerator, phase change refrigerator and pulse tube refrigerator.

Keywords natural gas liquefaction refrigeration method device LNG storage LNG pipeline vapor-assisted refrigeration

I. Analysis of Liquefied Refrigeration Method

Combined with the current low temperature technology, the commonly used refrigeration methods for natural gas liquefaction are as follows. For natural gas liquefaction, three-stage cascade refrigeration cycles with propane, ethylene and methane as refrigerants are often used to provide the cooling capacity

1. Cascade refrigeration cycle

Cascade refrigeration cycle consists of several refrigeration cycles operating at different temperatures. High, medium and low temperature refrigerants are used in its high, medium and low temperature parts respectively. The evaporation of the refrigerant in the high-temperature part is used to condense the refrigerant in the low-temperature part, and the refrigerant in the low-temperature part is evaporated again to output cold energy. These parts are connected by several evaporative condensers, which are both evaporators in the high temperature part and condensers in the low temperature part. It can not only meet the appropriate evaporation temperature when evaporating at a lower evaporation temperature, but also meet the moderate condensation pressure when condensing at ambient temperature.

For naturalgas liquefaction, three-stage cascade refrigeration cycles with propane, ethylene and methane as refrigerants are often used to provide the cooling capacity needed for natural gas liquefaction. Their refrigeration temperatures are-45°C and-100°Crespectively°C and-160 C. The flow chart of this cycle principle is shown in Figure 1. The purified natural gas is gradually cooled, condensed, liquefied and supercooled in the cooler s of three refrigeration cycles, and finally sent to the sto rage tank by a cryogenic pump. The advantages of this cycle are large average temperature difference between cold and hot media, small heat exchanger area, and inde pendent refrigeration cycle in natural gas liquefaction s ystem, less interaction, stable operation, strong adaptabi lity, mature technology and simple design and calculati on. The disadvantage is that the process is complicated, there are many units, at least three compressors, and eq uipment for producing and storing various refrigerants a re required.

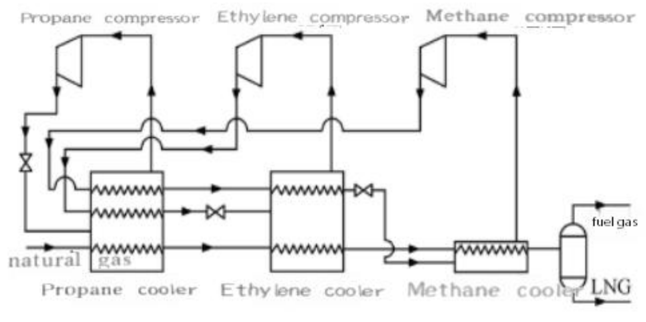

Fig. 1 schematic diagram of cascade refrigeration liquefaction cycle

The cold circulation system is not allowed to leak each other, the pipeline and control system are complicated, the management and maintenance are inconvenient, and the purity of refrigerant is strict. At present, this refrigeration cycle has been applied in natural gas liquefaction, mainly used in large-scale and continuous production base factories.

2. Mixed refrigerant cycle

Because of the inherent limitations of single working medium, liquid can only be formed during throttling, which makes the potential of throttling refrigerator far from being exerted. When the mixed working medium is used, the liquid phase appears in the heat exchanger. After throttling, the mixture gradually evaporates when transferring heat, so that part of condensation and evaporation occurs in the heat exchanger. In this case, the high throttling effect of the mixture is ensured, and at the same time, the high boiling point components with the required heat equivalent ratio in the heat exchanger are ensured. Therefore, since Alfeev discovered in the early 1970s that adding a small amount of high boiling point working fluid to nitrogen can improve the efficiency of throttling cycle by 10 ~ 112 times, the research on mixed refrigerant cycle has been continuously developed. First of all, this cycle greatly reduces the pressure of throttling operation, and it has been successful at home and abroad.

A commercial single-stage oil-lubricated airconditioning compressor is developed to drive the closed-cycle mixture refrigerant throttling refrigerator,which greatly reduces the manufacturing cost of the throttling refrigerator. In addition, due to the high throttling effect of the reasonably selected mixture working medium, it can also effectively improve the water equivalent matching of circulating high and low pressure airflow and reduce the regenerative loss, thus reducing the throttling loss and finally improving the system efficiency.

Using mixed refrigerant can increase the refrigeration capacity of the system, improve the temperature distribution in the heat exchanger and further improve the efficiency of the system, and can affect the temperature distribution curve of the heat exchanger by changing the component ratio, and its refrigeration temperature can reach 70 ~ 150 K.

Compared with cascade, the mixed refrigerant liquefaction cycle has the characteristics of simple process, fewer units, less investment cost and low requirement on refrigerant purity. Because the energy consumption of single-stage mixed refrigerant cycle isabout 20% higher than that of overlapping cycle, multi-stage mixed refrigerant cycle is adopted to reduce energy consumption. The evaluation results of multistage cycle characteristics show that energy consumption decreases with the increase of stages.Through technical and economic optimization, it is generally reasonable to adopt three-stage mixed refrigerant cycle. A typical natural gas liquefaction cycle with mixed working medium is shown in Figure 2. Because of the multi-stage liquefaction and the efficient and multi-channel aluminum fin heat exchanger, the heating efficiency of the whole system is improved and the energy consumption of the multistage mixed refrigeration cycle is basically close to the overlapping level.

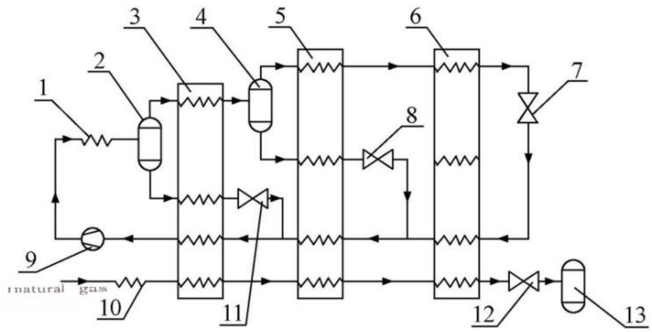

Fig. 2 Liquefaction Cycle Diagram of Mixed Working Medium Natural Gas

1. precooler; 2. The first separator; 3. The first heat exchanger; 4. The second separator; 5. The second heat exchanger; 6. The third heat exchanger; 7. Throttle valve III; 8. Throttle valve II; 9. Compressor 10. precooler; 11. Throttle valve ; 12. Throttle valve; 13. separator

The mixed refrigerant throttling refrigeration cycleshould consider the choice of each component according to the refrigeration temperature to be achieved, the normal evaporation temperature and freezing point of each component, and choose the best ratio of mixed refrigerant when the system reaches the maximum efficiency. The distribution ratio of mixed working fluids is very important to the performance and behavior of mixture heat exchanger, and the mixture should be classified according to the heat exchange section with small temperature difference.

At present, in the natural gas liquefaction refrigeration system, the mixture composed of more than five components, such as C1-C5 hydrocarbons and nitrogen, is often used as the refrigerant to replace many pure components in cascade refrigeration.Using this mixture as refrigerant not only covers the whole temperature range required for natural gas liquefaction, but also can use only one compressor, which greatly simplifies the process. Therefore, it has been widely used in natural gas liquefaction and separation technology.Widely used, at present, the mixed refrigerant circulation system has several forms: open, closed, regenerative and non-regenerative.

3. Expansion refrigeration cycle

The expansion refrigeration cycle mostly adopts the inverse Brayton cycle, in which the working medium is isentropic compressed by the compressor, cooled by the aftercooler, and then isentropic adiabatic expanded in the turbo-expander to do work, so as to obtain low-temperature air flow to produce cold energy. With the development of low temperature turboexpander, especially high-speed gas bearing turboexpander and high-efficiency compact heat exchanger, the efficiency of turbine reverse Brayton cycle has been significantly improved, and a very low refrigeration temperature and a wide refrigeration range can be obtained with high reliability.

Therefore, in recent decades, the reverse Brayton refrigeration cycle has been greatly developed, and its application range is getting wider and wider.

In the process of natural gas liquefaction, the following four forms are mainly adopted: ① Direct expansion refrigeration of natural gas directly utilizes adiabatic expansion of high-pressure natural gas in an expander to liquefy natural gas. Its liquefaction capacity mainly depends on expansion ratio and expansion efficiency. This cycle has the advantages of simple process, compact equipment, less investment, flexible adjustment and reliable operation. Its schematic diagram is shown in Figure 3. ② Nitrogen expansion refrigeration, which is direct expansion refrigeration.

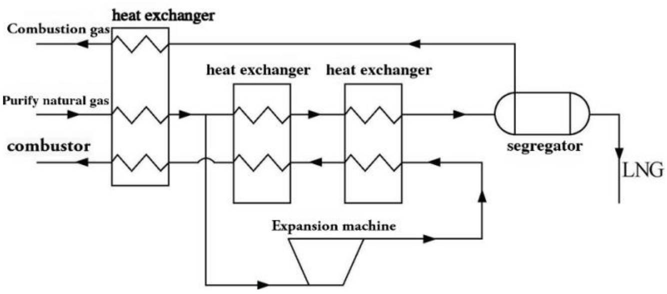

Fig. 3 schematic diagram of natural gas direct expansion liquefaction refrigeration

A variant has the advantages of strong adaptability, high liquefaction capacity, simple process, flexible operation and convenient operation, but the disadvantage is high energy consumption; Nitrogen-methane mixed ③ expansion refrigeration, which is an improvement of nitrogen expansion refrigeration cycle, has the advantages of simple process, easy control and short start-up time, and saves 10% ~ 20% power consumption compared with pure nitrogen expansion refrigeration, but the technology is still immature and needs further development; The gas wave ④ refrigerator is a new refrigeration machine developed by the Institute of Gas Wave Technology of Dalian University of Technology. It is developed on the basis of the thermal separator by using the theory of gas wave motion. It absorbs the advantages of the thermal separator, makes more effective use of the gas pressure, improves the refrigeration efficiency, and makes great improvements in structure and other aspects, with high pressure resistance and large refrigeration capacity. Moreover, it has the advantages of simple structure, convenient operation and maintenance, and no need for auxiliary equipment, which not only ensures the high efficiency of the equipment, but also is convenient and reliable to operate. Its principle is shown in Figure 4.

The main characteristics of the expansion refrigeration cycle are: making full use of the pressure energy of natural gas, consuming little electric energy， saving equipment investment, and adopting gas bearings with small volume, light weight, high efficiency and long-term reliable operation.

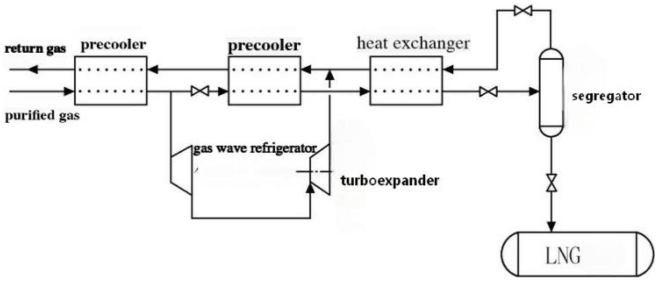

Fig. 4 schematic diagram of combined refrigeration of gas wave refrigerator and expander

Turbo-expander, which improves the system efficiency, can be used in peak-shaving devices with frequent operation and fast start-stop requirements. Now it has developed into a multi-stage expansion liquefaction system, and the expansion refrigerator is becoming more and more mature, which has the characteristics of long life, high reliability, low vibration and light weight, and has a good development prospect in natural gas liquefaction. With the increasing demand for liquefied gas, this cycle has greater advantages.

4. Absorption refrigeration cycle

Absorption refrigeration is a device that uses the change of solution concentration to obtain cooling capacity, that is, the refrigerant evaporates under a certain pressure to absorb heat, and then the absorbent is used to absorb refrigerant vapor. The low-pressure steam from the evaporator enters the absorber and is absorbed by the absorbent. The heat released in the absorption process is taken away by the cooling water, and the formed concentrated solution is pumped into the evaporator, heated by the heat source and evaporated to generate high-pressure steam, which enters the condenser for cooling, and the dilute solution is decompressed and refluxed to the absorber to complete a cycle. It is equivalent to replacing the compressor with an absorber and an evaporator, which consumes heat energy.

Absorption refrigeration can be driven by low-grade heat sources such as solar energy, geothermal energy and industrial waste heat. It is a green refrigerant with no damage to the atmospheric ozone layer, and it has great potential in environmental protection and energy saving. However, the evaporation temperature of the traditional absorption refrigerator is not low, which is a prominent defect of absorption refrigeration, and the high refrigeration temperature greatly limits the application scope of absorption refrigeration. In recent years，with the maturity of cascade refrigeration technology, the continuous development of absorption refrigeration cycle and the use of non-azeotropic mixture refrigerant have laid the foundation for a new cascade absorption refrigeration cycle. It uses non-azeotropic mixture as refrigerant and combines cascade cycle with absorption refrigeration cycle to achieve the purpose of obtaining lower refrigeration temperature by using low-grade heat energy. This circulating system is suitable for offshore natural gas liquefaction devices and also suitable for areas rich in solar energy and geothermal energy, which uses a lot of natural energy of solar energy and geothermal energy and greatly reduces the cost of products. The refrigeration process is shown in Figure 5. With the development of technology and the emergence of new refrigerants and absorbents, the solution circulation part of the absorption system adopts multieffect or multi-stage circulation, which can effectively increase the concentration difference of absorption refrigeration and greatly reduce the refrigeration temperature, and is expected to become another energysaving and efficient new refrigeration method for LNG.

II, the auxiliary refrigeration method in the transportation and storage device

Because the temperature of liquid natural gas is much lower than that of the outside world, and it is impossible to be completely insulated from the outside world, there will be some gasification during the loading of natural gas. In the process of transportation and storage, a small amount of steam is generated, which causes product loss and becomes a safety hazard. Therefore, it is necessary to adopt auxiliary refrigeration in transportation and storage devices as an effective means to supplement cold energy.

1. G-M refrigerator and Stirling refrigerator

G-M cycle refrigerator was put forward by Gifford and Mcmahon, and its principle is adiabatic gas degassing refrigeration. Due to the different requirements of temperature, single-stage, two-stage and three-stage G-M cycle refrigerators have been developed. The single-stage generally operates at 77 K, and the lowest can reach 23 K.. Stirling cycle refrigerator was put forward by Kirk in 1861 and produced by Holland in 1954. It uses reverse Stirling cycle for refrigeration. At that time, it could reach a low temperature of 83 K.Now Stirling cryocooler has developed into various specifications, which can be divided into rotary drive type and linear drive type according to the working mode of motor, and the linear drive type can be divided into single piston and double piston, and can be divided into integral type and separate type according to the structural compressor and expander. It has been able to produce 90 K, 26 kW Stirling cryocoolers and 80 K, 0.5 W miniature cryocoolers. Such a refrigerator can be used for the liquefaction of nitrogen, air and natural gas. These two kinds of refrigerators are characterized by compact structure, small volume, light weight, short start-up time, wide refrigeration temperature range and short cooling time. At present, it is mainly used in the field of low temperature and products with small refrigeration capacity. In combination with the situation that a small amount of liquefied natural gas is gasified during transportation and storage, a G-M or Stirling refrigerator can be installed on the device to re-liquefy the gasified natural gas above the device irregularly.

2. Phase change refrigeration

Material phase change refrigeration uses the evaporation process of liquid at low temperature and the melting or sublimation process of solid at low temperature to absorb heat from the cooled object to achieve the purpose of refrigeration. Therefore, phase change refrigeration can be divided into liquid gasification refrigeration, solid melting and sublimation refrigeration and liquid pumping refrigeration.

For liquefied natural gas, solid methane can be used for phase change refrigeration. The working temperature range of solid methane is-183 ~-213 , ℃ and its melting releases a lot of latent heat. A certain amount of solid methane can be pre-stored above the transportation and storage device, and the high sublimation latent heat of solid methane can be used to absorb the heat released by the condensation of gasification products, and the solid methane can be dissolved into liquid state, which will not cause any pollution to the products. This method will not add new equipment to transportation and storage equipment, but a small amount of natural gas must be condensed into solid state in advance for use.

3. Pulse tube refrigerator

In 1963, Gifford and longsworth first put forward the pulse tube refrigerator, and since then, the research of pulse tube refrigerator has begun. Its basic principle is to obtain the cold effect by using the adiabatic outgassing process of high-pressure gas. However, the performance of this basic pulse tube refrigerator in refrigeration capacity and refrigeration temperature is limited. Subsequently, a series of major breakthroughs appeared, such as small-hole pulse tube refrigerator, two-way inlet pulse tube refrigerator and auxiliary small-hole pulse tube refrigerator. All these structural improvements, coupled with the adoption of new regenerator materials, have made the pulse tube refrigerator have a rapid improvement in refrigeration performance and refrigeration temperature. At present, single-stage, two-stage and three-stage pulse tube refrigerators have been developed, and their refrigeration temperature has developed from 124 K at first to below 4 K now. With the development of technology, the refrigeration capacity of pulse tube refrigerator is increasing, and it will become one of the main auxiliary refrigerators of the new generation. At present, some scholars at home and abroad have also extended the research and application of pulse tube refrigeration method to the fields of natural gas liquefaction and general cold temperature zone.

Take part in the examination and contribute

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